UNIVERSITÀ
DEGLI STUDI
DI BRESCIA

DOTTORATO DI RICERCA IN
INGEGNERIA CIVILE, AMBIENTALE, DELLA COOPERAZIONE INTERNAZIONALE E DI MATEMATICA

Settore scientifico disciplinare:
ICAR/03 Ingegneria Sanitaria-Ambientale

CICLO
XXXIII

Municipal Solid Waste Management and Health Risks: is it time for a Solid Waste Safety Plan?

Analysis of case studies from Serbia and Ghana

DOTTORANDO
Giovanni Vinti

RELATORE
Prof. Mentore Vaccari

CORRELATORE
Dr. Christian Zurbrügg

"I stand upon my desk to remind

myself that we must constantly look at things

in a different way" (cit. Dead Poets Society)

CONTENTS

INDEX OF FIGURES

INDEX OF TABLES

ABSTRACT (ITALIAN VERSION)

La gestione dei rifiuti solidi rappresenta un tema delicato che se non affrontato adeguatamente può portare a gravi rischi per la salute umana e per l'ambiente. In proposito, va tenuto conto che la produzione di Rifiuti Solidi Urbani (RSU) è in costante aumento, ed è più che triplicata negli ultimi 50 anni, superando oggi due miliardi di tonnellate annue. Parte di questi rifiuti, soprattutto nei Paesi in Via di Sviluppo (PVS), non viene raccolta o smaltita adeguatamente, causando maggiori rischi che altrove. In questa tesi di dottorato, nel capitolo introduttivo viene affrontato il tema dei contaminanti associati alle diverse pratiche di gestione dei rifiuti, alle loro vie di trasporto e ai rischi che possono determinare nei recettori umani. Viene anche evidenziata l'esistenza di recenti studi epidemiologici. Inoltre, data la mancanza di un piano di sicurezza dei rifiuti solidi universalmente riconosciuto è emersa l'esigenza di una sua realizzazione. Prima di ciò si è proceduto alla realizzazione di una review sistematica della letteratura scientifica che tra il 2006 e il 2020 ha analizzato il legame tra pratiche di gestione dei rifiuti e rischi per la salute. E' così emerso che molti studi, in particolare epidemiologici, si sono concentrati sulle discariche controllate e sugli inceneritori. Altre pratiche hanno ricevuto minore attenzione. Questo può essere dovuto al fatto che la combustione incontrollata dei rifiuti così come la presenza di discariche incontrollate (dumpsites) sono più diffuse nei Paesi del Sud del Mondo, o in zone in cui la raccolta dei rifiuti non viene condotta adeguatamente. Si tratta di pratiche meno sicure ma svolte in contesti in cui è più difficile condurre ricerche scientifiche di rilievo, per via della carenza di fondi o per le difficoltà nel reperire sufficienti informazioni. Quanto emerso dalla review ha avvalorato la necessità di sviluppare un piano di sicurezza dei rifiuti solidi, al pari di quanto fatto negli ultimi anni in ambito di acque potabili e acque reflue attraverso il Water Safety Plan (WSP) e il Sanitation Safety Planning (SSP). Questi ultimi sono stati promossi dall'Organizzazione Mondiale della Sanità. Data la vastità della tematica, è stato deciso di concentrarsi sugli RSU. Di conseguenza è stata realizzata una prima proposta di Piano di Sicurezza dei Rifiuti Solidi Urbani (in inglese Municipal Solid Waste Safety Plan, MSWSP). Per cui, dopo averne illustrato la struttura generale, in cui forte peso viene dato alla costituzione del team di esperti con cui confrontarsi e alle matrici di rischio per la salute, sono stati introdotti due casi studio. Nel primo è stata analizzata la discarica municipale del centro urbano di Novi Sad, in Serbia. Come potrà notarsi, si tratta di un sito avente molto in comune con i dumpsites, determinando notevoli rischi per salute di abitanti e lavoratori. Il secondo caso studio ha riguardato nove villaggi rurali nel Nord del Ghana, in cui sono stati analizzati una serie di pratiche e i conseguenti rischi per la salute. I contesti oggetto della ricerca sono caratterizzati da profonde differenze, che hanno rappresentato un valore aggiunto, offrendo diverse prospettive di analisi. La pandemia (Covid-19) improvvisamente scoppiata nei primi mesi del 2020 ha determinato degli ostacoli fortunatamente superati grazie alla rete di contatti in loco e alle attività svolte da remoto. Nei risultati, dopo la review sistematica vengono presentate le matrici di rischio sanitario realizzate. Successivamente vengono presentate le misure di controllo concepite per ridurre gli eventi pericolosi classificati con rischio alto e molto alto. Tali misure di controllo, cioè gli interventi previsti per ridurre i rischi, hanno tenuto conto del concetto di tecnologie ambientali appropriate. Infine, è stata svolta un'analisi economica di massima associata alle misure di controllo previste, con l'obiettivo di stimare l'ordine di grandezza dei costi necessari ad implementarle. Questa prima versione di MSWSP è probabilmente migliorabile, e ulteriori casi studio andranno considerati. Sarà anche necessario un confronto interno alla comunità scientifica, ma il primo passo in questa direzione è stato compiuto.

ABSTRACT (ENGLISH VERSION)

Solid waste management is a sensitive issue that can lead to severe risks to human health and the environment if not properly addressed. As for Municipal Solid Waste (MSW), its production is continuously increasing, having more than tripled in the last 50 years. Today its annual production exceeds two billion tons. In some cases, especially in Developing Countries (DCs), solid waste is not collected or disposed of properly, leading to severe problems more than elsewhere. In this PhD thesis, the introduction chapter deals with contaminants associated with different waste management practices, transport routes, and the risks they can pose to human receptors. The existence of recent epidemiological studies is also highlighted. Given the current lack of a universally recognised solid waste safety plan, it was decided to implement it in the thesis. This step was preceded by a systematic review of the scientific literature published between 2006 and 2020 that has analysed the link between waste management practices and health risks. It emerged that many studies, especially the epidemiological ones, have focused on sanitary landfills and incinerators. Other practices have received less attention. It can be because the uncontrolled combustion of waste and the presence of dumpsites are more common in the countries of the Global South, or in areas where waste collection is not carried out correctly. These are less safe practices but more common in contexts where it is more challenging to conduct relevant scientific research, due to lack of funds or sufficient information. The review's findings confirmed the need to develop a solid waste safety plan, like what has been done in recent years in the field of drinking water and wastewater through the Water Safety Plan (WSP) and the Sanitation Safety Planning (SSP). The World Health Organization promoted both. Given the extent of the topic, the focus was on MSW. Consequently, the first proposal for a Municipal Solid Waste Safety Plan, MSWSP, was created. After having illustrated the general structure, in which substantial weight is given to the team of experts' constitution and the matrices of health risks, two case studies are introduced. In the first, the municipal landfill of the urban centre of Novi Sad, in Serbia, was analysed. Such a landfill has a lot in common with dumpsites, causing significant health risks for inhabitants and workers. The second case study involved nine rural villages in Northern Ghana, where a range of practices and the related health risks were analysed. The research contexts are characterised by profound differences, which represented an added value, offering different analysis perspectives. The pandemic (Covid-19) suddenly broke out in the first months of 2020 and caused obstacles which were fortunately overcome thanks to the network of contacts made and the activities carried out remotely. The results start with the systematic review. Then, the health risk matrices obtained from the case studies are illustrated. After discussing how to conduct future activities to get more information, control measures to reduce hazardous events classified as high and very high risk are presented. These control measures have taken into account the concept of appropriate environmental technologies. Finally, a general economic analysis is carried out; it is associated with the planned control measures to estimate the order of magnitude of the costs necessary to implement them. This first version of MSWSP is likely to be improved, and further case studies will need to be considered. An internal discussion within the scientific community will also be necessary, but the first step in this direction has been taken.

1 INTRODUCTION

1.1 Municipal Solid Waste Management and Adverse Health Outcomes

Municipal solid waste (MSW) is intended as any material from residential, commercial, and institutional activities, which is discarded. Industrial, medical, hazardous, electronic, and construction and demolition wastes usually belong to other categories (Kaza et al., 2018); even though industrial waste is sometimes included, it depends on the reporting standard (Chen et al., 2020). However, in this thesis, industrial waste will not be included in the category of MSW.

In the last decades, MSW generation has globally increased significantly, from 0.63 billion tonnes (bt) in 1965 (Chen et al., 2020) to 2.01 bt in 2016, and it is expected to increase up to 3.40 bt by 2050 (Kaza et al., 2018). MSW can pose a threat to public health and the environment if it is not safely managed. This axiom is true both in low- and high-income countries and can involve all the phases of waste management, namely separation, collection, transfer, treatment, disposal, recycling, and reuse. Nevertheless, solid waste management (SWM) usually improves moving from low- to high-income countries (Wilson et al., 2015). Therefore, it is crucial to define the best site-specific activities to reduce or eliminate the risks. Simultaneously, as noted in many studies, when adequately managed, MSW can represent a resource rather than a problem (Pietzsch et al., 2017) and the waste hierarchy principle, based on prioritising reduction, recycling, and reuse of waste, could be beneficial (Vinti and Vaccari, 2021).

Over the years, the World Health Organization (WHO) has highlighted the possible health risks associated with the SWM regarding soil, water, air pollution for populations surrounding the involved areas (WHO, 2016).

In investigating the relationship between solid waste and human health, it is necessary starting with hazard identification and exposure assessment (WHO, 2016). Figure 1 schematically represents the linkages between waste management practices, the respective hazards associated with these practices, the possible environmental pathways of transmission by which human receptors can absorb contaminants, and possible adverse health outcomes.

In reducing the health risks related to solid waste management, it is crucial to focus on the exposure assessment, developing a site-specific methodology. In the last two decades, this has been done by the World Health Organization (WHO) in the field of drinking water and wastewater, through the Water Safety Plan (WSP) (Davison et al., 2005) and the Sanitation Safety Planning (SSP) (WHO, 2015), respectively. In the field of solid waste, such a manual has not been fulfilled yet. Consequently, the Municipal Solid Waste Safety Plan (MSWSP) first attempt has been developed in this thesis. Waste practices and health risks were analysed in some inhabited areas from Serbia and Ghana. Great importance was assumed by the health risk matrices, based on a semi-quantitative approach, as it will be better discussed in the next chapters.

As shown in Figure 1, health outcomes can vary a lot. It is due to different substances having various characteristics that can be involved and because of environmental transport pathways and human exposure.

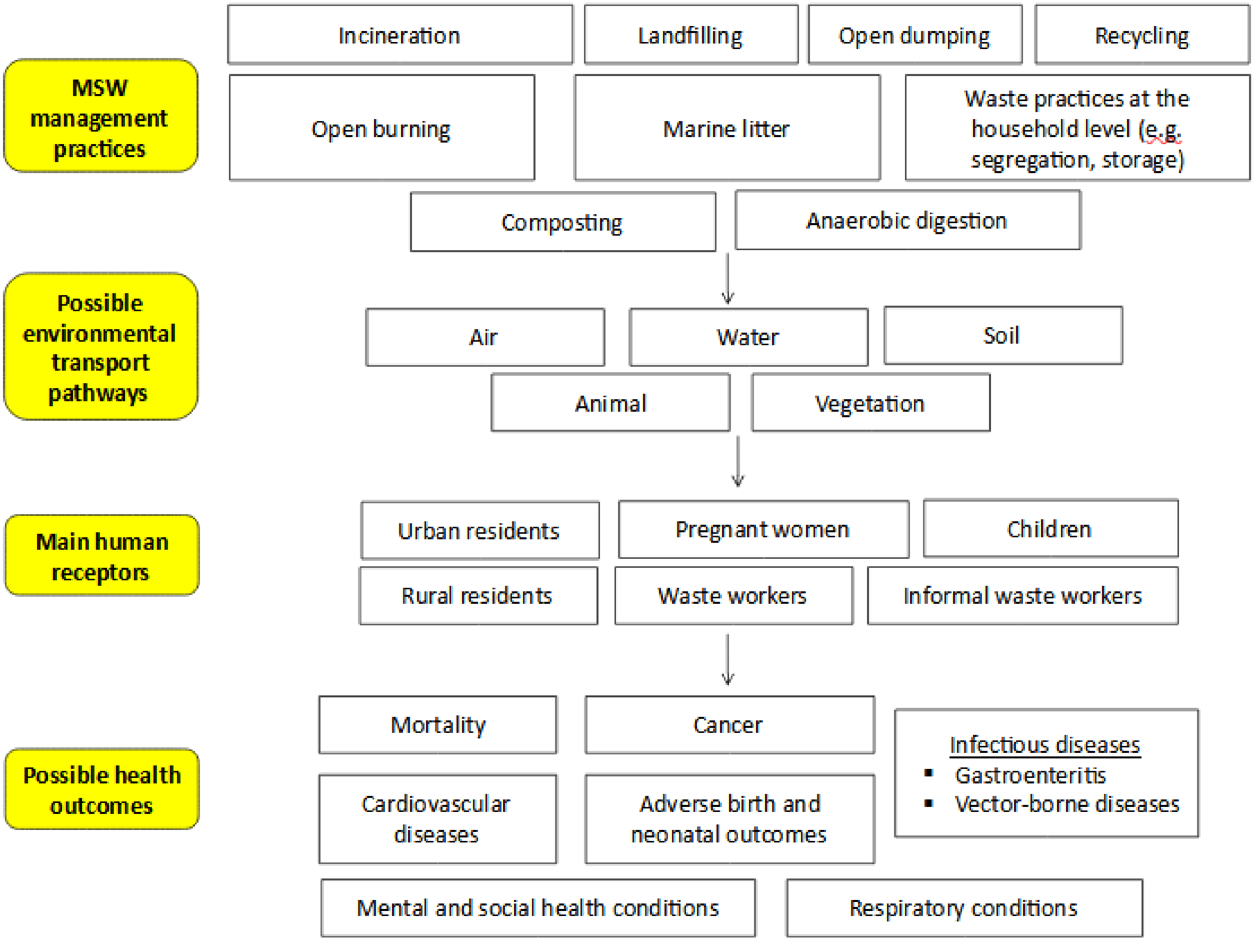

Figure 1: Schematic representation of the linkages between solid waste management practices and possible adverse health outcomes

1.1.1 Contaminants, environmental transport pathways and biological threats

Biological hazards refer to biological substances that pose a threat to human beings' health (Shroder and Sivanpillai, 2015). They can be due to solid waste. For instance, inadequate solid waste accumulation is often assumed as a risk factor for infectious and vector-borne diseases (Krystosik et al., 2020). It is not surprising if some studies found an increase in malaria cases (vector-borne disease) among people living close to dumpsites in African countries (Abul, 2010; Sankoh et al., 2013). Besides, Aedes aegypti, a mosquito vector that spreads Zika, dengue and other vector-borne diseases, seems to prefer breed in trash, tires and recyclable plastic containers (Krystosik et al., 2020). Aguiar et al. (2018) reported an association of an increase in Zika and chikungunya infections in Brazil and limited waste collection. Furthermore, diseases transmitted by rodents are associated with solid waste, mainly when garbage accumulates over time, creating food reservoirs (Krystosik et al., 2020).

Gerba et al. (2011) evaluated the relative contribution of enteric pathogens into MSW landfills in the USA. The authors found that food waste was the primary source for faecal coliforms, while pet faeces for salmonellae, human enteroviruses, and protozoan parasites. At the same time, biosolids from wastewater treatment plants were the leading source for human noroviruses. In dumpsites, the situation can be more dangerous. Indeed, access to such sites is typically not controlled. Consequently, children can also move in them, and pathogens can infect wounds, causing sepsis, mortality, or secondary infections (Achudume and Olawale, 2007). However, even if not wounded, children could be more exposed than adults by contaminated soil ingestion (US EPA, 2011). It should also appear clear that leachate generated in landfills and dumpsites contain a lot of threatening pathogens (Matejczyk et al., 2011). Leachate is a cocktail of many chemicals and biological products generated due to water passing through waste and saturating it with organic and inorganic matter (Khalil et al., 2018).

Besides, bioaerosols inhalation can represent a health risk. For example, Hoffmeyer et al. (2014) found that bioaerosol exposures from composting plants can cause infectious, toxic, and allergenic effects on workers.

Noteworthy, the pandemic (Covid-19) that has been affecting the world since the end of 2019 (WHO, 2020a) is also a biological threat that can be influenced by solid waste mismanagement (Nzediegwu and Chang, 2020). Such a risk is mainly related to waste generated in healthcare facilities (Mol and Caldas, 2020). Still, some authors (Nzediegwu and Chang, 2020) noted that contaminated PPEs (e.g., facemasks and gloves) when to end up as waste, if improperly managed, can pose environmental and health threats. Indeed, coronavirus can survive for some days on material surfaces (Kampf et al., 2020). The threats appear to be higher in developing countries with low waste management strategies (Nzediegwu and Chang, 2020). WHO and UNICEF (2020) recommended that waste generated at home by people affected of Covid-19 has to be packed in bags and closed completely before disposal and collection by municipal waste services.

1.1.2 Contaminants, environmental transport pathways and chemical threats

Other substances have to be more considered from a chemical point of view. Chemical substances can be directly part of the waste stream or be a consequence of certain waste practices. For instance, some dangerous chemicals can already be in the waste stream, and others, such as dioxins, can result from burning specific fractions of waste, e.g., chlorinated plastic (Cook and Velis, 2020). Chemical substances can result in carcinogenic, mutagenic and/or toxic effects. It is the case of Persistent Organic Pollutants (POPs), a group of chemicals intentionally or inadvertently produced and introduced into the environment. POPs represent a global concern due to their persistence in the environment, the potential for long-range transport, ability to bioaccumulate in ecosystems, and their significant adverse effects on human health (Xu et al., 2013). Since 2001, POPs listed in the Stockholm Convention increased to 22 (Xu et al., 2013). As aforementioned, some POPs can be generated during waste combustion, such as Polychlorinated dibenzo-p-dioxin (PCDD), Polychlorinated dibenzofuran (PCDF), polychlorinated biphenyls (PCBs) (Xu et al., 2019b; Viel et al., 2011). PCDD/Fs represent the most remarkable emissions released from waste incinerators due to incomplete combustion (Xu et al., 2019b). PCBs can also be released during waste combustion as by-products (Viel et al., 2011). Focusing on dioxins they are mainly bioaccumulated by humans through ingestion of contaminated foods of animal origin (WHO, 2019c), with up to 90% of the total exposure via fats in fish, meat and dairy products (FAO and WHO, 2018).

Exposure to chemicals primarily occurs through one or a combination of three routes, i.e. inhalation, ingestion, and dermal absorption (Pellizzari et al., 2019).

Focusing on landfills and dumpsites, a typical risk to consider is represented by leachate. Leachate characteristics can vary greatly, but among the most dangerous pollutants often found in dumpsites and landfills are heavy metals and metalloids (e.g. As, Cd, Cr, Pb) (Vaccari et al., 2019a). Ineffectiveness or absence of waterproof layer at the bottom can result in high environmental and health risks (Vaccari et al., 2018). Indeed, analysing groundwater contamination caused by the escape of leachate from a landfill (or a dumpsite) the following processes have to be taken into account (APAT, 2005):

- Production of leachate in the landfill (or dumpsite).
- Leachate flux through any holes present in the liner system or directly through the soil (if the liner system does not exist).
- Leachate flux through the unsaturated soil zone.
- Leachate mixing with the aquifer (if any).
- Migration of the contaminants through the groundwater.

At this point, contaminants can be transported with the groundwater flow, eventually reaching pumping wells, streams or lakes (Vaccari et al., 2018), that people may use as drinking water, for personal hygiene or for recreational purposes. A series of phenomena usually contribute to reducing contaminants' concentration through the flow (diffusion, dispersion, degradation), and hydrogeological characteristics of the areas can have a significant influence (Vaccari et al., 2018). In this case, the risks can be both biological and chemical. It must be noted that even modern landfills with good quality geomembranes can sometimes leak leachate due to thermal expansion of the material, defects or folds generated during installation, causing a potential risk for water bodies and consumers (Paladino and Massabò, 2017).

However, it should be evident that with more controlled and engineered practices such as with waste incinerators or sanitary landfills the risk are lower than with haphazard practices such as open burning or open dumping. These last two practices are widespread in low-income countries (Ferronato and Torretta, 2019; Kaza et al., 2018) and exist less scientific studies about them and the related health outcomes (Mattiello et al., 2013). Furthermore, in some cases, it is not entirely correct to apply estimates from studies related to high levels of emissions from the past to new-generation incineration plants. For instance, in many European countries, modern technology has been reducing dangerous emissions, and measurable health impacts have become smaller (WHO, 2016). The situation is also improving in China, where, in the last years, more restrictive legislation for MSW incinerators emissions has been approved (Lu et al., 2017).

1.1.3 Contaminants, environmental transport pathways and health risk assessment

The health risks associated with some substances are provided by international agencies, such as WHO or the International Agency for Research on Cancer (IARC). For instance, IARC (2019) classifies groups of carcinogenic substances as follows:

- Group 1: Substances having carcinogenic impacts on humans

- Group 2A: Substances that probably have carcinogenic impacts on humans
- Group 2B: Substances with a possible carcinogenic effect on humans – potentially carcinogenic substances
- Group 3: Substances that cannot be classified as carcinogenic for humans

Usually, humans are more sensitive than animals at lower chemical doses, and children are more sensitive than adults (Pellizzari et al., 2019). Chung and Herceg (2020) highlighted that early life exposure to environmental toxicants at relatively low concentrations could have lasting effects on human health in chronic and non-communicable diseases.

In this context, it is possible to talk about modifiable environmental factors, defined as those reasonably amenable to management or change using current knowledge and technology (Prüss-Ustün et al., 2016). In a global assessment, Prüss-Ustün et al. (2016) considered the following modifiable environments for measuring the environmental impact on health:

- Air, soil or soil pollution with chemical or biological agents.
- Ultraviolet and ionizing radiation.
- Noise, electromagnetic fields.
- Built environments.
- Occupational risks.
- Anthropogenic climate changes, ecosystem degradation.
- Major infrastructural and engineering works such as roads, dams, railways, airports.
- Human-made vector breeding places or breeding places catering to vectors' specific ecological requirements (e.g. old tyres or water containers).
- Agricultural methods, irrigation schemes.
- Individual behaviours related to the environment (e.g. hand-washing, food contamination with unsafe water or dirty hands).

The authors found that, in 2012, 23% of global deaths and 22% of DALY (disability-adjusted life year) were due to modifiable environmental factors (Prüss-Ustün et al., 2016). Furthermore, 26% of deaths among children under five years were also due to modifiable environmental factors (Prüss-Ustün et al., 2016).

Moreover, there are the so-called emerging contaminants (ECs), defined as synthetic or naturally occurring chemicals or microorganisms not commonly monitored in the environment but with the potential to enter the environment and cause known or suspected adverse ecological and/or human health effects (Rosenfeld and Feng, 2011). They are consistently being found in groundwater, surface water, wastewater, drinking water, and food sources (Rosenfeld and Feng, 2011). According to Barroso et al. (2019), also in the air of urban, rural and remote areas, ECs have become a significant issue for environmental science.

Furthermore, environmental chemical exposures can adversely affect children's health, and children are more sensitive than adults (Pellizzari et al., 2019). Notwithstanding, for example in the United States over 40,000 chemicals are approved for commercial use, but the health effects of few of them have been monitored in the U.S. population (Pellizzari et al., 2019; Seltenrich, 2020).

As recently highlighted by Leslie and Depledge (2020), it is dangerous to believe that the absence of evidence of risk translates into evidence for the lack of risk. It is essential to remember that to obtain the appropriate evidence associated with high-quality data, requires resources, i.e. time, money, people (Gouin et al., 2020).

However, thanks to the current knowledge, through a computational approach it is possible to assess the health risk resulting from exposure to one or more contaminants if health effects and threshold limit of the given pollutants have already been established (for instance by WHO or IARC). In these cases, it is necessary to calculate both the dose that a person intakes (as a result of exposure) and the contaminant's potential health effects (Fjeld et al., 2007). Such a model should include all four components of the risk calculation: release, transport, exposure, and consequence**.**

With this in mind, some countries have introduced new environmental regulations, for instance, conceiving a health risk analysis procedure for sanitary landfills, such as in Italy (D.Lgs. 152/2006). In some cases, very advanced and detailed studies have been conducted. For instance, Kvasnicka et al. (2019) recently estimated the health benefits to local people of reducing PCB contamination in fish consumed from the Hudson River. Furthermore, the authors estimated adverse health effects based on the inhalation of PCBs and $PM_{2.5}$ due to dredging activities and the inhalation of $PM_{2.5}$ among communities along rail transport routes to several landfills.

These methods make risk, or the maximum permissible concentrations of particular contaminants, site-specific. For instance, the risk related to landfill leachate is also related to distance from groundwater and wells. Anyway, as it will be better discussed later, for many reasons, it is not always possible to implement such an accurate procedure, mainly in low-income settlements. Indeed, as witnessed in the Ghanaian case study, it can be a scarcity of quantitative information at a local level and/or collect very detailed site-specific data could require too much time and effort (also under an economic point of view). In these cases, different approaches could be more effective and flexible, even if less accurate. These alternative methodologies can represent a step preceding studies more advanced both in developing and industrialised countries. For instance, concerning water safety, WHO (2016a) published a document in which the knowledge on quantitative microbial risk assessment (QMRA) was summarised. Furthermore, both the WSP (Davison et al., 2005) and the SSP (WHO, 2015), i.e. safety plans related to drinking water and wastewater respectively, have been published in the last years and employed worldwide. However, in the field of solid waste, such a plan has not yet been published.

1.1.4 Studies on solid waste management and adverse health outcomes

To evaluate solid waste management practices and adverse health outcomes, several epidemiological studies have been conducted, as well as some human biomonitoring studies. As anticipated, the impact of solid waste on health may vary depending on numerous factors such as the nature of waste management practices, characteristics and habits of the exposed population, duration of exposure, and interventions conceived to prevent or mitigate the risks (Ferronato and Torretta, 2019; Ziraba et al., 2016).

In the last 15 years, two types of studies have explored the effects of solid waste management to the human population:

- Reviews of literature or different reports and conclusion on general issues without context specific research.
- Detailed studies at one or multiple location of a specific context.

The first category (i.e. reviews and reports) mainly includes studies from the second category. In particular, Cointreau (2006) published a report on solid waste and health risks in population and waste workers, noting that low-income countries' situation is usually worse. Porta et al. (2009) conducted a review examining health effects associated with solid waste management in population and workers at waste processing plants. In a further review, Mattiello et al. (2013) analysed the health effects of the people living close to landfills and incinerators. Ashworth et al. (2014) reviewed data focusing on waste incineration and adverse birth outcomes. Ncube et al. (2017) analysed epidemiological studies related to MSW management, gathering the results in function of the health risks, but this made a bit difficult a comparison among MSW practices. However, none of the review aforementioned considered studies published later than in 2014. In a more recent review, Tait et al. (2020) analysed studies until 2017. Still, the authors focused only on incinerators, handling all kind of waste (e.g. MSW, industrial waste), and the related health impact on population and waste workers. Pearson et al. (2015) and Robertson et al. (2019) carried out reviews that focused on composting facilities, analysing health outcomes in both population and facility workers, but only for bioaerosols exposure.

Among the works mentioned above, that of Cointreau (2006) is the oldest but perhaps the most exhaustive of the last 15 years. With a moderate level of confidence, some authors derived effects from old landfills and incinerators. In particular, an increased risk of congenital malformation within 2 km from landfills and cancer within 3 km from incinerators (Porta et al., 2009). Other authors (Mattiello et al., 2013) found an increased risk of congenital anomalies, but mainly nearby special waste landfills. Some authors found some limited risks of cancer and birth defects associated with incinerators, highlighting technology changes are producing more encouraging results (Mattiello et al., 2013; Tait et al., 2020). In the case of composting facilities, the authors concluded there is insufficient evidence to provide a quantitative comment on the risk to nearby residents, although there is sufficient evidence to support a precautionary approach (Pearson et al., 2015; Robertson et al., 2019). Noteworthy, vector-borne diseases were not included and analysed in most of the reviews mentioned above. Indeed, only Cointreau (2006) cited a couple of studies related to vector-borne diseases, and Ncube et al. (2017) indicated one research related to malaria. More recently, Krystosik et al. (2020) carried out a review on vector-borne diseases and solid waste, but their work structure was not rigorous, and the main findings remained generic. In general, the authors of all the reviews agreed that further research is needed.

Further recent reviews studied health outcomes related to waste, but focusing on populations living near hazardous waste sites (Fazzo et al., 2017), or analysing waste incinerators with particular attention to those treating hazardous waste (Domingo et al., 2020). The results of the study of Fazzo et al. (2017), although not conclusive, found evidence of health effects for inhabitants, highlighting the need for more effective public health policies on hazardous waste management. Furthermore, Domingo et al. (2020) raised a series of crucial questions, such as if the safety limit value of 0.1 ng TEQ/Nm^3 for PCDD/Fs was enough to protect human health, concluding that more complete epidemiological studies are needed. In a further review (Vaccari et al., 2019b) we analysed environmental pollution and health consequences related to the informal treatment of another waste category, i.e. waste electrical and electronic equipment (WEEE), common in some low-income settlements. Indeed, not rarely, WEEE has been exported from industrialised to developing countries, representing a secondary source of valuable materials (e.g. gold, copper, silver) (Vaccari et al., 2019b). In order to evaluate differences in impacts between treatment technologies, the following categories were considered: mechanical treatment; open burning; leaching processes; mixed (if more than one treatment technology was applied). Open burning resulted in the most polluting practice.

However, WHO (2016b) noted the health effects of waste management and disposal activities are currently only partly understood, highlighting the need for updated evidence about solid waste practices and adverse health outcomes (WHO, 2016). Indeed, despite the studies mentioned above, uncertainties remain. Therefore, in this PhD thesis, a new systematic review was undertaken, having the objective to assess and summarise the most recent scientific evidence on the association between MSW management practices and health risks to populations residing nearby. Such a systematic review was crucial in implementing the Municipal Solid Waste Safety Plan (MSWSP) discussed later because it extended the understanding of the health risks related to SWM practices.

1.2 Research questions, hypothesis and objectives

1.2.1 Research questions

The following main question has led the research:

- Is it possible to conceive a Municipal Solid Waste Safety Plan (MSWSP)?

The following sub-questions were used to help in answering the previous question:

- What does the most recent scientific literature state about the link between MSW management practices and adverse health outcomes?
- If an MSWSP is needed, how should its structure be?
- How to implement an MSWSP in Developing Countries?

1.2.2 Research hypothesis

Solid waste, if not adequately managed, can represent a threat to human health. The risk is usually higher in Developing Countries because their SWM systems are often affected by more issues (Wilson et al., 2015).

An MSWSP still does not exist, but it can be crucial in managing MSW in the most appropriate ways, particularly in Developing Countries. It can help identify the events with the highest health risks, selecting the most appropriate interventions to reduce such threats. Furthermore, as for the sanitation safety plan (WHO, 2015) and the water safety plan (Davison et al., 2005), a solid waste safety plan could have broad use and be implemented both in Developing and Industrialised Countries.

1.2.3 Research objectives

The main objective of the research was to develop a Municipal Solid Waste Safety Plan (MSWSP). In achieving it, the following specific objectives were identified:

- To conduct a systematic review of the recent scientific literature related to MSW management practices and adverse health outcomes. Indeed, understanding what the scientific community has discovered on this topic appeared crucial for the proper development of an MSWSP.
- To define the structure of an MSWSP and identify some case studies from Developing Countries to implement it.

2 MATERIALS AND METHODS

As anticipated, the PhD thesis has the following objectives:

- To conduct a systematic review of the recent scientific literature related to MSW practices and adverse health outcomes.
- To develop and implement an MSWSP.

Therefore, materials and methods to achieve each objective have been different. This chapter starts describing the procedure followed in the systematic review process. Afterwards, it is given broad space to the steps that characterized the MSWSP development and the implementation through the two case studies identified (Serbia and Ghana).

2.1 Methodology used in the systematic review

The methods used in the systematic review were developed based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria (Liberati et al., 2009; Moher et al., 2009). Studies were eligible for inclusion if they met specified criteria for population, exposure, and health effects. The eligible population and exposures were people, both children and adults, living, studying, or spending time near MSW treatment or disposal sites. Occupational risks and waste workers (regular or informal) were not assessed, considering they were related to a different category, subjected to diverse exposures in time, distance, and possibly mitigating through personal protective equipment (PPE). The search for eligible studies was conducted using three relevant search engines (Scopus, ScienceDirect, Google Scholar) with a combination of keywords based on possible MSW exposures and health effects. Studies had to be peer-reviewed and published in English, to be eligible for inclusion. The review is receiving the last adjustments and will be sent to a scientific journal soon.

Additional details regarding the procedure are available in the protocol registered on PROSPERO (Vinti et al., 2020a), an international database of prospectively registered systematic reviews.

In the review, dumpsites and open burning were categorised together since burning waste in dumpsites is common, especially in developing countries (Ferronato and Torretta, 2019), making it very difficult to conceive two separate categories. Furthermore, in the case of dumpsites, it was not always possible to distinguish between MSW and other waste categories. Consequently, dumpsites were excluded when the sites did not receive MSW but only different solid waste categories. Furthermore, it was not possible to find a clear distinction between sanitary and engineered landfills in many cases. The two classes were combined, as previously done in a further review we published and related to leachate from dumpsites and landfills (Vaccari et al., 2019a).

The review's health effects were mortality, adverse birth and neonatal outcomes, respiratory conditions, gastroenteritis, vector-borne diseases, mental and social health conditions, and cardiovascular diseases.

Studies reporting on human biomonitoring for exposure were also eligible. Besides, vector-borne diseases (WHO, 2020) as an outcome were included. Although they represented a modification from the pre-specified protocol submitted to PROSPERO, no changes were made to the search strategy. Randomised controlled trials (RCTs) and the following non-randomised controlled studies (NRS) were included: quasi-RCTs, non-RCTs, controlled before-and-after studies, interrupted-time-series studies, historically controlled studies, case-control studies, cohort studies and cross-sectional studies that have a comparison group. Studies were excluded if they reported qualitative data only.

The definition of the studies that were found and included in the review are given below (Mann, 2003).

- Cohort study (prospective): a group of people, who do not have the outcome of interest, is chosen. Over a period of time, the people are monitored to see if they develop the outcome of interest. In single cohort studies, those who do not develop the outcome are used as internal controls. If two cohorts are used, one group has been exposed to or treated with the agent of interest, and the other has not.

- Cohort study (retrospective): the methodology is the same as the prospective cohort study, but the analysis is performed after the facts. Consequently, the cohort is followed up retrospectively. If the study period would be many years, the time to complete the study is only related to the collection and analysis of the already existing data.

- Case-control study: in this case, people with the outcome of interest are matched with a control group who does not have. The researchers determine which individuals were exposed to the agent or the prevalence of a variable in each study group. Case-control studies may be the best approach, where the outcome is rare.

- Cross-sectional studies: primarily used to determine prevalence, i.e. the number of cases in a population at a given point in time. All the measurements are made at one point in time.

All the four studies above are referred to as observational studies, because the investigators observe, unlike RCT (Mann, 2003).

Following an initial screening of paper titles and abstracts, the full paper was examined for eligibility. There were substantial differences among the included studies regarding settings, populations, study designs, contexts, MSW management practices, exposure assessment, case definitions, outcome definitions, and outcome assessment. Consequently, it was agreed that a pooled analysis using meta-analysis or meta-regression was not appropriate. Accordingly, a narrative approach was adopted.

The last part of the review summarised the strength of evidence to develop the different health outcomes in the function of the categories of exposure analysed. The following values were given: (0) no studies; (-) studies, but no evidence of increased risk; (+) studies, providing some evidence of increased risk; (++) studies, with stronger evidence of increased risk.

2.2 A proposal of Municipal Solid Waste Safety Plan (MSWSP)

2.2.1 Where to start? The Water Safety Plans (WSP) and the Sanitation Safety Planning (SSP)

The Municipal Solid Waste Safety Plan (MSWSP) discussed below represents an ambitious work. Above all, because such a manual does not exist in the field of Solid Waste yet. As a consequence, in the development of this first proposed version of the manual, previous works published by the World Health Organization (WHO) have been taken as a reference; in particular the Water Safety Plans (WSP) (Davison et al., 2005) and the Sanitation Safety Planning (SSP) (WHO, 2015).

The WSP was published for the first time in 2005 (Davison et al., 2005) to help in ensuring safe drinking-water through good water supply practices and strategies. The main objectives were (Davison et al., 2005):

- To prevent contamination of water bodies used as a source.
- To reduce or eliminate existing contaminations through appropriate treatments.
- To avoid re-contamination that could happen during storage, distribution and handling of drinking-water.

The authors started with the assumption that a wide range of both chemical and microbial contaminants can be found in drinking water. As a consequence, understanding the nature of sources of contamination, how they may enter the water supply and be aware of the risk they can pose is crucial for guaranteeing water safety (Davison et al., 2005).

A complete water safety plan comprises system assessment and design, operational monitoring and management plans. The WSP was intended at practitioners at all levels (e.g., water quality managers, regulators, consultants, international organizations).

In the version of the WSP published in 2005, two case studies where chosen and followed step-by-step. The case studies represented very different contexts; one was from an industrialised country (Australia), and the other was from a developing country (Uganda). Similarly, for this first attempt of an MSWSP, two very different case studies were analysed.

The SSP is more recent than the WSP. Indeed it was published in 2015 (WHO, 2015), representing a risk-based management tool for sanitation systems. Sanitation systems can be defined as a multi-step process in which human excreta and wastewater are managed from the point of generation to the end of use or final disposal (Tilley et al., 2014). Indeed, the risk can come from biological pathogens and chemical substances.

The manual aimed to assists users to (WHO, 2015):

- Identify and adequately manage health risk along the sanitation chain.
- Propose investments based on risks management, intended to reduce adverse health impacts.
- Provide a safe system to the public.

Figure 2 shows the cyclic steps characterizing an SSP, in which everything starts with the sanitation system description.

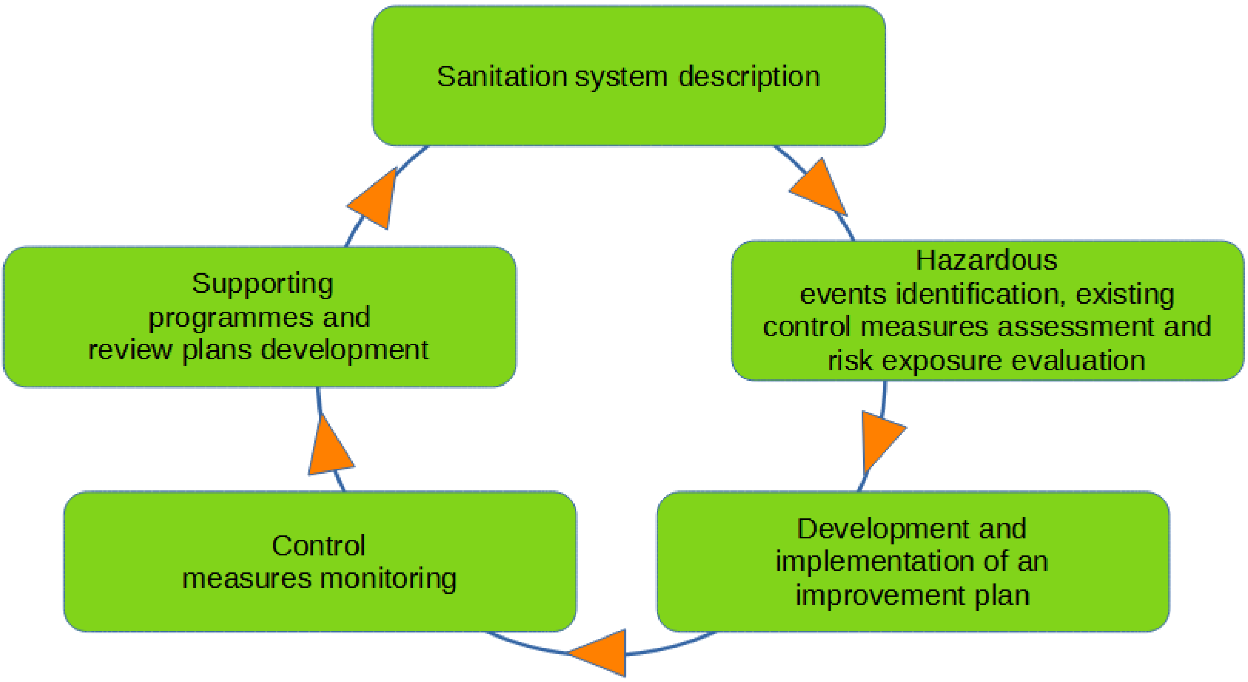

Figure 2: SSP structure, taking as a reference WHO (2015)

As discussed later, both the SSP and the WSP conceived the assembly of a team with experts having the required skills to develop the plan.

In the next sections, while discussing the general structure that an MSWSP should have, elements from the WSP and the SSP are mentioned.

It is essential to take into account that the MSWSP discussed hereafter aims to represent a risk-based management tool for systems that manage solid waste. The approach consists of practical step-by-step guidance providing a methodology for developing site-specific assessment and management plans to reduce health impacts from solid waste. The MSWSP process coordinates stakeholders along the solid waste management chain and prioritizes improvements based on health risk. The process is iterative and highlights the necessity for continuous improvement, monitoring and evaluation activities.

2.2.2 Health-based targets

In both the WSP and the SSP, health-based targets were considered health protection objectives for given exposures. Health-based targets provide benchmarks useful to confirm the adequacy of existing systems and control measures or the need for their improvement.

Health-based targets should be part of an overall public health policy. Indeed, as highlighted in the drinking water guidelines (WHO, 2017a), to meet health-based targets should be viewed in the context of broader public health policy. It would be useful to consider initiatives to improve drinking water, sanitation, waste disposal, personal hygiene, and public awareness campaigns to reduce personal exposure to hazards and impacts of activities on environmental matrices.

At the same time, at a national level, decisions related to risk acceptance and tolerable burdens of the disease need to consider the probability and severity of impact in addition to environmental, social, cultural, economic and political dimensions that influence decision-making (WHO, 2017a). In such a context, definitions of tolerable burdens of disease and reference levels of risk can be essential to provide a baseline for the development of health-based targets.

In the drinking water guidelines, WHO (2017) mentions four distinct types of health-based targets:

- Health outcomes targets (defined in terms of tolerable burden of disease (DALY) or negligible risk (risk assessment)).
- Water quality targets (guidelines values, which in the context of this MSWSP can also be extended to air and soil).
- Performance targets (specified removal of hazards).
- Specified technology targets (defined technologies to use).

The most precise is the health outcome target, which supports the derivation of the remaining targets.

A concept considered in the SSP (WHO, 2015) is the tolerable health risk, defined as the level of health risk from a specific exposure tolerated by society and used to set health-based targets.

In the WHO (2017) drinking-water guidelines, the reference level of risk is 10^{-6} disability-adjusted life-years (DALYs) per person per year. The DALY is a summary measure combining time lost through premature death and time lived in states of less than optimal health (i.e. disability) (WHO, 2013). It is approximately equivalent to a lifetime cancer risk (LTCR) of 10^{-5} (i.e. one additional case of cancer per 100,000 people ingesting drinking-water containing the substance at the guideline value over a lifespan). Similarly, the WHO (2006) guidelines for safe use of wastewater, excreta and greywater recommended a health-based target of 10^{-6} DALY per person per year.

As anticipated, in the field of solid waste, some national legislations have already started to evaluate the acceptable level of risk, such as in landfills, through health risk analysis. For instance, in Italy (APAT, 2005) for carcinogenic risk, a threshold value of 10^{-6} is considered if applied to single contaminants and 10^{-5} in cumulative risks.

In section 2.2.5 (Identify hazards and threats), the health risks are discussed as well, along with the health risk assessment matrices. Definitions connected with the severity of hazardous events are given as well as risk descriptors. As analysed later, in evaluating the level of risk, different approaches can be followed, taking into account the local context.

2.2.3 Organising the development of the MSWSP and establishing a team

For the successful implementation of an MSWSP, a formal adoption and management commitment will be essential. The responsibility can involve local authorities and institutions, private companies and even groups of citizens, depending on the local context.

The MSWSP represents an approach that can highlight how the responsible for the waste management system is applying best practices and methods to reduce environmental and health risks. This element can make its formal adoption more attractive.

The process towards an MSWSP should be started by one or several interested individuals or organisations. Simultaneously, one of the first steps has to consist of assembling a team with the necessary skills to develop the plan.

A team leader has to be appointed to drive the project and, when it will be completed, deliver it to the applicants. The team leader must be an expert with strong organisational and technical capacities and experience to ensure project implementation.

The MSWSP team members can be identified through stakeholder analysis. People with a mix of environmental, health and technical knowledge should be included, to have a team able to adequately define the system, identify hazards and hazardous events, and understand how to eliminate or reduce the risks. Someone able to achieve a cost analysis could be included as well, to have a broader impact. The team can also include members from the local solid waste management authority or staff to facilitate the activities. However, if the required skills are unavailable locally, the team leader should explore external support opportunities.

When possible, equity should be found in terms of gender. Furthermore, the needs of vulnerable or socially excluded groups should be taken into account.

It is the team's responsibility to define the scope of the MSWSP by agreeing with who commissioned the work. The team has to describe which parts of the solid waste chain are involved, and the risk level to address.

It can also be useful to include in the team people that:

- Already know the site-specific system and the related hazards.
- Have the authority to implement any necessary changes in the system
- Are directly involved with the daily operations.

The right balance must be found in the team looking for a number of people who allow a right multi-disciplinary approach without making decision processes too complicated or lengthy. As it can be expected, the team's size can vary in function of characteristics of the system itself.

As aforementioned, the overall objective of an MSWSP is to reduce health impacts related to solid waste chain; at the same time, each plan will have its site-specific goals and peculiarities. As a consequence, clearly defining specific objectives helps to determine better the path to follow. For instance, a plan can give more importance to safe reuse of some solid waste fractions or can have more broad regional significance for the promotion of some products (e.g. promotion of low-density polyethylene (LDPE) waste collection, recycling and reuse, or to ensure safe reuse of compost from biowaste).

In this thesis, two teams were constituted, one for the case study in Serbia, and the other for the case study in Ghana. For the case study in Serbia, the MSWSP team that was assembled consisted of:

- Professor Mentore Vaccari, from the University of Brescia (Italy), Faculty of Engineering, Department of Civil, Environmental, Architectural Engineering and Mathematics, as a team leader and supervisor. He has long experience in solid waste management and remediation technologies, both in industrialised and developing countries.

- As the author of the PhD thesis, Giovanni Vinti was the person in charge of the work. He developed this first attempt of the MSWSP, analysed the case studies, updated the other members of the team, exchanged opinions and received revisions and suggestions from them.

- Professor Bojan Batinic, from the University of Novi Sad (Serbia), Faculty of Technical Sciences, Department of Environmental Engineering. He was the academic who allowed collecting most of the information related to the Serbian case study. His field of research regards designing and development of waste management systems.

- Professor Thomas Clasen, from the Emory University (Atlanta, USA), Rollins School of Public Health, Department of Environmental Health. He is expert in environmental health and epidemiology. Professor Clasen leads a group of researchers whose work consists mainly of health impact evaluations of water, sanitation and household air pollution interventions in low-income countries.

- Dr Valerie Bauza, from the Emory University (Atlanta, USA), Rollins School of Public Health, Department of Environmental Health. She is a Postdoctoral Fellow and has experience working on water and sanitation projects in the USA, Sub-Saharan Africa, and South Asia.

- Dr Christian Zurbrügg, from Eawag Swiss Federal Institute for Aquatic Science and Technology (Switzerland), Sandec Department Sanitation, Water and Solid Waste for Development. He heads the research group on solid waste management in developing countries at Sandec. Dr Zurbrügg has conducted applied research on urban environmental management (sanitation and solid waste) fro many years.

- Dr Terry Tudor, former Professor at the Northampton University (UK). His academic activities were related to the Circular Economy, and Waste and Resources Management. Dr Tudor currently works as an independent consultant.

For the case study in Ghana, most of the MSWSP team members were the same. Indeed the team consisted of Professor Mentore Vaccari, Giovanni Vinti, Professor Thomas Clasen, Dr Valerie Bauza, Dr Christian Zurbrügg, Dr Terry Tudor.

The composition of the two teams is summarised in Figure 3.

MSWSP team – Case study of Serbia:

- Professor Mentore Vaccari (University of Brescia – Italy)
- Giovanni Vinti (University of Brescia - Italy)
- Professor Bojan Batinić (University of Novi Sad - Serbia)
- Professor Thomas Clasen (Emory University – Atlanta, USA)
- Dr Valerie Bauza (Emory University – Atlanta, USA)
- Dr Christian Zurbrügg (EAWAG – Switzerland)
- Dr Terry Tudor (Independent consultant – UK)

MSWSP team – Case study of Ghana:

- Professor Mentore Vaccari (University of Brescia – Italy)
- Giovanni Vinti (University of Brescia - Italy)
- Professor Thomas Clasen (Emory University – Atlanta, USA)
- Dr Valerie Bauza (Emory University – Atlanta, USA)
- Dr Christian Zurbrügg (EAWAG – Switzerland)
- Dr Terry Tudor (Independent consultant – UK)

Figure 3: Composition of the two MSWSP teams

It is essential to highlight that in the current work, the first proposal of the MSWSP in both the case studies was not launched by local authorities, but from the MSWSP team members. The reasons are essentially two:

- The novelty of the work. Indeed an MSWSP does not officially exist yet. Consequently, such a proposal could not arrive from administrations, officials or other local stakeholders because they did not know the plan.

- The constraints due to the pandemic (Covid-19) hampered direct contacts with many potential stakeholders and local authorities.

2.2.4 Solid waste management system description

It is crucial to provide a full description of the solid waste management system, at least within the boundaries that reflect the plan's specific objectives. Consequently, depending on the goals, even the whole system can be covered, from generation, segregation, storage, collection and transport of solid waste, to treatment and disposal activities. The safe reuse of waste can also be investigated. Sometimes it can even be useful to start "from the cradle", namely from the characteristics of a product which will become waste. It is advantageous to define the composition of solid waste fractions and establish their path through the system.

It is up to the team choose which information is more necessary. Examples of data that can be considered to describe the solid waste management system extensively are listed in Table 1.

Table 1: Data noteworthy to describe the SWM system extensively

1	Source of most common and/or potentially hazardous waste entering the specific system in the area
2	Environmental description of the area (geology, morphology, hydrology, general information about local flora and fauna)
3	Information about the local population
4	Information about (formal and informal) waste workers
5	Other potentially polluting human activities in the area (e.g. factories)
6	Solid waste characterization and quantification
7	Technical and qualitative information about waste segregation and storage characteristics
8	Technical and qualitative information about the waste collection system
9	Technical and qualitative information about waste treatment, recovery, reuse and disposal processes
10	Information about adverse health outcomes in the area (if any), both for residents and workers

Besides, to build a flow diagram can be useful, also to simplify the hazards identification discussed below.

2.2.5 Identify hazards and threats; the use of the health risk assessment matrix

After describing the solid waste management system within the boundaries of interest, the next step will be crucial. It consists of conducting a hazard analysis to establish priorities on what requires more urgently control measures. Indeed, some events can carry a high risk for many reasons, such as its intrinsic nature, because the lack of existing control measures or the current control measures is not good enough. However, as will be better explained later, control measures are intended as those interventions aiming to mitigate the risk.

Risk management requires identifying all potential hazards, their sources, possible hazardous causes, and evaluating the weight for each risk. The MSWSP team must consider all potential chemical, biological, physical or radioactive (if any) hazards associated with the SWM activities. Suppose the system is investigated “from the cradle”. In that case, the team should start from the origins of waste itself. For instance, if a high risk of contamination is in a specific area due to LDPE bags, even the replacement of this material could be taken into account.

As mentioned by Davison et al. (2005) in the WSP:

- A hazard is any chemical, biological, physical or radioactive (if any) agent having the potential to cause harm.
- A hazardous cause (or event) is a situation that can lead to the presence of a hazard.
- The risk is the likelihood that identified threats could cause harm having a given magnitude in exposed populations.

For instance, in a sanitary landfill, a hazardous event can be represented by spreading leachate because of damage in the waterproof layer. The related hazard can be contaminated groundwater that people could use for drinking purposes. In an incinerator, the hazardous event can be represented by gaseous emissions produced and not adequately treated by the plant. The related hazard can be due to the high concentration of dioxins in the air and soils and human beings' consequent absorption. The health-based targets can be legislation limits in terms of pollutant emissions by the incinerator or groundwater contamination. In other instances, the target could be more generic because of the lack of legislation to take as a reference or the impossibility to take measurements with the needed devices. As a consequence, it is up to the MSWSP team members to find the best way to act with the means and resources available in the local context. As aforementioned, existing control measures could be already operational but not efficient enough. In any case, through the MSWSP, more robust control measures should be determined and proposed to reduce the level of health risk.

The team should identify hazards and the associated hazardous causes at each step of the solid waste chain taken into consideration.

Hazardous causes can be related to:

- Current operations which lack control measures, or with inadequate control measures.
- Change in operating conditions.
- System failure or accidents.
- Variations due to weather conditions.

As aforementioned, flow diagrams can help in hazards and hazardous causes identification.

Furthermore, the source-pathway-receptor relationship has to be borne in mind. Indeed, hazards in the environment do not automatically pose a risk to a human receptor. Moreover, the level of risk from the same source can vary a lot. It depends on the pathways by which the contaminants can reach the receptor. It is up to the MSWSP team to choose how to develop the procedure. It should be evident ranking the hazards becomes crucial to establish priorities. The necessary control measures and the frequency of monitoring activities will depend on it.

A health risk assessment matrix can be applied, as already conceived in the WSP and the SSP. The MSWSP team has to decide how to rank the hazards. Given the heterogeneity of the possible hazards and hazardous causes, a semi-quantitative approach can represent the best choice.

This study's general structure of the semi-quantitative health risk assessment matrix is shown in Table 2. In the matrix's construction, the definitions of hazard, hazardous event and risk previously discussed were taken as a reference. Furthermore, the parameters used in the SSP (WHO, 2015) were employed for the severity, likelihood, and risk level measurement scales as summarised in Table 4. However, as exposure pathways and risks related to SWM were different from drinking water and wastewater, the SSP definitions were adapted to develop distinct explanations for the SWM semi-quantitative risk assessment parameters, and are summarised in Table 3. The descriptions given in Table 3 represent a crucial step for the development of the MSWSP. They are the results of exchanging ideas and points of view occurred in particular with a member of the MSWSP teams, Dr Valerie Bauza. As anticipated, every member's skills are essential, and her broad vision on how to evaluate the adverse health outcomes was determinant.

As noted in the SSP (WHO, 2015), in assessing the severity, the concentration of pollutants in the waste and the magnitude of associated health outcomes should be considered (WHO, 2015). However, the team may choose to develop its definitions for likelihood and severity, considering aspects related to the potential health impact, regulatory elements and effects on community perceptions (WHO, 2015).

The values in terms of likelihood and severity can be assigned analysing data and after consultations among the team members. The matrices played a crucial role, as it will be better discussed in Chapter 4 (Results and Discussion). As mentioned in the WSP (Davison et al., 2005), the team can calculate a priority score, for each identified hazard, and the risk posed does not need to be necessarily quantified. There are several possible approaches to ranking risk, and it is up to the team to determine which method it will be used (Davison et al., 2005). It is also important to note that likelihood and severity can be derived from the team's technical knowledge and expertise, literature data and guidelines. Therefore, the risk ranking is site-specific and related to each system and its characteristics.

Table 2: General structure of the semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**

Table 3: Risk definitions conceived for semi-quantitative health risk assessment related to solid waste management practices

Severity	
Insignificant	Hazard or hazardous event resulting in no or negligible health effects both in long and short term.
Minor	Hazard or hazardous event potentially resulting in minor and temporary health effects (e.g. temporary symptoms like irritation, nausea, headache).
Moderate	Hazard or hazardous event potentially resulting in moderate temporary health effects (e.g. acute illness

	such as diarrhoea or upper respiratory illness).
Major	Hazard or hazardous event potentially resulting in major and prolonged or permanent health effects (e.g. malaria, chronic diarrhoea, chronic respiratory problems); and/or may lead to legal complaints and concern; and/or major regulatory non-compliance.
Catastrophic	Hazard or hazardous event potentially resulting in major and permanent health effects or loss of life (e.g. cancer, serious birth defects, miscarriage or mortality); and/or will lead to a major investigation by the regulator with prosecution likely.
Likelihood	
Very unlikely	If the event has not locally happened in the past [a] and if the current local context makes the event highly improbable.
Unlikely	Either the event has or has not locally happened in the past [a], if the current local context makes it possible at least once per year
Possible	If the event has locally happened in the past [a] and the current local context makes it possible at least once per month
Likely	If the event has locally happened in the past [a] and it can happen at least once per week
Almost certain	If the event has locally happened in the past [a] and it can almost certainly occur in most circumstances in the future (at least once a day)

[a] If there is some doubts about the past, it is more important to focus on the current local context to select the most appropriate Likelihood

Table 4: Scale used in the semi-quantitative risk assessment matrix

Severity
• Insignificant [1][a] • Minor [2] • Moderate [4] • Major [8] • Catastrophic [16]
Likelihood
• Very unlikely [1] • Unlikely [2] • Possible [3] • Likely [4] • Almost certain [5]
Risk Level = Severity × Likelihood
• Low risk [<6] • Medium risk [6-12] • High risk [13-32] • Very high risk [>32]

[a] The number in parenthesis represents the corresponding weight of the value

In analysing the hazardous events, priority was given to the circumstances resulting in high or very high risk. However, in cases in which no event has such a level of risk, it would be recommended to concentrate the next steps on activities having moderate risks. In this way, the implementation of the MSWSP will allow in any case to improve the quality of the system, further reducing some health risks.

It was conducted a risk assessment for each specific SWM activity that occurred in each village of the case study in Ghana. When a particular activity (e.g., burying of waste) was not performed in a location, a related risk assessment was not conducted. If it was not possible to assert the presence, likelihood and/or severity of a specific activity, it was included in the matrix but with the acronym NA (Not Available). In Serbia's case study, the risk assessment was conducted for the municipal landfill of Novi Sad. The reasons are discussed in Chapter 4 (Results and Discussion).

2.2.6 The link between health risks and the number of people affected

After evaluating the level of health risks for every hazardous event identified, the number of people that can be affected should be analysed in the next step. Indeed, it is not rare that two events with the same level of risk can involve a different amount of people. When this happens, the risk level for the people potentially reached will not change, but the way to deal with the problem can vary.

For example, in a rural village, groundwater consumption contaminated by leachate from a dumpsite could represent a very high risk for people who use a well downstream of the water flow. Consequently, if a few wells are affected, the risk will be very high, but for a limited number of people. Besides, the control measures to be conceived will be influenced by that. It could be necessary to stop using contaminated wells. A different situation in the same village, probably more challenging to deal with, could be represented by the inhalation of by-products (e.g. dioxins) from the uncontrolled combustion of waste. In such a case, the related risk can probably affect more people. Indeed, the spread of contaminants through waste combustion is not influenced by groundwater flow but from wind direction, which is more variable. Residents in a larger area could absorb the pollutants, and a broader intervention would be necessary.

Many approaches can be followed to estimate the number of people involved. The choice will depend on the available information, maps, databases, and field missions to help understand the real situation, questionnaires, and models. The presence of local stakeholders can facilitate the process.

2.2.7 Possible need for further investigations

An aspect that should not be underestimated is linked to the possible need for further investigations, due to uncertainties that emerged, for example, during the compilation of risk matrices. As will be seen below, it was impossible to evaluate some dangerous events due to difficulties mainly related to obstacles posed by Covid-19. Sometimes, factors such as the current lack of scientific data have also contributed to maintaining this uncertainty margin. Furthermore, particular care should be taken at least to assess the risks evaluated as high and very high and suggest further investigations for them if, despite the assessment, non-negligible uncertainties have emerged.

2.2.8 Control measures and priorities

Control measures are actions, activities and processes applied to prevent or minimise hazards (Davison et al., 2005). As anticipated, the prioritised threats identified during the hazard analysis have to be managed by some mitigating processes to reduce the level of risk to an acceptable value. During the MSWSP process, many control measures (also defined as barriers) can already be found in place. In these cases, the control measures need to be assessed to evaluate if they meet the safety requirements. Simultaneously, some processes can need further control measures, for example, if the related hazardous events were not previously identified.

Control measures are identified by considering the hazardous events that can cause contamination (or disturbance) of environmental matrices and reach humans through direct or indirect exposure. Then, the interventions that can mitigate the risks from those events have to be elaborated.

Control measures can be represented by (WHO, 2015):

- Capital works (e.g. new or improved management facilities).
- Operational interventions (e.g. restrictions in the use of soil or groundwater, longer residence time in some existing units).
- Behavioural measures (e.g. leading awareness campaigns in terms of safe practices and health education).
- A combination of the preceding measures.

The experience among the members of the MSWSP team is essential in identifying the most appropriate control measures.

Figure 4 is a step-by-step schematic representation of hazardous events, related hazards and control measures that could be identified.

However, it is essential to conceive control measures that are appropriate for the local context. Otherwise, the proposals would represent an idealistic solution that is inapplicable or could lead to negative results in the long term, mainly in resources-limited countries. As a consequence, the MSWSP team should seek for appropriate technologies, that have to (Sorlini et al., 2015):

- Be economically affordable.
- Minimize environmental impact.
- Be based on local needs.
- Be straightforward in operation and maintenance.

- Use local materials and resources to reduce costs and improve the local market.

For both the case studies (Serbia and Ghana), control measures are discussed in Chapter 4 (Results and Discussion) to reduce risks identified as high and very high.

WM activity	Hazardous Event	Hazard	Control Measures
Disposal of solid waste in a dumpsite	Leaking of leachte into groundwater	Groundwater contamination (and human consumption)	• Restrictions in the use of groundwater (operational interventions) • Landfill mining (capital works) • Permeable reactive barriers (capital works)

Figure 4: Schematic representation of hazardous event, hazard and control measures associated with the disposal of solid waste in a dumpsite

2.2.9 Monitoring and management procedures for corrective actions; supporting programmes

Control measures have to be periodically monitored in selected points. Since monitoring all control measures may not be practical, at least the most critical monitoring points should be chosen, based on the prioritized hazards. The parameters settled for operational monitoring have to be well related to each control measure.

Some parameters can be used as surrogates or indicators for characteristics for which testing it would be more difficult or expensive. Similarly to WSP and SSP, for the monitoring points, the following elements should be considered:

- Parameter (measured or observational).
- Method of monitoring.
- Frequency of monitoring.
- Operational or critical limits (discussed afterwards).
- Subjects that will monitor.
- Responsibilities and necessary qualifications of staff.

- Requirements for documentation and management of records, including how monitoring results will be recorded and stored.
- Requirements for reporting and communication of results.
- Actions to be undertaken when the critical limit is exceeded.

Taking into account the WSP, an operational limit is defined as a pattern that indicates whether the control measure is functioning as designed (Davison et al., 2005); a critical limit has the aim to identify operational limits linked directly to absolute acceptability (Davison et al., 2005).
For each control measure, the limits should be defined by the MSWSP team. The limits are usually numerical values, but in some cases, qualitative limits can be appropriate as well (e.g. odours acceptance for residents living nearby). Current knowledge and expertise, including technical data and international standards and locally derived historical data, can be used by the MSWSP team as a guide when determining the limits.

Several operational parameters can be monitored during solid waste treatment processes, for example:

- Heavy metals (e.g. Cr, Hg, Cu, Pb) in environmental matrices.
- Dioxins in soil and/or air.
- Fences conditions.

As can be noted, the first two categories are related to chemicals, while the last is intended to prevent unauthorized people or animals getting too close to some MSW units.

If during monitoring processes operations outside the limits are detected, it is necessary to act correcting them. To establish corrective actions which identify the operational responses related to specific deviations from the set limits represents an important element of the MSWSP.

Corrective actions procedure can be very different. For example, they can comprise:

- Contact details for specialized personnel or external entities.
- A clear description of the actions required to solve the problem.
- Troubleshooting manual.

Supporting programmes are intended to indirectly support the waste management safety chain, through codes of acceptable operating, management and hygienic practices. They can be included in the MSWSP.

Supporting programmes can cover:

- Training of operation and maintenance activities for workers.
- Regular hygiene practices in the workplace.
- Education of communities whose actions may influence and increase the risk associated with solid waste.
- Calibration of monitoring equipment.

- Operation and maintenance.
- Record-keeping.

However, the current work represents the first attempt to develop and implement an MSWSP. As shown in Chapter 4 (Results and Discussion), monitoring and management procedures and supporting programmes were not included because further details were needed. It was not possible to exchange enough ideas about it with the other MSWSP team members. Priority was given to the health risk assessment matrices, further investigations proposed, and control measures to reduce the significant risks. Furthermore, a general analysis of the cost to achieve the proposed control measures was carried out in the end.

2.2.10 Possibility to include a cost analysis

The last step in the MSWSP implementation should consist of the cost analysis. Indeed, interventions proposed have to be sustainable also under an economic point of view (Das et al., 2019), both in capital works and maintenance costs.

How to carry out cost analysis depends on the information available and the experience in this field among the MSWSP team members. Furthermore, a cost analysis is strictly related to the control measures conceived and the case study's boundary conditions. A cost analysis is usually easier to develop in industrialised countries. Indeed, in such contexts, price lists for some materials are often available as well as other detailed data. Mainly in developing countries, field visits could be necessary to collect data about local materials costs. However, scientific literature can represent a good compromise to overcome the lack of data. For example, the activities of waste collection in developing countries are well described by Coffey and Coad (2010), who also analyse financial aspects. Notwithstanding, it must be noted that both the WSP and the SSP focus on health risks assessment and control measures identification, without pay strong attention to the costs of the interventions. Such an exclusion is related to the safety plans' main scope, i.e., the health aspects. But a cost analysis can give an added value to the work. Indeed, the importance to include a first cost analysis already in the MSWSP is due to the opportunity to show that the project and the control measures conceived are economically sustainable.

It is necessary to highlight that in the MSWSP, a preliminary cost analysis can be enough. To develop a detailed economic project, taking into account the MSWSP, will be the task of those stakeholders in charge of implementing the plan.

2.3 Constraints due to the pandemic (Covid-19) in data collection, analysis and elaboration methodology

Similarly to the WSP (Davison et al., 2005), the proposed MSWSP was implemented in two different countries, Serbia and Ghana. However, in the WSP, the two case studies represented an advanced economy country (Australia) and a developing country (Uganda). The case studies in Serbia and Ghana are diverse, but both are categorised as developing economies (IMF, 2020a).

As shown below, the cases analysed in this PhD research represent different situations in terms of data availability, field missions carried out or not, and kind of issues and tools to face them. Consequently, the case studies offer useful examples to take as a reference to implement an MSWSP in developing countries. However, the approach can be considered the same also in advanced economy countries.

During the work, an unexpected constraint that nobody could foresee has been represented by Covid-19 (WHO, 2020a). The current epidemic began to spread in late 2019, and WHO assessed that Covid-19 could be characterised as a pandemic on 11 March 2020 (WHO, 2020b). Italy was the first western country significantly affected by the pandemic, and on 9 March 2020, a national lockdown was declared (Infodata, 2020). Since then, it has been complicated to move from a region to another for many months. Leave Italy to go abroad has been difficult as well. This global catastrophe also hit the pathway of this PhD thesis and the related research activities. A first field assessment in Ghana, the case study identified, had been conducted between November and December 2019. The field assessment involved nine Ghanaian rural villages. Unfortunately, Ghana closed its borders and stopped international flights since March 2020, following the outbreak of the Covid-19 pandemic, and it has only started reopening them in September 2020 (AS English, 2020). The research in Ghana has been developed within an international development cooperation project led by an Italian Non-Governmental Organisation (NGO) named Cooperazione Internazionale Sud Sud (CISS) (CISS, 2020a; Vinti et al., 2020b).

Due to Covid-19, the CISS field coordinator left Ghana in March 2020 and returned there in November 2020, making it impossible for me to conceive new field missions in 2020. As discussed later, it was agreed with Professor Vaccari that the situation required looking for a further case study. As a consequence, in May 2020, professor Bojan Batinic from the University of Novi Sad (Serbia) was contacted, mainly for two reasons: Professor Batinic had a lot of data available from the SWM system of Novi Sad; in May 2020, the pandemic in Serbia appeared to be less dangerous than in other countries, and the restrictions on movement were not excessive (WorldAware, 2020). Unfortunately, in July 2020, Italy introduced travel restrictions to Serbia because of the pandemic (Il Messaggero, 2020). In October 2020, the second wave of Covid-19 hit Europe again (The Guardian, 2020). In Serbia, new daily cases dramatically increased since the second half of October 2020 (Georank, 2020). However, in Serbia's choice of the case study, risks for new restrictions were taken into account. Despite the impossibility of carrying out field missions in that country, the necessary information was collected thanks to Professor Batinic.

Finally, it was decided to keep both the case studies for the research, i.e., Ghana and Serbia. Indeed, as it is better shown later, differences that characterised the two contexts represented added values for the study and the proposal of MSWSP. A mix of qualitative and quantitative methods was used to achieve the expected results, given the great diversity in data available. A field mission was conducted in Ghana, but the paucity of quantitative data characterised the case study. In Serbia, as aforementioned, no missions were carried out, but a lot of quantitative data were collected. As will be shown, both case studies have critical elements in terms of solid waste management and related health risks. Notwithstanding, boundary conditions were very different.

2.4 Data collection methodology

In the research activities, many methodologies were used for data collection and analysis. They have been included interviews, observations, analysis of scientific publications, analysis of reports, maps and further technical documents received by experts (e.g., Professor Batinic, administrative offices), news on events related to solid waste locally. An essential element was represented by the creation of two MSWSP teams, one per case study.

In Ghana, information was derived from the observations and data collected during field assessments. At the same time, data from the field assessment were used as a first step. Indeed, the difficulties due to the pandemic and the fact that quantitative data in terms of concentration of contaminants in the environment required specialised technological devices that are expensive and usually difficult to obtain in developing countries' rural settlements, represented factors that influenced the research. As a consequence, the data were integrated with the search for scientific publications from similar contexts. In some cases without sufficient collected or published data, scores related to the health risk matrices discussed later were derived from the team members' technical knowledge and expertise that were involved, as recommended in the WSP (Davison et al., 2005). The nine Ghanaian villages were visited in November 2019. The environmental assessment was part of broader monitoring, within the Sustainable Livelihoods project (Vinti et al., 2020b), co-funded by the European Union. The first step consisted of evaluating the villages under the environmental, sanitary, economic and social point of view. In each assessment, information about solid waste management practices, the most common diseases among people, sanitation services, and general environmental issues was sought. Data on SWM in each of the nine villages were collected through qualitative field observations and information received by local stakeholders, such as opinion leaders, traditional authorities from the villages and people living near dumpsites, with the help of a local interpreter and the project manager of the NGO locally involved, i.e. CISS NGO. The questions posed to local stakeholders during the assessment in the villages are available in Annex 1. The data collected allowed to describe the case study (see Chapter 3). When SWM sites were identified, they were visited. It is important to note that observational methodologies have been extensively used in waste management research, especially in studies focused on SWM in developing countries (Vidanaarachchi et al., 2006). In some cases, a combination of methods has been used to obtain better results (Soltani et al., 2015). A portable device was employed to measure the concentration of $PM_{2.5}$ and PM_{10} in the air at different points of each village (Trotec International, particle measuring device BQ20, measurement interval 0-2000 μg/m^3, resolution 1 μg/m^3, detector type: scattered light measurement). In each village, the field assessment lasted a few hours. It was due to many reasons, such as the distance from the headquarter of the mission, located in Tamale, capital of the Northern Region of Ghana, and the bad quality of most road connections. Furthermore, for safety and convenience reasons, it was not possible to stay overnight in the villages. The staff shortages in remote areas represented an issue common in such contexts (Lehmann et al., 2008) that also affected the duration of field assessments.

In the nine rural villages in Ghana, direct observations played a fundamental role. Indeed, given the particular context, it would be complicated thinking about control measures to reduce the highest health risks in the absence of a first field visit. Indeed, observational approaches allow the evaluator to learn about which he/she may be unaware of. Besides, observations can help discover details that cannot be discussed during interviews (Gaaski, 2015). A significant example: as discussed later, the inaccessibility to most of the

villages was a crucial issue that hindered a centralised and frequent waste collection system with trucks. This issue became evident during the travel to reach the communities by car.
In Ghana, a risk assessment was conducted for each specific SWM activity in each village. When a specific action was not performed in a particular village, a related risk assessment was not conducted. If it was not possible to assert the presence, likelihood and/or severity of a specific activity, it was included in the matrix but with the acronym NA (Not Available).

In Serbia, Novi Sad was selected as a case study. Field missions were hindered because of the pandemic (Covid-19). As a consequence, it was not possible to collect qualitative and quantitative data through direct field observations. However, Novi Sad is an urbanised area, and much research has been conducted in the last years. As anticipated, even a technical university exists (University of Novi Sad – Faculty of technological sciences). Data collection started in May 2020, when it was clear that the pandemic required new approaches, and the situation in Ghana was very uncertain. Novi Sad was strategically elected due to a series of potential health issues related to solid waste activities and taking into account the possibility of receiving detailed information even if the pandemic had prevented field visits, as happened. The obtained data were integrated with the search for scientific publications from similar contexts. Furthermore, some scientific publications from Novi Sad were available. To better understand the context, local stakeholders were asked to take photographs in some cases, and they were included in this manuscript. Specific questions related to the municipal landfill of Novi Sad were posed to Professor Batinic, and are available in Annex 2. The data collected allowed to describe the case study (see Chapter 3).
In compiling the health risk assessment matrix related to the case study in Serbia, when it was not possible to assert the presence, likelihood and/or severity of a specific hazardous event, it was included in the matrix but with the acronym NA (Not Available). Additional information was collected during further online meeting.

In Serbia's case study, the high amount of quantitative data already available allowed to fill the gaps related to the impossibility to conduct any field mission and direct observations. Furthermore, except for some suburbs, Novi Sad is an urbanised city, in which the living conditions are similar to a typical Italian town. Issues characterising Novi Sad in solid waste management, such as sites defined landfills but that look like dumpsites, mainly existed in European industrialised countries decades ago, and now are generally fixed. Still, the context of Novi Sad is less challenging to conceptualise than the Ghanaian one.
As discussed later, in Serbia, the semi-quantitative risk assessment was conducted only for the municipal landfill of Novi Sad. This decision was finally taken when it was clear that a field mission was impossible, due to the second wave of Covid-19 that afflicted Europe since October 2020 (The Guardian, 2020). As anticipated, the risk of new pandemic waves was already taken into account in May 2020, when Novi Sad was selected as a further case study. Indeed, the information available made it possible to develop a health risk assessment matrix related to the city's municipal landfill. The general structure of the matrix is similar to that of Ghana, though other hazardous events are included, given the specific context. When a particular activity was not performed in the landfill, a related risk assessment was not conducted. If it was not possible to assert the presence, likelihood and/or severity of a specific activity, it was included in the matrix but with the acronym NA (Not Available).

2.5 Data analysis and elaboration methodology

The data from observations, interviews, scientific literature, and reports, were initially used to describe the case studies and the related SWM practices. Given the available information related to each case study's boundary conditions, most of the health-based targets were selected in terms of health outcomes targets but using a semi-quantitative approach, as it can be noted observing Table 3 that showed the risk definitions conceived. Consequently, a semi-quantitative risk analysis was conducted in each location, to allow the implementation of MSWSP. Risk assessment matrices were developed, specific to the SWM practices observed, based on literature review and internal consultation among the MSWSP teams members, adopting a similar approach used in the WSP (Davison et al., 2005) and the SSP (WHO, 2015). In some cases without sufficient collected or published data, scores were derived for likelihood and severity from the technical knowledge and expertise of the MSWSP team members, as recommended by Davison et al. (2005) in WSP. When available, values in environmental matrices analysed (e.g., groundwater) in the case studies were compared with national or international guidelines and current knowledge in terms of health risk related to the given concentration. Furthermore, to find information from similar cases, scientific literature was conducted, and a conservative approach was used. Indeed, especially the case study of Ghana was often delineated by the lack of quantitative information due to the isolation, difficulties characterising the communities and the pandemic that hampered additional field missions.

The main elements characterising the risk matrix, used in this study, were anticipated in section 2.2.5. The general structure of the health risk assessment matrix was shown in Table 2. The SWM activities are better discussed in Chapters 3 and 4 and the specific characteristics of the matrices.

The methodology followed in weighing each hazardous event in terms of likelihood and severity, for the case study of Novi Sad (Serbia), was based on the information obtained and analysed taking into account the elements summarised in Table 5. The hazardous events considered came from the municipal landfill of Novi Sad, and are discussed in detail in Chapters 3 and 4.

Table 5: Disposal of solid waste in the municipal landfill of Novi Sad - Methodology followed to weigh each hazardous event in terms of likelihood and severity

Hazardous event	Likelihood based on	Severity based on
Leaking of leachate in groundwater	• Presence of groundwater • Rainfall in the area • Hydrogeological characteristics in the area (e.g. soil, groundwater) • Absence of waterproof layer at the bottom of the landfill • Absence of leachate collection and treatment system • Data from publications in similar conditions (if available) • Size of the landfill	• Verification of the presence or absence of hazardous waste (and contaminants) • Characteristics of leachate • How groundwater is used by residents (e.g., drinking, bathing, cooking) • Proximity to inhabited areas (concentration of pollutants is higher decreasing the distance with point of exposure) • Data from publications in similar conditions (if available)

		• Size of the landfill
Spread of leachate in surface water	• Rainfall in the area • Hydrogeological characteristics in the area • Proximity to surface water • Verification of the connection between leachate and drainage system up to the river • Absence of leachate collection and treatment system • Data from publications in similar conditions (if available) • Size of the landfill	• Verification of the presence or absence of hazardous waste (and contaminants) • Characteristics of leachate • Use of surface water by residents (e.g. for bathing or drinking purposes) • Data from publications in similar conditions (if available) • Size of the landfill
Waste combustion – inhabitants	• Frequency of waste open burning (if any) • Amount of waste usually burned (if any) • Absence of fences and barriers • Presence of flammable materials • Risk that materials burn • Verification of fire safety systems • Emission control system • Data from publications in similar conditions (if available)	• Waste characteristics, to evaluate toxicity or carcinogenicity of contaminants generated during combustion • Proximity to inhabited areas • Presence and frequency of people in the landfill • Type of animals • Size of animal breeding sites • Size of crop growing sites • Data from publications in similar conditions (if available)
Waste combustion – inhabitants (injuries)	• Frequency of waste open burning (if any) • Amount of waste usually burned (if any) • Absence of fences and barriers • Presence of flammable materials • Presence of farm animals and crops nearby • Risk that materials burn • Verification of fire safety systems • System of control of biogas. • Data from publications in similar conditions (if available)	• Proximity to inhabited areas • Presence and frequency of people in the landfill • Use of personal protective equipment (PPE) in the landfill • Data from publications in similar conditions (if available)
Waste combustion – formal waste workers	• Frequency of waste open burning (if any) • Amount of waste usually burned (if any) • Presence of flammable materials • Risk that materials burn • Verification of fire safety systems • Data from publications in similar conditions (if available) • Presence and frequency of waste	• Waste characteristics, to evaluate toxicity or carcinogenicity of contaminants generated during combustion • Presence and frequency of waste workers in the landfill • Use of personal protective equipment (PPE) in the landfill

	workers in the landfill	• Data from publications in similar conditions (if available) • Location of the combustion area
Waste combustion – formal waste workers (injuries)	• Frequency of waste open burning (if any) • Amount of waste usually burned (if any) • Presence of flammable materials • Risk that materials burn • Verification of fire safety systems • Data from publications in similar conditions (if available) • Presence and frequency of waste workers in the landfill	• Use of personal protective equipment (PPE) in the landfill • Data from publications in similar conditions (if available) • Safe protocol in place to prevent burn injuries • Location of the combustion area (if any)
Waste combustion – informal waste workers	• Frequency of waste open burning (if any) • Amount of waste usually burned (if any) • Presence of flammable materials • Risk that materials burn • Verification of fire safety systems • Data from publications in similar conditions (if available) • Presence and frequency of informal waste workers in the landfill (if any), for instance in relationship with valuable waste	• Waste characteristics, to evaluate toxicity or carcinogenicity of contaminants generated during combustion • Use of personal protective equipment (PPE) in the landfill • Data from publications in similar conditions (if available) • Safe protocol in place to prevent burn injuries • Location of the combustion area
Waste combustion – informal waste workers (injuries)	• Frequency of waste open burning (if any) • Amount of waste usually burned (if any) • Presence of flammable materials • Risk that materials burn • Verification of fire safety systems • Data from publications in similar conditions (if available) • Presence and frequency of informal waste workers in the landfill (if any), for instance in relationship with valuable waste	• Use of personal protective equipment (PPE) in the landfill • Data from publications in similar conditions (if available) • Location of the combustion area
Free movement of farm animals in the landfill	• Presence of farm animals in the area, possibly observed while feeding on waste (Were they observed during the site visit? How often have operators observed farm animals and also	• Waste characteristics • Type of animals • Number of animals • Verification of the presence or absence of hazardous waste (and contaminants)

	feeding on waste?) • Absence of fences or barriers • Data from publications in similar conditions (if available) • Size of the landfill	• Verification of the presence or absence of burned waste • Data from publications in similar conditions (if available)
Free movement of inhabitants in the landfill	• Absence of fences and barriers (I arranged some questions for waste workers) • Use of the landfill as an open defecation area • Data from publications in similar conditions (if available) • Size of the landfill	• Verification of the presence or absence of hazardous waste (and contaminants) • Verification of the presence or absence of organic waste • Presence of animals (e.g. rodents, mosquitos) that can transmit infectious diseases (mainly related to the presence or organic waste) • Use of the landfill as an open defecation area • Data from publications in similar conditions (if available) • Use of personal protective equipment (PPE) in the landfill
Free movement of inhabitants in the landfill (injuries)	• Absence of fences and barriers • Use of the landfill as an open defecation area • Data from publications in similar conditions (if available) • Size of the landfill	• Verification of the presence or absence of sharp waste, which increase severity in case of toxic or carcinogenic substances, or that can cause infectious diseases • Data from publications in similar conditions (if available) • Use of personal protective equipment (PPE) in the landfill
Movement of formal waste workers in the landfill	• Rate of diseases among waste workers (if any) • Safety courses attended by workers • Refresher courses attended by workers • Number of waste workers • Use of personal protective equipment (PPE) and other safety protocols in the landfill • Data from publications in similar conditions (if available)	• Waste characteristics • Use of personal protective equipment (PPE) in the landfill • Kind of diseases among waste workers • Data from publications in similar conditions (if available)
Movement of formal waste workers in the landfill (injuries)	• Frequency of accidents that occurred in the past • Safety courses attended by	• Verification of the presence or absence of sharp waste, which increase severity in

	workers • Refresher courses attended by workers • Number of waste workers • Use of personal protective equipment (PPE) and other safety protocols in the landfill • Data from publications in similar conditions (if available)	case of toxic or carcinogenic substances, or that can cause infectious diseases • Use of personal protective equipment (PPE) in the landfill • Data from publications in similar conditions (if available)
Movement of informal waste workers in the landfill	• Presence of valuable waste (e.g. to sell as recyclable products or containing precious metals • Documented presence of informal waste workers (through interviews) • Use of PPE by informal waste workers • Data from publications in similar conditions (if available) Data from publications in similar conditions (if available)	• Waste characteristics • Use of personal protective equipment (PPE) in the landfill • Kind of diseases among informal waste workers • Data from publications in similar conditions (if available)
Movement of informal waste workers in the landfill (injuries)	• Presence of valuable waste (e.g. to sell as recyclable products or containing precious metals • Documented presence of informal waste workers (through interviews) • Use of PPE by informal waste workers • Data from publications in similar conditions (if available) Data from publications in similar conditions (if available)	• Verification of the presence or absence of sharp waste, which increase severity in case of toxic or carcinogenic substances, or that can cause infectious diseases • Use of personal protective equipment (PPE) in the landfill • Data from publications in similar conditions (if available)
Feed for rodents and other animals (including insects)	• Presence of organic waste • Presence of human or animal faeces • Use of the landfill as an open defecation area • Rainfall in the area • Type and frequency of waste coverage • Presence of infectious and vector-borne diseases in the area • Proximity to inhabited areas (considering it would be easier for animals to reach people) • Data from publications in similar conditions (if available) • Size of the landfill	• Proximity to inhabited areas (considering it would be higher the number of dangerous animals that get in contact with people) • Dangerous diseases present in the area • Data from publications in similar conditions (if available)
Spread of contaminants	• Type and frequency of waste	• Proximity to inhabited areas

in the air (excluding waste combustion)	coverage • Absence of gas collection systems • Bad smells in the area • System of control of biogas • Proximity to inhabited areas • Presence of Volatile Compounds (VCs) • Data from publications in similar conditions (if available) • Size of the landfill	(pollutants concentration increases when distance decreases) • Waste characteristics, to evaluate toxicity or carcinogenicity of emissions • Data from publications in similar conditions (if available)
Spread of contaminants into the soil (excluding waste combustion)	• Type and frequency of waste coverage • Proximity to inhabited areas • Presence of groups of children • Absence of fences and barriers • Absence of waterproof layer at the bottom of the landfill • Type of land use • Data from publications in similar conditions (if available) • Size of the landfill	• Waste characteristics, to evaluate toxicity or carcinogenicity of contaminants • Lack of hygiene practices by people • Data from publications in similar conditions (if available)

The methodology followed in weighing each hazardous event in terms of likelihood and severity, for the case study in Ghana, was based on the information obtained and analysed taking into account the elements summarised in Table 6. As it will be better explained later, the hazardous events considered were associated with four different waste management practices found in the nine rural villages. Such waste practices are included in the first column of Table 6 (i.e. disposal of solid waste in dumpsites; open burning of waste; uncontrolled burying of solid waste; reuse of solid waste from dumpsites as compost by local farmers). The waste management practices and the related dangerous events are discussed in detail in Chapters 3 and 4.

Table 6: Methodology followed to weigh each hazardous event in terms of likelihood and severity, considering four different waste management practices in the nine rural villages in Ghana

Waste management practice	Hazardous event	Likelihood based on	Severity based on
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	• Rainfall in the area (see Table 4 in the main manuscript) • Groundwater in the area (based on presence of wells used by people and direct information, if any) • Absence of waterproof layer at	• Verification of the presence or absence of hazardous waste (based on questions posed to residents and field surveys) • Verification of the presence or absence of WEEE (based on questions posed to residents and field

		the bottom of the dumpsite • Absence of leachate collection and treatment system • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village	surveys) • Use of wells by residents • Proximity to inhabited areas (concentration of pollutants is higher decreasing the distance with point of exposure) • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village
	Free movement of farm animals in the dumpsite	• Presence of farm animals in the area • Absence of fences or barriers • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village	• Verification of the presence or absence of hazardous waste (based on questions posed to residents and field surveys) • Verification of the presence or absence of WEEE (based on questions posed to residents and field surveys) • Verification of the presence or absence of burned waste (based on questions posed to residents and field surveys) • Data from publications in similar conditions (if available)
	Free movement of people in the dumpsite	• Absence of fences and barriers • Presence of valuable waste (e.g. to sell as recyclable products or containing precious metals) • Use of the dumpsite as an open defecation area	• Verification of the presence or absence of hazardous waste (based on questions posed to residents and field surveys) • Verification of the presence or absence of WEEE (based on questions posed to

		• Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village	residents and field surveys) • Verification of the presence or absence of organic waste (based on questions posed to residents and field surveys) • Presence of animals (e.g. rodents, mosquitos) that can transmit infectious diseases (mainly related to the presence or organic waste) • Data from publications in similar conditions (if available)
	Free movement of people in the dumpsite (case of injuries)	• Absence of fences and barriers • Presence of valuable waste (e.g. to sell as recyclable products or containing precious metals) • Use of dumpsite as an open defecation area • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village	• Verification of the presence or absence of sharp waste, which increase severity in case of toxic or carcinogenic substances, or that can cause infectious diseases, (based on questions posed to residents and field surveys) • Data from publications in similar conditions (if available)
	Feed for rodents and other animals (including insects)	• Presence of organic waste • Rainfall in the area (see Table 4 in the main manuscript) • Absence of effective and continuous waste coverage • Presence of infectious and vector-borne diseases in the area • Proximity to	• Proximity to inhabited areas (considering it would be higher the number of dangerous animals that get in contact with people) • Dangerous diseases present in the area (e.g. malaria) • Data from publications in

		inhabited areas (considering it would be easier for animals to reach people) • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village	similar conditions (if available)
	Spread of contaminants in the air	• Absence of effective and continuous waste coverage • Absence of gas collection systems • Bad smells in the area (based on questions posed to residents and field surveys) • Proximity to inhabited areas • Presence of farm animals and crops nearby • Presence of Volatile Compounds (VCs) • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites in the village	• Proximity to inhabited areas (pollutants concentration increases when distance decreases) • Waste characteristics (based on questions posed to residents and field surveys), to evaluate toxicity or carcinogenicity of emissions • Data from publications in similar conditions (if available)
	Spread of contaminants into the soil	• Proximity to inhabited areas • Presence of groups of children • Absence of fences and barriers • Kind of land use • Presence of farm animals and crops nearby • Data from publications in similar conditions (if available) • Size of dumpsites • Amount of dumpsites	• Waste characteristics (based on questions posed to residents and field surveys), to evaluate toxicity or carcinogenicity of contaminants • Lack of hygiene practices • Data from publications in similar conditions (if available)

		in the village	
Open burning of waste	Leaking of leachate into groundwater	• Rainfall in the area (see Table 4 in the main manuscript) • Groundwater in the area (based on presence of wells used by people nearby and direct information, if any) • Data from publications in similar conditions (if available)	• Use of wells by residents • Proximity to inhabited areas • Waste and by-products characteristics (based on questions posed to residents and field surveys), to evaluate toxicity or carcinogenicity of contaminants in the leachate • Data from publications in similar conditions (if available)
	Spread of contaminants in the air	• Proximity to inhabited areas • Absence of PPE (e.g. masks) • Absence of effective and continuous waste coverage • Presence of farm animals and crops nearby • Data from publications in similar conditions (if available)	• Proximity to inhabited areas (pollutants concentration increases when distance decreases) • Waste and by-products characteristics (based on questions posed to residents and field surveys), to evaluate toxicity or carcinogenicity of contaminants • Absence of flue gases treatment • Data from publications in similar conditions (if available)
	Proximity to open fires	• Proximity to inhabited areas • Houses made in flammable material (e.g. wood) • Absence of PPE during open burning practices (e.g. masks and gloves) • Data from	• Proximity to inhabited areas • Magnitude of open fires • Data from publications in similar conditions (if available)

		publications in similar conditions (if available)	
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	• Rainfall in the area (see Table 4 in the main manuscript) • Groundwater in the area (based on presence of wells used by people and direct information, if any) • Absence of waterproof layer at the bottom of the hole • Data from publications in similar conditions (if available)	• Verification of the presence or absence of hazardous waste (based on questions posed to residents and field surveys) • Verification of the presence or absence of WEEE (based on questions posed to residents and field surveys) • Use of wells by residents • Proximity to inhabited areas (concentration of pollutants is higher decreasing the distance with point of exposure) • Data from publications in similar conditions (if available)
	Spread of contaminants in the air	• Proximity to inhabited areas • Absence of effective and continuous waste coverage • Presence of VCs • Presence of farm animals and crops nearby • Data from publications in similar conditions (if available)	• Waste characteristics (based on questions posed to residents and field surveys), to evaluate toxicity or carcinogenicity of emissions • Data from publications in similar conditions (if available)
	Spread of contaminants into the soil	• Proximity to inhabited areas • Absence of fences and barriers • Kind of land use • Presence of farm animals and crops nearby • Data from	• Waste characteristics (based on questions posed to residents and field surveys), to evaluate toxicity or carcinogenicity of contaminants • Lack of hygiene practices

		publications in similar conditions (if available) • Data from publications in similar conditions (if available)	• Data from publications in similar conditions (if available) • Data from publications in similar conditions (if available)
	Feed for rodents and other animals (including insects)	• Presence of organic waste • Absence of waste coverage • Rainfall in the area (see Table 4 in the main manuscript) • Presence of infectious and vector-borne diseases in the area • Proximity to inhabited areas (considering it would be easier for animals to reach people) • Data from publications in similar conditions (if available)	• Proximity to inhabited areas (considering it would be higher the number of dangerous animals that get in contact with people) • Dangerous diseases present in the area (e.g. malaria) • Data from publications in similar conditions (if available)
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	• Rainfall in the area (see Table 4 in the main manuscript) • Groundwater in the area (based on presence of wells used by people and direct information, if any) • Data from publications in similar conditions (if available)	• Absence of separation of waste at source (i.e. organic waste vs. all the other categories of waste) • Presence and characteristics of other waste categories in the homemade compost (based on questions posed to residents and field surveys) • Use of wells by residents • Proximity to inhabited areas (concentration of pollutants is higher decreasing the distance with point

			of exposure) • Data from publications in similar conditions (if available)
	Feed for rodents and other animals (including insects)	• Presence of organic waste • Absence of waste coverage • Rainfall in the area (see Table 4 in the main manuscript) • Presence of infectious and vector-borne diseases in the area • Proximity to inhabited areas (considering it would be easier for animals to reach people) • Data from publications in similar conditions (if available)	• Proximity to inhabited areas (considering it would be higher the number of dangerous animals that get in contact with people) • Dangerous diseases present in the area (e.g. malaria) • Data from publications in similar conditions (if available)
	Spread of contaminants into the soil	• Proximity to inhabited areas • Absence of fences and barriers • Presence of farm animals and crops nearby • Data from publications in similar conditions (if available)	• Absence of separation of waste at source (i.e. organic waste vs. all the other categories of waste) • Presence and characteristics of other waste categories in the homemade compost (based on questions posed to residents and field surveys) • Lack of hygiene practices • Data from publications in similar conditions (if available)
	Spread of contaminants in the air	• Proximity to inhabited areas • Presence of VCs • Presence of farm animals and crops	• Absence of separation of waste at source (i.e. organic waste vs. all the other categories

		nearby • Data from publications in similar conditions (if available)	of waste) • Presence and characteristics of other waste categories in the homemade compost (based on questions posed to residents and field surveys) • Data from publications in similar conditions (if available)

The creation of the matrices allowed to identify the highest hazards. It was agreed to focus on the hazardous events whose risks resulted in high or very high. Indeed, as anticipated, the next step consisted of identifying control measures aiming to reduce the highest level of risk. After internal consultation among the MSWSP teams members, control measures were determined, taking into account the different elements characterizing Ghana and Serbia's case study. Then, the risk was recalculated, and new health risk matrices were made. The last activity consisted of cost analysis. Given the novelty of the topic, the related absence of such plans in the field of solid waste, and because of the constraints represented by the current pandemic (Covid-19), it was agreed not to go beyond this step. For example, for monitoring programmes, deeper contacts with local stakeholders would be needed and further on-field missions would be instrumental. The methodological steps characterizing the present work are shown in Figure 6.

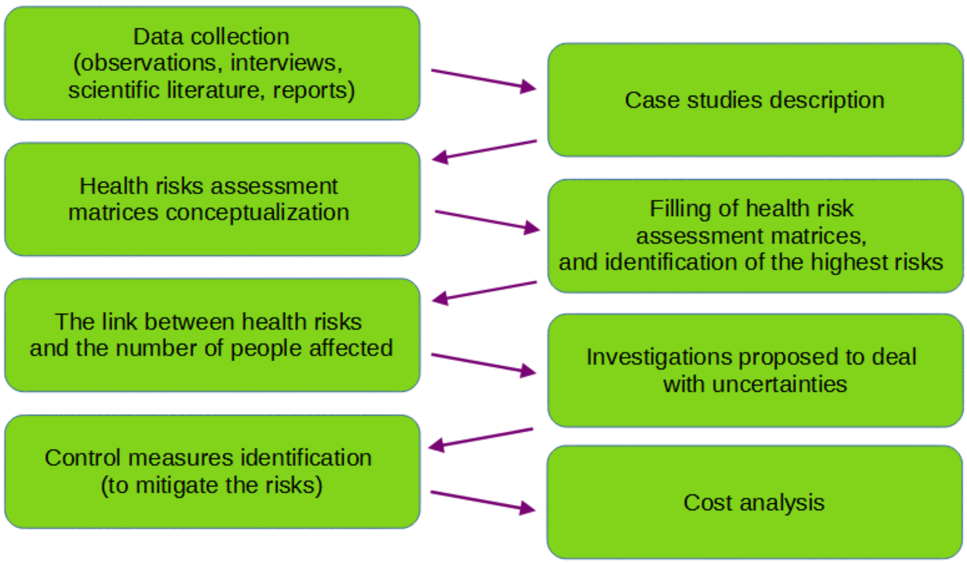

Figure 5: Schematic representation of the steps characterizing the work methodology

3 CASE STUDIES

Chapter 3 begins providing an overview of the countries of the case studies (Serbia and Ghana). Then, specific information about solid waste practices characterizing the case studies identified in Serbia and Ghana are given. Such data are the results of:

- Questions posed to Professor Batinic by emails and online meetings, related to the case study in Novi Sad (Serbia).
- Analysis of site-specific reports and scientific literature found or received by Professor Batinic related to Novi Sad (Serbia).
- The surveys carried out in Ghana in November 2019.
- Analysis of local documentation pertaining to the case study in Ghana received by the staff of CISS NGO.

As mentioned in section 2.2.4, in developing the MSWSP, it is crucial to provide a full description of the SWM system, at least within the boundaries that reflect the specific objectives of the plan. At the same time, a broader representation can help understand the whole system's strengths and weaknesses, identifying additional solutions. Consequently, the following sections focused not only on the fundamental elements needed for the case studies' health risk matrices but also on other relevant components collected, taking Table 1 as a reference.

It is necessary to add that many definitions can be used to categorise countries. The distinction in advanced economies and emerging/developing economies is considered more politically correct by some authors (Khokhar and Serajuddin, 2015).

The International Monetary Fund (IMF) classify the world into advanced economies and emerging market and developing economies taking into account (IMF, 2020b):

- The per capita income level.
- The export diversification.
- The degree of integration into the global financial system.

The World Bank defines four categories of countries in the function of the gross national income (GNI) per capita (World Bank, 2020):

- Low-Income countries.
- Lower-Middle-Income countries.
- Upper-Middle-Income countries.
- High-Income countries.

However, the Human Development Index (HDI) used by the United Nations (UNDP, 2019) offers a broader vision. It is another index that allows categories countries taking into account the lifespan, the education level, and the GNI per capita, through which countries are categorised in four groups (UNDP, 2019):

- Very high human development.
- High human development.
- Medium human development.
- Low human development.

Some authors also mentioned the term “resource-poor (or limited) countries” (Geiling et al., 2014), referring to settlements with limited resources.

Using the ways mentioned above to categorise countries, it will be easier to better define Serbia and Ghana. However, in both countries, and in particular in the case studies analysed, solid waste management represents a significant issue that poses many environmental and health risks currently not adequately managed.

3.1 Serbia overview

Serbia is a parliamentary republic with about 8.7 million inhabitants (United Nations, 2019). Excluding Kosovo, the Serbian population in 2019 was about 7 million (Statistical Office of the Republic of Serbia, 2020). Serbia is situated in the Balkan Peninsula, southeastern Europe. As shown in Figure 6, Serbia borders Hungary to the north, Romania to the north-east, Bulgaria to the south-east, North Macedonia to the south, Croatia and Bosnia Herzegovina to the west, and Montenegro to the south-west. Serbia claims a border with Albania through Kosovo's disputed territory, which declared independence in 2008 (CBC News, 2008). Serbia covers an area of 77,474 km^2 (CIA, 2020b).

Serbia is defined as a developing economy by the IMF (2020a), an upper-middle-income country by the World Bank (2020), and a high human development country by the United Nations (UNDP, 2019).

Serbia has a troubled recent history, as the Yugoslav Wars (1991–2001) highlights (Ellington, 2005). Until 2003 it belonged to Yugoslavia, but that year the Federal Republic of Yugoslavia was renamed Serbia and Montenegro (Ellington, 2005). In 2006, Serbia and Montenegro separated, after a referendum held in May 2006 for the independence of Montenegro (BBC, 2006). In 2014 negotiations to join the European Union started (BBC, 2014). The EU negotiation includes Chapter 27: “Environment”, in which SWM is one of the critical components of the Chapter (IMG, 2016).

Although Serbia is upgrading its MSW management, the system is not much advanced and efficient yet, and it generally consists only of waste collection and land disposal activities (Ilić and Nikolić, 2016). As a consequence, many cities in Serbia are facing severe problems in managing solid waste. Dangerous disposal methods, such as open dumping and discharge into surface water, are still frequent (Ilić and Nikolić, 2016). Furthermore, landfilling should be preceded by other processes such as composting and recycling, obtaining an environmentally and economically sustainable waste management. Although Serbia's strategic goal is to join the European Union, the state of waste management is still below EU targets, and ongoing processes to harmonise local laws with EU legislation are needed (Ilić and Nikolić, 2016).

Figure 6: Map of Serbia and its borders (from Google Maps, modified)

Serbia has been following the processes of adopting and introducing a circular economy and is adopting EU recommendations on circular economy (Pavlović et al., 2020). One of the crucial documents for achieving a new vision of development was adopted in 2008, and it is the National Sustainable Development Strategy for the Republic of Serbia (Pavlović et al., 2020). With this in mind, Serbia is investing resources in establishing the circular market by increasing the institutional capacity to support it (Pavlović et al., 2020). Furthermore, Serbia is changing the economic system to a more qualitative circular economy, and it foresees that by 2035 this new way of business will become the dominant (Pavlović et al., 2020).

3.2 Novi Sad overview

Novi Sad is the second-largest city in Serbia and the capital of the autonomous province of Vojvodina, in the northern part of the country. The city is located on the Danube River banks and in the southern part of Pannonian Basin with the largest area in the South Bačka at an altitude between 75 and 80 m (Kamariotakis and Bogdanov, 2016). Figure 7 shows satellite images of Serbia and Novi Sad.

Novi Sad's area has a temperate-continental climate, with warm summers, cold winters, and short springs and autumns. In summer, the average temperature ranges between 21 and 23 °C, and winter temperature is about 2 °C. Average multi-annual air temperature from 1981 to 2014 is 11.5 °C (Kamariotakis and Bogdanov, 2016).

At the same time, a small amount of precipitation has been recorded in this area. Indeed, average multi-annual rainfall for the period from 1981 to 2014 is 633.7 mm. It is important to note that precipitation is a crucial factor affecting the groundwater regime by direct infiltration. The terrain in this area is relatively flat; consequently, a considerable amount of rain infiltrates the soil (Kamariotakis and Bogdanov, 2016).

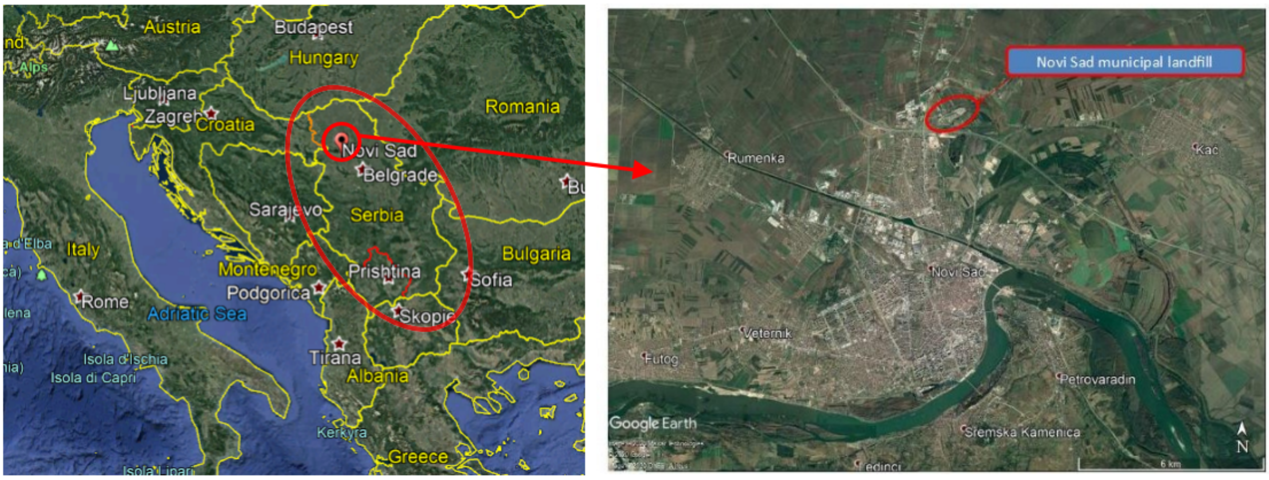

Figure 7: Satellite images of Serbia (left) and Novi Sad (right) (from Google Earth, modified)

Data about average relative humidity for the period from 1981 to 2014 were analysed. The lowest air humidity was recorded in summer months, and the highest was recorded in winter. Average monthly multi-annual air humidity ranged from a minimum of 66.6% in August to 85.9 in December, with an average annual value of 74.1% (Kamariotakis and Bogdanov, 2016).

The wind is a further significant factor. Indeed, it influences the diffusion of contaminants and bad smells from landfills (Li and Li, 2018). Four types of winds blow in the area of Novi Sad. The strongest is the Košava wind, which results from air currents from South Russia heading towards the Mediterranean Sea. Košava is a winter wind which starts in October and stops in May, reaching a speed over 9 m/s. The North wind is a cold winter wind, the South wind is warm, and the West wind brings rain and snow. Periods without winds are most common from June to September. In contrast, the least calm period is from February to April (Kamariotakis and Bogdanov, 2016).

The area is characterised by lowland, mountainous and hilly terrain and lower parts of Fruška Gora Mountain from the morphological aspect. Enormous river valleys characterise lowland with severe lateral erosion and weak vertical erosion. These processes resulted in the creation of accumulation forms represented by vast alluvial plains on the left bank of the Danube River and river terraces. Danube alluvial plain is formed of gravels, sands and clayey sediments (Kamariotakis and Bogdanov, 2016).
Novi Sad is the administrative, cultural, educational and business centre of Vojvodina province. Industry plays a vital role in Novi Sad's economy in energy (oil production and processing), food industry, metal works and chemical industry. In addition to industry, very important are both the trade and the construction business (Kamariotakis and Bogdanov, 2016).

The municipality consists of 16 settlements, with a total of 160,236 households in 2017. More information about the settlements is available in Table 7. Projections to 2020 foresee a little increase, with a total of 408,738 inhabitants (GIZ, 2019).

Table 7: Settlements, population and households in the municipality of Novi Sad (from GIZ, 2019)

Settlement name	Population	Households
Novi Sad	284,351	128,086
Begeč	3,520	1,054
Budisava	3,964	1,139
Futog	20,561	4,804
Kać	12,838	3,242
Kisač	5,280	1,913
Kovilj	5,640	1,757
Rumenka	6,862	1,746
Stepanovićevo	2,064	695
Veternik	18,519	4,171
Čenej	2,270	501
Petrovaradin	17,720	5,034
Bukovac	4,117	1,037
Ledinci	2,004	496
Sremska Kamenica	13,369	4,191
Stari Ledinci	1,040	370

Novi Sad and other seven municipalities (Backa Palanka, Backi Petrovac, Beocin, Zabalj, Srbobran, Temerin and Vrbas) established a region intending to develop an integrated waste management system. According to the National Waste Management Strategy and the Law on Waste Management, the optimal solution for waste management in Serbia was identified in regional centres covering at least 200,000 inhabitants (IMG, 2015). The regional centres should focus on the construction of sanitary landfills with other treatment technologies.

3.3 Description of the SWM system in Novi Sad

3.3.1 Overview

As anticipated, to implement the MSWSP first attempt discussed above, the Serbian municipality of Novi Sad was selected as a case study. Data from Novi Sad was collected, through scientific literature and reports, previous field activities, and direct knowledge from academics at the University of Novi Sad. Particularly with the support of professor Bojan Batinic.

As aforementioned, the ongoing pandemic (Covid-19) hindered field missions initially conceived, because of government restrictions, both in Italy and Serbia (Georank, 2020; Il Messaggero, 2020; The Guardian, 2020; WorldAware, 2020). However, between May and November 2020, more than ten online meetings were conducted with professor Batinic. Several documents and data about the solid waste management status in

Novi Sad were shared by email. Professor Batinic also clarified further doubts. All the collected information, useful for the thesis, is presented hereupon.

Novi Sad municipality occupies an area of 699 km^2. A recent census is not available, and the last one dates back to 2011 (IMG, 2016). The total population in Novi Sad's municipality in 2017 was estimated in 404,118 inhabitants (GIZ, 2019). The right side of Figure 7 shown before contains a satellite image of Novi Sad and some settlements of the same municipality, as well as the location of the municipal landfill that it is better discussed later.

The specific information collected about the MSW management system of the municipality of Novi Sad is discussed in detail below, with the primary purpose of providing a full description within the boundaries that reflect the specific objectives necessary to fulfil the proposed MSWSP.

3.3.2 Solid Waste governance in Novi Sad

Waste governance embraces government and policy instruments as well as the role played by other stakeholders involved in the solid waste management system (Wilson et al., 2015).

Respect to the National Waste Management Strategy and the Law on Waste Management in Serbia mentioned above the local situation appears different. There are no sanitary landfills in the Novi Sad municipality, but a municipal landfill (defined as controlled landfills) represents the best solution. The landfill does not meet the EU Landfill Directive minimum criteria, such as a base protective layer and a system for collecting and treating leachate (IMG, 2015). Most of the collected waste is landfilled in the municipal landfill (Figure 7). It is the largest in the region, and it is located approximately 6 km north of the city centre (IMG, 2015; Vujic et al., 2012).

In addition to the municipal landfill, there are about 19 illegal dumpsites on Novi Sad's territory (Faculty of Technical Science, 2012). The number is uncertain and variable because of the illicit nature of dumpsites. In Novi Sad, there is a public utility company (PUC) in charge of waste management (IMG, 2015). PUCs are conceived for each municipality, multi-functional in the region, and perform further services, such as water supply, wastewater collection, treatment, and public areas maintenance (IMG, 2016). The PUC of the Novi Sad municipality is named Čistoća.

PUC Čistoća has more than 600 employees who are involved in the following services (IMG, 2015; 2016):

- Service for waste removal and disposal.
- Landfill service.
- Service of public hygiene.
- Maintenance service.

Among the employees, about 450 are involved in the SWM services (IMG, 2016).

As anticipated, one of the main activities of PUC Čistoća consists of waste collection in the city of Novi Sad and its suburban areas. Besides MSW collection, PUC is in charge of collecting bulky and garden waste, and the sanitation services of illegal dumps in terms of communal inspection (IMG, 2015). The landfill service listed above is responsible for managing the Novi Sad landfill, which is owned by the city (IMG, 2015). The service of public hygiene performs maintenance and cleaning of public and green areas (IMG, 2015). Maintenance service concerns the maintenance of vehicles and city containers (IMG, 2015). It has to be highlighted that only the collection and transportation of waste are charged, while there is no specific charging for landfilling of the waste or other treatments (IMG, 2015). The revenue collection efficiency for Novi Sad households is high, i.e. 96% (IMG, 2015).

3.3.3 Municipal Waste Production in Novi Sad

In 2017, the total MSW generation in Novi Sad municipality was 135,700 ton (GIZ, 2019). Data on waste generation and composition in Novi Sad municipality are summarised in Tables 8 and 9. Waste generation is related to urbanisation, economic development, and population growth. Indeed, when areas become more populated, industrialised and get richer, they offer more products and services to inhabitants, resulting in a more significant amount of waste to manage (Kaza et al., 2018).

It is important to note that waste generation per capita per day in Novi Sad is 0.92, namely higher than average values of lower-middle and upper-middle-income countries (Kaza et al., 2018). The increased waste generation can be because Novi Sad is one of the main cities of Serbia. However, waste generation rate is well below the average values of high-income countries (Kaza et al., 2018). Table 8 shows waste generation per capita per day in Novi Sad (average values considering the 16 settlements of the municipality) (GIZ, 2019), and the average values per income country level (Kaza et al., 2018).

Table 8: Waste generation rate in Novi Sad, and in countries per income

Average waste generation [kg/(capita×day)]	**Reference**
0.95	Novi Sad municipality [a]
1.57	High income countries [b]
0.69	Upper-middle income countries [b]
0.61	Lower-middle income countries [b]
0.43	Lower income countries [b]

[a] From GIZ (2019)

[b] From Kaza et al. (2018)

Waste composition categorises types of materials in MSW, and it varies considerably by income level. Waste composition in Novi Sad is more similar to lower-middle and upper-middle-income countries than high-income countries, except for plastic, as it can be seen in Table 9.

Table 9: Waste composition in Novi Sad, and in other countries per income

Waste component	Novi Sad [a] [%]	High income countries [b] [%]	Upper-middle income countries [b] [%]	Lower-middle income countries [b] [%]	Low income countries [b] [%]
Food and green	49.5	32.0	54.0	53.0	56.0
Paper and cardboard	10.7	25.0	12.0	12.5	7.0
Metal	1.1	6.0	2.0	2.0	2.0
Plastic	14.2	13.0	11.0	11.0	6.4
Glass	3.5	5.0	4.0	3.0	1.0
Rubber and leather	>0.4	4.0	1.0	<1.0	<1.0
Wood	NA	4.0	1.0	1.0	<1.0
Other	20.6	11.0	15.0	17.0	27.0

[a] From GIZ, 2019

[b] From Kaza et al. (2018)

NA = Not Available

3.3.4 Waste collection in Novi Sad

Compared to most Serbian municipalities, officially the waste collection rate in the cities of the Novi Sad region is very high. In particular, Novi Sad municipality has a coverage of about 100%. The value is based on 160,236 households considered (GIZ, 2019). However, about 19 illegal dumpsites are located in the municipality, highlighting sine waste streams not officially considered.

28 waste trucks (mostly 16 m^3 and 30 m^3 capacity) and 4 skip loader trucks are used for waste collection (GIZ, 2019). PUC Cistoca owns 3,500 containers with a volume of 1.1 m^3 each, mainly used in apartment blocks, 300 containers with a volume of 5 m^3 each, for commercial and industrial waste and 65,000 waste bins of 120 litres each, for individual households (GIZ, 2019). Containers are intended for waste produced in buildings; bins are for garbage collected in houses. In most cases, restaurants and offices throw waste in containers. Frequency of waste collection from containers changes in the function of the area of Novi Sad. In central areas waste is collected even 1-2 times per day; on average, the city waste is collected about two times per week; in suburbs and areas further away from the city centre, waste collection can happen one time per week. From bins, waste is collected about once per week. In settlements Petrovaradin and Sremska Kamenica, about 9,000 families live, and 9,000 bins are used for separate collection of recyclables, but the system is not fully developed (IMG, 2016). Furthermore, 570 underground containers are installed in some areas in the city, like those shown in Figure 8. The photograph was taken in January 2021 by Isidora Berežni, PhD student at the University of Novi Sad. The authority is trying to start a separate waste collection using one container for recyclable waste and another for unsorted waste by underground containers, but it is not very convincing yet.

Figure 8: Underground containers in Novi Sad - photograph taken by Isidora Berežni (University of Novi Sad)

3.3.5 Waste treatment and disposal in Novi Sad

As anticipated, waste management in Novi Sad mainly comprises disposal on the municipal landfill and, illegally, in some dumpsites; none of the sites is compliant with the EU Landfill Directive (IMG, 2016). The landfill is located in the northern part of the city, at about 600 m from the closest houses. However, a supermarket and some factories are closer to the landfill, as shown in Figure 9, where point 1 represents the supermarket, and points 2-6 represent other shops and factories.

The landfill distance from highway E75 and the city centre is 180 m and approximately 6 km, respectively. The landfill is constructed in a flat part of the city, on sand pits, and surrounded by agricultural lands (Vujic et al., 2012). It was estimated that more than 2.8 million m^3 of municipal and non-hazardous industrial waste had been landfilled there (IMG, 2016). There is no accurate data on when the landfill started to operate. Still, it is estimated it was around 1980 (Vujic et al., 2012) and it currently covers an area of about 28 ha, of which 24 ha are used for waste disposal (IMG, 2016; Vujic et al., 2012). The average waste depth is between 12 and 14 m, and the average height of waste above the soil level is 5 to 7 m (IMG, 2016; Vujic et al., 2012). The site is fully fenced and monitored by security guards.

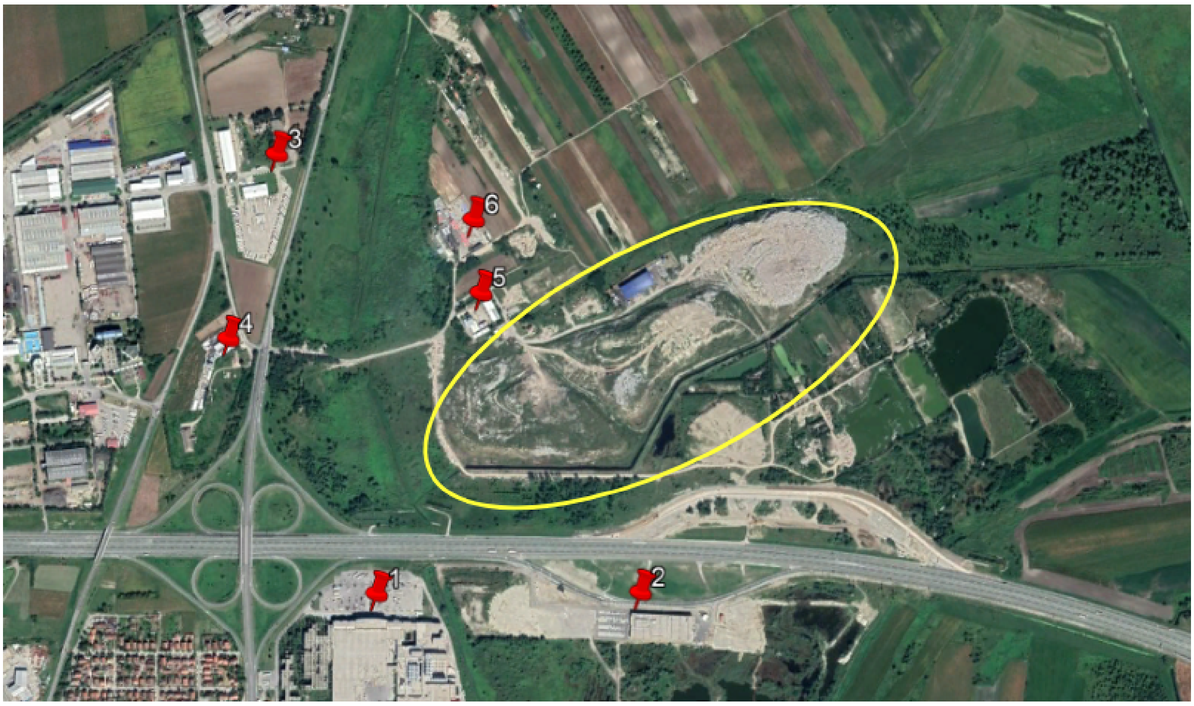

Figure 9: Satellite image of the landfill of Novi Sad, with the closest buildings indicated (from Google Earth - modified)

There are no daily cells in the landfill, and waste coverage is seldom practised. Some soil is used to cover waste; sometimes Construction and Demolition (C&D) waste in small size is used for the coverage. Waste coverage has a dual function: reduce bad smells and improve the path for motorized vehicles. The spread of particles and the diffusion of bad smells from the landfill is high. However, Tot et al. (2019) noted that in Serbia, the daily coverage is usually not used on the landfills, but in some sites, compactors and bulldozers conduct waste compaction.

People living in the unofficial settlement north to the landfill (about 100 houses) complain because of bad smells. Furthermore, a journalistic article (Stojanović, 2017) highlighted bad smells in the city having official dwellings close to the landfill, i.e. Klisa suburb (Figure 10). The report highlighted that people avoid spending time outdoors in the suburb because they find it difficult to breathe such an air (Stojanović, 2017).

In the landfill, waste is deposited from collection vehicles, which are weighed on weighbridge at the landfill entrance. After the waste is unloaded, bulldozers and compactors distribute the waste homogeneously and compact it (Vujic, 2012).

Figure 11 shows the three sections of the landfill. Regarding the capping layer, only section III of the landfill is permanently closed for waste disposal and has a top cover. But the material used for closure of this area is ordinary soil of 20 cm thickness from different excavations in the surrounding area; no synthetic material was used (Vujic, 2012). A range of local vegetation, mostly weeds, is present in this area of the landfill. Consequently, there is insufficient protection from surface water infiltration and oxygen inflow into the landfill body (Vujic, 2012). Besides, in Figure 11, the blue rectangle adjacent to the landfill represents the waste sorting facility. More information is available in Figures 12 and 13, in which additional elements are indicated.

Figure 10: Klisa suburb and municipal landfill in Novi Sad (from Google Maps - modified)

Figure 11: Novi Sad landfill sections. Section III is currently closed (from Vujic et al., 2012)

In particular, Figure 12 includes the entrance to the landfill, a small building for waste workers, a house for recording data on the weighbridge and parking areas. Figure 13 contains a zoom in to show the waste sorting facility and administrative buildings. Unfortunately, detailed information or drawings about the blue rectangle element (Figure 11) and the components indicated in Figures 12 and 13 were not available. Only some additional data related to the sorting facilities are discussed further on.

Figure 12: Elements characterizing the landfill entrance area (from Google Earth - Modified)

Figure 13: Waste secondary separation line and administrative buildings
(from Google Earth – modified)

Gas extraction from the landfill body is, in theory, performed with 96 gas wells, and six monitoring wells (piezometers) are installed (IMG, 2016). Depending on the depth of the section, the gas wells are 11 to 14 m in depth. However, gas wells at Novi Sad landfill have not been built adequately; consequently, a lot of wells have pipe perforations near or above the ground level. Results from a gas analysis conducted in 2011 are shown in Table 10, in which a general low concentration in methane can be noted. Furthermore, an academic from the University of Novi Sad, Professor Maja Petrović, shared additional information by email.

She stated that in landfills in the province of Vojvodina where gas wells are appropriately placed, a significant presence of landfill gases is measured, determining high methane concentrations. Different concentrations of oxygen at the same landfill indicates insufficient measures of landfill insulation to the atmosphere.

Table 10: Gas analysis results at Novi Sad landfill (from Vujic et al., 2012)

Gas well number	CH_4 [$\%_{vol}$]			
	23/02/2011	01/07/2011	27/09/2011	27/12/2011
S1 – 16	19.6	13.9	23.5	14.2
S1 – 21	15.4	-	19.5	20.4
S 2 – 6	14.4	24.9	20.9	12.4
S 2 – 8	49.6	52.4	52.5	-
S 2 – 10	-	31.3	35.0	-
S 2 – 11	14.4	-	23.3	-
S 2 – 12	15.0	-	22.2	25.8
S 2 – 18	25.5	15.1	18.3	13.7
S 2 – 19	28.3	17.4	17.2	20.7
S 2 – 34	21.8	18.4	25.8	17.4
S 3 – 4	58.8	45.2	42.9	39.5
S 3 – 5	19.5	23.3	19.9	8.7
S 3 – 6	29.3	25.6	21.0	16.2
S 3 – 7	30.9	35.0	33.6	28.6
S 3 – 8	48.7	39.4	45.9	36.3
S 3 – 11	225.3	20.8	35.7	20.8
S 3 – 12	10.9	12.4	20.6	10.0
S 3 – 13	42.5	34.0	33.6	26.0
S 3 – 15	19.4	18.2	22.8	17.1
S 3 – 16	35.1	35.2	32.2	22.7
S 3 – 17	18.6	18.8	27.5	23.8
S 3 – 18	23.2	21.1	35.5	15.6
S 3 – 20	53.8	47.8	39.8	32.2
S 3 – 21	38.9	37.4	37.0	34.5
S 3 – 22	27.8	24.2	44.4	36.0
S 3 - 23	12.9	9.9	19.7	8.0

Further results, from a gas pumping trial at section III of the landfill, are shown in Table 11 (Vujic et al., 2012). It is essential to consider that section III was closed in 2009, also with a capping layer. Tests were conducted at different frequencies, RPM and gas flows. The frequencies used for testing were 5, 10, 20 and 30 Hz. Increased frequency (and gas flow) and oxygen concentration grew up, while methane and carbon monoxide decreased. It highlights oxygen inflow through the wells.

Figure 14 shows a satellite image modified by Vujic et al. (2012) to indicate the position of gas wells. As anticipated, many gas wells were damaged and covered with waste during the landfill operations, and they are shown in Figure 14 with a red mark. However, biogas wells are just drilled, and none of them is connected to a gas treatment system (e.g. a torch). Currently, there is some monitoring of biogas emissions, making their presence useful under an experimental point of view.

Table 11: Methane, carbon monoxide and oxygen concentrations in relation to frequency and gas flow rate (from Vujic et al., 2012)

Frequency [Hz]	CH_4 [$\%_{vol}$]	CO_2 [$\%_{vol}$]	O_2 [$\%_{vol}$]	Flow [m^3/h]
5	47.1	33.9	3.4	13
10	35.5	24.4	7.1	27
20	24.3	16.0	11.3	56
30	22.2	16.4	12.1	NA

NA: Not Available

Figure 14: Novi Sad landfill gas wells layout (from Vujic et al., 2012)

It is essential to highlight that decades ago when the ground was prepared for the landfill, no geomembranes were used as a waterproof layer at the bottom (Vujic, 2012). Consequently, as typical in dumpsites (Vaccari et al., 2018), the spread of leachate to groundwater can be very high. Furthermore, in the landfill, there is no leachate treatment system. Leachate drains in surface canals that run around the landfill. The landfill belongs to the drainage system Vrbak, with a basin area of 2,230 ha (Kamariotakis and Bogdanov, 2016). Drainage system Vrbak covers a broader area of the existing municipal landfill and collects leachate and stormwater in the peripheral landfill canals (Djogo et al., 2017). The irrigation system Vrbak in the regional landfill area consists of the channel Novi Svinjarev, around 1845 m long, and canal Vrbak proper, 1250 m long. A previous canal, named Svinjarev, was displaced more than 30 years ago because it ran through the landfill which needed to be expanded. After displacement, the channel was renamed Novi Svinjarev canal. Novi Svinjarev flows into the central irrigation canal, Vrbak, and the water ends in the pumping station Vrbak. Finally, the pumping station Vrbak pumps the water into another canal from which is further pumped by pumping station directly in the Danube river. Besides the Svinjarev Novi canal, the Vrbak irrigation system's basin consists of secondary channels (Kamariotakis and Bogdanov, 2016). The municipal landfill of Novi Sad and the drainage system Vrbak are shown in Figure 15.

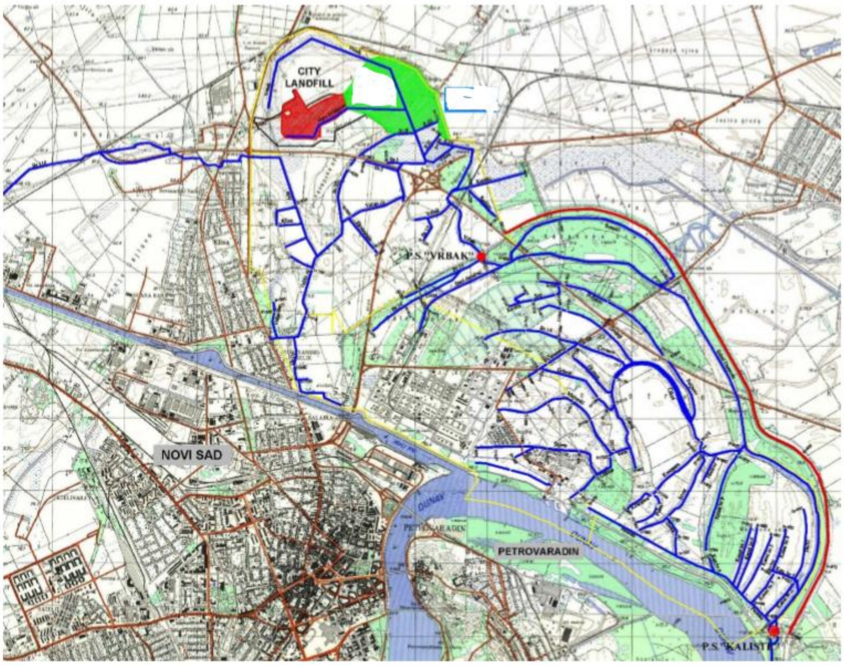

Figure 15: Map of the drainage system Vrbak and the municipal landfill of Novi Sad (in red) (from Kamariotakis and Bogdanov, 2016)

Between 2014 and 2015, leachate samples were collected from the landfill's peripheral canals (Djogo et al., 2017), as shown in Figure 16. The values are summarised in Table 12.

Figure 16: Novi Sad landfill. Points 1 and 2 represent the canals in which leachate was collected (from Google Earth)

Table 12: Psychochemical composition of leachate from the MSW landfill in Novi Sad (from Djogo et al., 2017).

Parameter [U.M.]	Point 1	Point 2
pH [-]	7.65	7.72
NH_4 [mg/l]	28.10	30.75
BOD_5 [mg/l]	80.25	117.25
COD [mg/l]	163.75	189.75
SO_4^{2-} [mg/l]	45.75	90.00
Ca [mg/l]	117.18	113.22
Mg [mg/l]	67.35	92.40
Na [mg/l]	273.45	206.90
K [mg/l]	45.72	42.45
Fe [mg/l]	0.88	1.30
Zn [mg/l]	0.19	0.09

In any case, it is essential to note that most of the channels, including those around the landfill, are dug in the ground, as shown in Figure 17. Consequently, the leachate from the landfill can rarely reach the Danube River, but it leaches into the soil towards the groundwater. The aquifers of Novi Sad are discussed later. However, as professor Batinic explained, the Danube River's principal risks, in terms of pollution and human health, are represented by wastewater from households and industries. Indeed, except for a few big factories, all wastewater is discharged in the Danube River without any treatment. People do not use the Danube River for drinking purposes but swimming and fishing.

Figure 17: Drainage channel delimiting the landfill (photograph received from Professor Batinic)

In Novi Sad, three aquifers are located in the area of the municipal landfill:

- An aquifer with a free water table (aquifer I)

- Shallow sub-artesian aquifer (aquifer II)
- Deep sub-artesian aquifer (aquifer III)

The entire location lies on the alluvial plain of the Danube. Aquifer I is at a depth from 5 to 30-35 m, and it is a sub-artesian aquifer in a wide investigation area because of clayey sediments in the roof. However, there are boundary drainage canals of system ”Vrbak” around the existing landfill, and the groundwater table is artificially regulated by pump stations (Kamariotakis and Bogdanov, 2016).

In aquifer I, deeper parts are mostly constituted of gravel sands to coarse-grained sands, and higher amounts are formed of fine-grained to powdered sands. Coarse-grained sediments have higher water permeability. Replenishment of the first aquifer is through the infiltration of water from the atmospheric deposit and underground inflow of water from the north (Kamariotakis and Bogdanov, 2016). The general direction of groundwater flow is north-south, and the groundwater flow gradient is 1.2% (IMG, 2016).

Hydrogeological study on numerous wells in the area defined the filtration coefficient of $5\times10^{-4} – 6.8\times10^{-4}$ m/s and transmissibility coefficient of $1.0\times10^{-2} – 1.2\times10^{-2}$ m^2/s. Clayey sediments at the bottom of the first aquifer represent a hydraulic barrier against groundwater mixing from the first and the deeper aquifers. Depth of sediments ranges from 6 to 15 m (Kamariotakis and Bogdanov, 2016). It is clear that aquifer I is the most in danger in terms of contamination.

Between April 2014 and August 2015, groundwater physicochemical characteristics from five sampling locations on Novi Sad's landfill were carried out (Djogo et al., 2017). The average values are shown in Table 13. Such values highlight the influence of leachate in the underlying aquifer (Djogo et al., 2017).

Table 13: Groundwater quality below the municipal landfill of Novi Sad (from Djogo et al., 2017)

Parameter [U.M.]	**Point 1**	**Point 2**	**Point 3**	**Point 4**	**Point 5**
pH [-]	7.4	7.5	7.5	7.4	7.5
P_{tot} [mg/l]	0.175	0.125	0.300	0.800	0.200
Nitrites: NO_2^- [mg/l]	0.938	0.850	0.788	0.700	6.362
Nitrates: NO_3^- [mg/l]	0.028	0.152	0.126	0.076	0.076
NH_4^- [mg/l]	12.450	1.762	4.950	7.262	1.112
N_{tot} [mg/l]	38.475	35.500	20.225	23.475	8.975
SO_4^{--} [mg/l]	1.000	1.000	1.500	96.500	38.000
BOD_5 [mg/l]	68.250	23.000	33.750	21.750	11.750
COD [mg/l]	114.300	28.700	71.475	62.225	40.725
B [mg/l]	1.300	0.262	0.338	0.400	0.350
Ca [mg/l]	167.400	107.475	99.950	175.725	123.875
Mg [mg/l]	54.600	37.100	54.425	72.450	51.200
Na [mg/l]	168.950	168.125	193.275	98.175	133.100
K [mg/l]	13.750	14.350	24.850	22.550	15.175
Fe [mg/l]	3.600	4.825	4.975	2.338	0.612
Zn [mg/l]	1.400	0.500	0.200	0.044	0.181

In some areas of the landfill, there is stagnation of leachate. It can be mainly noted after rainy days. As discussed later, given the proximity with the first aquifer, the absence of a waterproof layer at the bottom, weather conditions, waste characteristics, and following a precautionary approach, it can be assumed a continuous flow of leachate towards the first aquifer.

It is useful to remember that leachate is the liquid generated from solid waste into landfills and dumpsites. It is a mixture of many chemicals and biological products resulting from water passing through the waste and saturating it with organic and inorganic matter (Khalil et al., 2018). Leachate characteristics can vary a lot, and in a recent review (Vaccari et al., 2019a) differences between geographical regions appeared to be limited. In contrast, statistically significant differences were found in organic, inorganic loads and heavy metals between landfills and dumpsites, with dumpsites having higher concentration (Vaccari et al., 2019a). The formation of leachate depends on the water balance of landfill site. It takes place when the moisture content in waste exceeds its field capacity, i.e. the maximum moisture content that a porous medium can hold (Kamarrudin et al., 2017). Ineffectiveness or absence of waterproof layer at the bottom can result in both environmental and public health hazards (Vaccari et al., 2018).

In Novi Sad, all houses (also the illegals) are connected with the water supply, and officially nobody uses water from the first aquifer. However, there is not an official prohibition of the use of the first aquifer. Consequently, some people have their water well, but there is no detailed information about it. It seems that the first aquifer is mostly used by people that live far away from the landfill (oral communication by Professor Batinic).

Air quality in the municipal landfill, in terms PAHs and POPs, were analysed by Petrovic et al. (2018). The authors measured air concentrations of 16 PAHs (i.e. naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(123cd)pyrene, dibenz(ah)anthracene, benzo(ghi)perylene), 7 PCBs (i.e. PCB 28, PCB 52, PCB 101, PCB 118, PCB 138, PCB 153, PCB 180), 3 HCHs (i.e. α-HCH, β-HCH, γ-HCH), 3 DDTs (i.e. DDD, DDE, DDT) and HCB. The median concentration of PAHs ranged between 2.47×10-5 and 2.03×10-8 mg/m^3. The median concentrations of PCBs ranged between 6.23×10-8 and 1.31×10-9 mg/m^3. The median concentrations of HCHs ranged between 2.61×10-8 and 1.50×10-9 mg/m^3. The median concentrations of DDTs ranged between 3.93×10-8 and 1.47×10-9 mg/m^3. The median concentrations of HCB were 7.04×10-8 mg/m^3. It is important to note that PAHs presence was probably due to accidental events of uncontrolled solid waste combustion on the MSW landfill site (Petrovic et al., 2018).

The authors also assessed the human health risk using the US EPA approach, analogous to that mentioned in Chapter 1. The carcinogenic risk was always lower than 10^{-6}, i.e., the limit value defined by EPA. However, the results have not to be considered as final, according to the authors. Only the gaseous phase of ambient air was analysed, significantly affecting the overall risk calculation (Petrovic et al., 2018). Indeed many of the measured carcinogenic substances are absorbed into the particulate phase of the air medium, leading to a possible underestimate of the health risks calculated by the authors.

As anticipated, the landfill is currently well fenced. Notwithstanding animal faeces can be found, due to wild animals such as cat, dogs, foxes. Faecal sludge is not disposed of in the landfill, although its fate is not well known.

Sometimes in the landfill, there is waste open burning. Open burning represents accidental events, mainly related to methane emissions. Usually, it generates a bit of smoke and little fires. But about 1-2 times per year, there is a big fire that lasts even some days (see Figure 18). These events happen in the active part of the landfill, where waste has been disposed of in the last 20-30 years, causing a higher methane production (oral communication from Professor Batinic).

In the landfill, there are no systems to prevent fire. But workers have some devices to extinguish it. Indeed, when a fire starts, the firsts in trying to stop it are the waste workers, and if they fail, firefighters are contacted.

In general, waste workers in the landfill use all sort of Personal Protective Equipment (PPE). Some accidents have happened in the landfill, involving waste workers. They were mainly due to waste combustion and sharp waste. Unfortunately, it was not possible to receive official information from the company.

As aforementioned, in addition to the municipal landfill, there are about 19 illegal dumpsites in the municipality. PUC Cistoca is also in charge of dumpsites' sanitation services, under the orders of communal inspection (IMG, 2015). Figure 19 shows the position of dumpsites in Novi Sad (Faculty of Technical Sciences, 2012). Previous assessments allowed to find out more information (Faculty of Technical Science, 2012), summarised in Table 14. It can be noted a bigger dumpsite (area of more than 5 hectares) in the Begeč settlement, a dumpsite of about 2 hectares in the Futog settlement. The remaining dumpsites have a size between 0.04 and 1.84 hectares.

Figure 18: Uncontrolled big fire at the landfill of Novi Sad (photograph received from Professor Batinic)

Furthermore, there are no technologies for the treatment of MSW in all the region, such as waste incineration plants or composting plants. The only exception is represented by recycling, but only in individual municipalities and small percentages (IMG, 2016). In particular, in Novi Sad small amounts of recyclable materials are separated at the waste sorting facility adjacent to the landfill mentioned above (Figures 11 and 13). The current capacity of the sorting facility is low. Indeed only about 10% of the total MSW generated in Novi Sad, can be processed. Furthermore, since the input is the mixed MSW stream, the percentage of sorted materials is meagre, and less than 10% of the input material. Consequently, the total amount of different recovered recyclable categories (paper, PET, glass, Al-cans, etc.) at the separation line in Novi Sad is about 2,000 t/year, i.e. less than 2% of the total (IMG, 2016). Available data about amounts and categories of recovered recyclable materials at the separation line in Novi Sad are shown in Table 15.

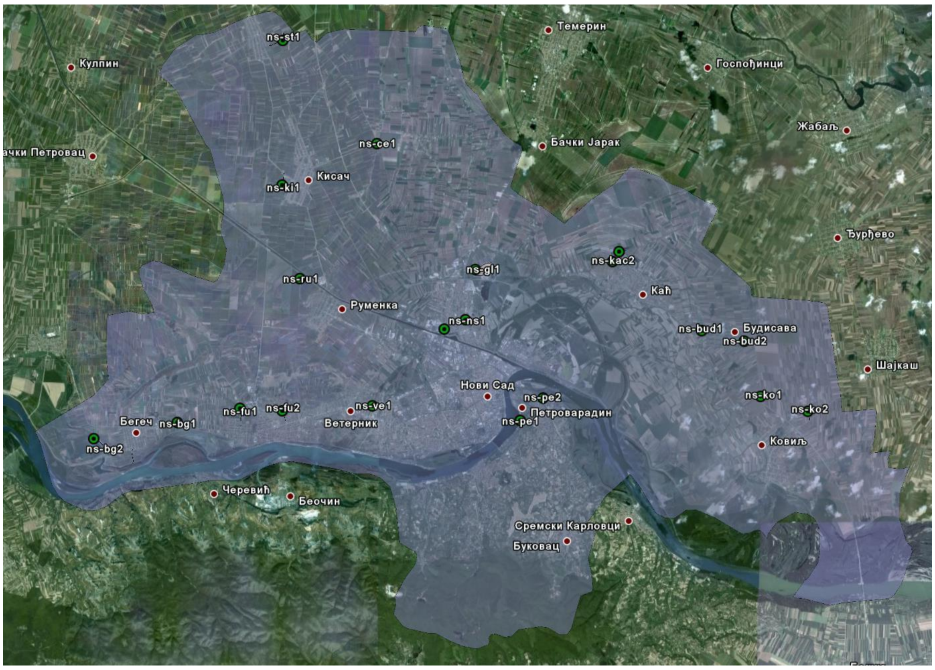

Figure 19: Position of dumpsites in Novi Sad (from the Faculty of Technical Science – Novi Sad, 2012)

Table 14: Main information about dumpsites in Novi Sad (Faculty of Technical Sciences, 2012)

No	Settlement	landfill code	Area (ha)	Average depth (m)	Estimated vollume (m^3)	GPS coordiantes	
						DMSLon	DMSLat
1	Begeč	ns-bg1	0,87	0,2	1740	19°39'4,05"E	45°14'37,37"N
2	Begeč	ns-bg2	5,18	0,3	15540	19°35'55,6"E	45°14'11,18"N
3	Budisava	ns-bud1	1,76	0,5	8800	19°58'46,87"E	45°17'3,35"N
4	Budisava	ns-bud2	0,06	0,5	300	20°0'22,79"E	45°16'46,54"N
5	Čenej	ns-ce1	0,05	0,4	200	19°46'33,81"E	45°22'0,81"N
6	Futog	ns-fu1	2,01	0,6	12060	19°41'25,19"E	45°15'0,02"N
7	Futog	ns-fu2	0,31	0,3	930	19°43'0,76"E	45°14'56,24"N
8	Kać	ns-kac1	1,3	1	13000	19°55'40,56"E	45°19'9,11"N
9	Kać	ns-kac2	0,05	0,4	200	19°55'25,69"E	45°18'53,36"N
10	Kisač	ns-ki1	1,49	1	14900	19°42'59,76"E	45°20'54,85"N

11	Kovilj	ns-ko1	1,84	0,3	5520	20°0'59,38"E	45°15'18,72"N
12	Kovilj	ns-ko2	0,86	0,3	2580	20°2'46,01"E	45°14'54,81"N
13	Novi Sad	ns-ns1	0,68	0,3	2040	19°49'53,74"E	45°17'21,11"N
14	Novi Sad	ns-ns2	0,14	0,4	560	19°49'6,01"E	45°17'6,19"N
15	Petrovaradin	ns-pe1	0,07	0,4	280	19°51'57,22"E	45°14'41,1"N
16	Petrovaradin	ns-pe2	0,15	0,3	450	19°52'48,83"E	45°15'16,73"N
17	Rumenka	ns-ru1	0,02	0,3	60	19°43'39,95"E	45°18'26,25"N
18	Stepanovićevo	ns-st1	0,72	0,2	1440	19°43'0,64"E	45°24'44,79"N
19	Veternik	ns-ve1	0,04	0,4	160	19°46'23,81"E	45°15'4,26"N

Table 15: Amounts and types of recovered recyclable materials at separation line in Novi Sad (from IMG, 2015)

Type of secondary raw materials	Year 2013	Year 2014
	Amount [t]	Amount [t]
Cardboard	543.03	450.0
Paper – mixed	608.11	235.41
Paper - white	94.52	73.58
PE foil (incineration)	96.48	0.00
PE foil (recycling)	110.4	130.43
PET	272.30	427.86
Aluminium cans	15.9	13.94
Mixed plastic	1.62	15.00
Sheet metal	146.4	0.0
Tires (incineration)	8.24	13.86
Glass – crushed	395.28	283.0
Tetra pack	86.1	72.2
PET HDP	0.00	22.95
Fe - cans	0.00	33.82
Fe – other waste	0.00	8.6
Waste Pb batteries	0.00	0.69
WEEE	0.00	0.00
Cu waste cables	0.00	0.00
Brass	0.00	0.00
TOTAL	**2,378.38**	**1,781.34**

Part of the waste stream, which is not separated as a valuable recyclable material for the market, is further processed as low quality Refuse Derived Fuel (RDF). It is afterwards utilised in the cement kiln in Beocin settlement, always in Novi Sad municipality, but detailed data are not available.

It is relevant to highlight that, although nowadays waste flow is mainly related to MSW, except for Construction and Demolition (C&D) waste sometimes disposed of by people in waste containers, industrial waste was disposed of in the past in the landfill.

3.3.6 Adjunctive information

Regarding informal waste workers (such as waste pickers), many went to the landfill in the past, looking for valuable waste. In the last years, it seems they have not been seen in the landfill because it is fenced now, there are watchmen, and it is not officially allowed to go inside. However, some photographs from the last years in part contradict this assertion. To clarify it, field visits and questionnaires to landfill workers would be necessary. Unfortunately, the pandemic (Covid-19) and related governmental restrictions made it difficult to carry out such activities, initially conceived.

However, many waste pickers informally work in Novi Sad, mainly looking for precious waste from waste containers. They usually do not use any personal protective equipment (PPE).

Based on the information collected, health risk assessment matrices were made, and they are discussed in Chapter 4.

3.4 Ghana overview

Ghana is a West African country, with just over 30 million inhabitants (United Nations, 2019). It is a presidential representative democratic republic that bordered by the Ivory Coast in the west, Burkina Faso in the north, Togo in the east, the Gulf of Guinea and the Atlantic Ocean south, as shown in Figure 20. The country covers an area of 238,533 km^2 (CIA, 2020a) and has three major geographic regions: coastal, forest and northern savannah (Miezah et al., 2015).

The coastal area is the smallest, but it has more than 25% of Ghana's population. The coast makes the region an essential commercial hub, leading to the growth of large cities and many urban centres compared to the other two geographical areas. Four of Ghana's six metropolitan cities (Accra, Cape Coast, Tema and Takoradi) are located here. The coastal region's main economic activities are fishing, small-scale agriculture, and trade (Miezah et al., 2015). In the forest region, the main economic activity is agriculture and most of the crops and food products in Ghana are produced here (Miezah et al., 2015). The Northern Savannah covers nearly two-thirds of the country. The Guinean savannah has a more comprehensive vegetative cover, a longer and heavier rainfall regime that averages 600-1200 mm per year. Economically this region is the poorest. However, the vegetation allows for extensive animal farming. The main urban centres are Tamale, Wa and Bolgatanga (Miezah et al., 2015).

Ghana is a developing economy (IMF, 2020a), a lower-middle-income country (World Bank, 2020), a medium human development country (UNDP, 2019).

Figure 20: Map of Ghana and its borders (from Google Maps, modified)

Ghana's administrative divisions consist of 16 regions, constituting the first level of subnational government administration (Modern Ghana, 2019). The second-level administrative subdivisions of Ghana is represented by 260 Metropolitan, Municipal, and District Assemblies (MMDA) (UNICEF et al., 2019). Metropolitans are administrative units with more than 250,000 inhabitants. Municipalities are administrative units with a population between 250,000 and 95,000 inhabitants, and Districts are administrative units with a population between 95,000 and 75,000 inhabitants. In each second-level administrative subdivision, cities or villages of different size are included.

As shown later, the context in which the Ghanaian case study was developed is very different from the Serbian one. Indeed, the Ghanaian villages analysed were nine, rural, and a field assessment was conducted. Further field assessments have been hindered due to the pandemic (Covid-19). Simultaneously, unlike in Serbia, the Ghanaian context made complicated the availability of detailed and quantitative data and reports. It is an issue that can affect many rural communities from developing countries. However, it was estimated that in 2018, 45% of the world population was still living in rural areas (World Bank, 2017), reaching about two-thirds of people in low- and lower-middle-income countries (LICs and LMICs). As a consequence, it appears crucial to focus on rural contexts as well.

In Ghana, the lack of sanitation seems mainly due to the rapid urbanisation, lack of funds and economic decline between the 1970s and 1980s (Porter, 1997; Tsiboe and Ernest, 2004). Open dumpsites still represent a dominant feature of solid waste disposal (Quartey et al., 2015). Furthermore, in recent decades, there has been a steady increase in plastic products' use with a consequent proportional increase in plastic waste in large cities in Sub-Saharan Africa, including Ghana (Fobil and Hogarh, 2006). Indeed, the amount of plastic waste in Ghana has increased over the years: in 1979 the percentage was 1.4%, which rose to 4% in 1993, in 1997 it was 5%, and in 2000 it increased up to 8% (Abota, 2012). The rising amount of plastic waste resulted from the country's growing demand for plastic products. In 1996, there were around 20 plastic manufacturing plants in Ghana. By the turn of the century, about 40 plastic manufacturing companies produced approximately 26,000 tons of assorted plastic products per year, with 90% of these companies in Kumasi and Accra's metropolitan areas. Besides, over 10,000 tonnes of finished plastic products are imported into Ghana each year (Owusu-Sekyere et al., 2013). National efforts towards MSWM in Ghana began after independence from British colonisation in 1957. State-run incinerators were used for solid waste treatment and management, but this technology did not survive over time due to financial and limited technical skills. The situation was aggravated in the 1980s (Cobbinah, 2014). Government agencies, both at the national and local level, continue to take sole responsibility for ensuring an effective municipal solid waste management (Adarkwa, 2005) often involving the private sector's participation (Oteng-Ababio et al., 2013).

Urbanised cities and/or district capitals, usually have more services, wealth and available equipment than rural villages. Big villages or located close to district capitals can more easily benefit from the government's services and managed by district assemblies. Consequently, inadequate road links with other wealthier areas represent a common issue that hinders efficient centralised waste management systems. In general, rural areas in Ghana are affected by more problems. Indeed, at the national level population using improved drinking water is about 44.3%, but in rural areas, it is only 17.9% (GoG, 2019). Furthermore, about 20% of the entire country's population practise open defecation. The practise is more widespread in the three regions of northern Ghana, where more than 70% of the population practices open defecation (GoG, 2019). Focusing on waste management practices, in many areas of Ghana, waste open dumping and open burning represent the prevalent practices (Bukari et al., 2017; Cobbinah et al., 2017). Despite some uncertainty about waste characterisation, the average waste generation rate at the household level can be assumed of 0.47 kg/(person x day). Still, the coastal and forest zones generated higher waste than the savannah (Miezah et al., 2015). Organic fraction constitutes more than 50% in most cases, and plastic represents the second most common fraction (Miezah et al., 2015). As previously discussed, this percentage is quite typical in such countries (Wilson et al., 2015). Furthermore, in rural areas the waste generation rate tends to be lower, and dangerous practices, such as open dumping and uncontrolled burning of solid waste, are typical also here (Cobbinah et al., 2017).

It is important to note that about malaria, Ghana is one of the countries with the highest incidence of this vector-borne disease worldwide (Riveron et al., 2016). This fact deserves strong attention because as aforementioned, some studies found an increase in malaria cases in African settlements among people living close to dumpsites (Abul, 2010; Sankoh et al., 2013). It will be better discussed later, in particular during the preparation of the health risk matrices.

Considering what discussed above, the field assessment was conducted, and health risk matrices were made to identify the highest issues and the control measures to propose.

3.5 Description of the SWM system in the nine rural villages in the Savannah ecological zone (Ghana)

In Ghana, the case study involved nine rural villages of the Northern and North East regions, i.e. the savannah zone, as shown in Figure 21. In this context, a field assessment on SWM practices, focusing on health and environmental issues, was conducted in November 2019.

As anticipated, the Ghanaian case study was developed in different conditions compared to the Serbian one. The Ghanaian villages analysed were rural, and it was possible to conducted a field assessment. Further visits have been hindered due to the pandemic (Covid-19). Simultaneously, unlike in Serbia, the Ghanaian context made complicated the availability of detailed and quantitative data and reports, although local documentation related to the case study and further information were received.

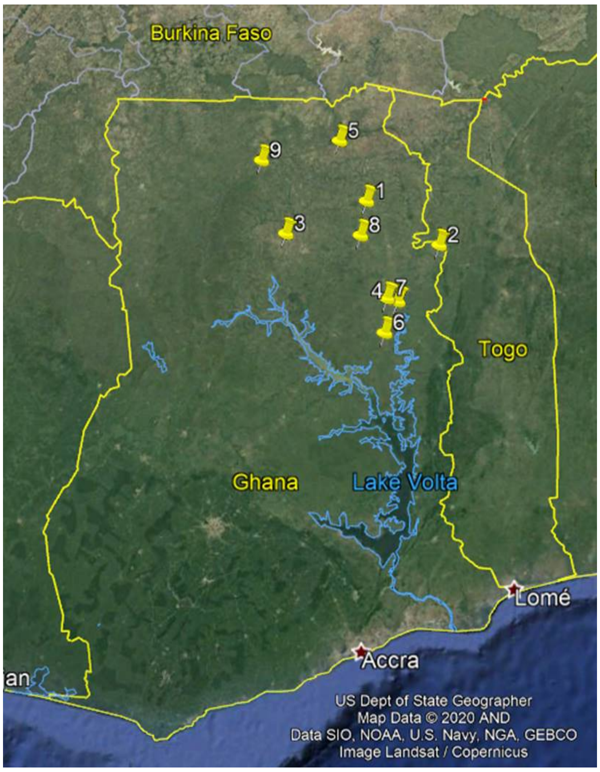

Figure 21: Physical map of Ghana marking the nine communities visited (from Google Earth)

The Ghanaian case study's different characteristics influenced the structure given to this subchapter. As it can be noted, unlike the Serbian case study, all the site-specific data were gathered differently in a unique subchapter. As anticipated, less quantitative and scientific information was available and the local level, given the constraints characterizing the context. A second field mission was not carried out because of the pandemic (Covid-19). However, the first field assessment conducted at the end of 2019 allowed understanding local conditions, issues, and challenges that crucially defined the communities. The nine rural villages had some fundamental differences, and it was not always possible to collect the same kind of information. As a consequence, to facilitate the description and the understanding of the findings, info was summarised in Table 16. The collected data, useful for the thesis development, is presented and discussed hereupon, in this subchapter. However, some additional information will be addressed better in Chapter 4, to delve into the results related to the health risk assessment matrices.

During the field assessments carried out in November 2019 in the nine rural communities shown in Figure 21, issues affecting Ghana were common in all the examined villages. Indeed, general problems were:

- Low waste management services.
- Poor sanitation services.
- Lack of safe drinking water.
- Use of rural cookstoves.
- Malaria.

Furthermore, roads connecting rural villages with more urbanised areas or bigger cities (such as Tamale) were often terrible. Trips through dirt roads, even more than two hours, were frequent during field assessments. An example is shown in Figure 22. This issue significantly affects the quality of the waste management service, hindering a possible centralised waste management system. It will be taken into account in the paragrah related to control measures to reduce health risks.

Figure 22: Dirt road on the way of village #5 (ph. Giovanni Vinti, November 2019)

Mainly because of their poverty and the lack of services that isolation amplifies, the villagers were unwilling to pay taxes, as also noted in some local plans (East Mamprusi District Assembly, 2018). Indeed, in the communities, life was based on livelihood, and most people were farmers.

A recap of information collected during the field assessment in the nine rural villages is shown in Table 16. A paper related to this case study, containing a table with some additional information will be sent to a scientific journal for publication.

Table 16: Information from the Ghanaian villages during the field assessment of November 2019

Village, district and region	Number of inhabitants	Road connections quality [a]	Dumpsites [b] within the village	Groundwater and wells	Scattered waste within the village	Open burning of solid waste	Burial of waste
#1. Gushegu district, Northern Region	5919	dirt roads	Yes	Yes	Yes	Yes	NA
#2. Zabzugu district, Northern Region	1700	dirt roads	No	Yes	Yes	Yes	NA
#3. Tolon-Kumbungu district, Northern Region	6000	dirt roads	Yes	Yes	Yes	Yes	NA
#4. Nanumba South district, Northern region	4000	dirt roads	Yes	NA	Yes	Yes	NA
#5. East Mamprusi district, Northeast Region	8681	paved roads	Yes	Yes	Yes	Yes	No
#6. Kpandai district, Northern region	350	dirt roads	Yes	Yes	Yes	Yes	Yes
#7. Nanumba North district, Northern region	2932	dirt roads	Yes	Yes	Yes	Yes	Yes
#8. Mion district, Northern Region	1100	paved roads	Yes	NA	Yes	Yes	NA
#9. Mamprugu Moagduri district, Northeast region	222	dirt roads	Yes	Yes	Yes	Yes	Yes

[a] Considering connections with inhabited centres nearby.

[b] Also considering small dumpsites

NA: information Not Available

As shown later, if a specific activity not occurred in a particular community, a risk assessment was not conducted. When it was not possible to state about the presence, likelihood and/or severity of a specific activity, it was included in the health risk assessment matrix, and the acronym NA (Not Available) was used.

Furthermore, village #5, was the only in which it was asserted the reuse of solid waste from dumpsites as compost by local farmers. In such a community, waste open burning mainly occurred by farmers.

The definition of uncontrolled burying of solid waste refers to all the period during which a hole is gradually filled with waste, as shown in Figure 23. This practice is usually related to the construction of new houses, which also soil is used; as a consequence, the resulting hole is often filled with waste.

A further important element that was considered is the annual rainfall. It increased a lot in 2019 if compared with previous years, as shown in Table 17, referring to the areas close to the nine rural villages involved. However, as an average from 2015 to 2019, the annual rainfall resulted always lower than 1,000 mm/year. In two cases (village #5 and village #9), it was even lower than 500 mm/year.

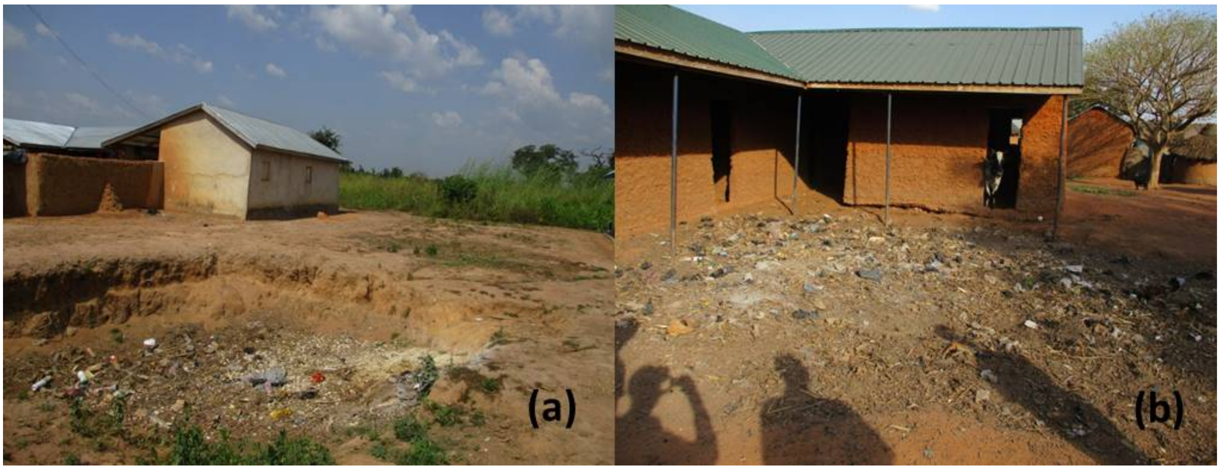

Figure 23: Uncontrolled burying of solid waste: (a) pit filling phase; (b) pit full of waste (ph. Giovanni Vinti, November 2019)

Table 17: Annual rainfall in the area of the nine rural villages

Village	Total annual rainfall[1] [mm/year]	Year	Average in the five years [mm/year]
Village #1	464.46	2015	768.48
	329.11	2016	
	320.82	2017	
	573.90	2018	
	2154.10	2019	
Village #2	464.43	2015	768.54
	328.48	2016	
	320.87	2017	
	573.90	2018	
	2155.00	2019	

Village #3	418.31	2015	657.63
	282.44	2016	
	304.22	2017	
	610.57	2018	
	1672.60	2019	
Village #4	464.46	2015	768.72
	328.48	2016	
	320.87	2017	
	573.90	2018	
	2155.90	2019	
Village #5	406.34	2015	498.53
	317.79	2016	
	254.24	2017	
	448.4	2018	
	1065.9	2019	
Village #6	572.28	2015	824.50
	529.73	2016	
	387.20	2017	
	671.41	2018	
	1961.90	2019	
Village #7	464.46	2015	808.10
	326.48	2016	
	320.87	2017	
	573.90	2018	
	2354.80	2019	
Village #8	464.46	2015	808.10
	326.48	2016	
	320.87	2017	
	573.90	2018	
	2354.80	2019	
Village #9	406.34	2015	498.93
	317.79	2016	
	254.24	2017	
	450.40	2018	
	1065.90	2019	

[1]From www.worldweatheronline.com

During the field assessments, SWM emerged as an issue present in all the villages. Four SWM activities were observed and assessed:

- Disposal of solid waste in dumpsites.
- Open burning of waste.
- Uncontrolled burying of solid waste.
- Reuse of solid waste from dumpsites as compost by local farmers.

Scattered waste was always noticeable, and waste open burning was practised in all the villages. Uncontrolled burying of solid waste was proved in at least three villages. Disposal of solid waste in dumpsites was noted in all the communities, except for village #2. Reuse of solid waste from dumpsites as compost by local farmers was ascertained in village #5. In almost all the villages, groundwater was available and used for drinking purposes through wells.

In the villages, except for some local chiefs, most people were poor. They were usually farmers that bred animals (e.g., goats, poultries, and in some cases, cows and pigs) and cultivated crops (e.g., yam, manioc, corn, rice, bean). Villages varied in size and distance from nearest urban centres, but all of them had less than 10,000 inhabitants. In two villages (#6 and #9), less than 500 people lived. Most of them had dirt roads; indeed, only two out of the nine rural villages were connected to the nearest urban centre through paved roads, influencing the time needed to reach the communities. The fields assessment, and further documentation received by local offices (East Mamprusi District Assembly, 2018; Zabzugu District Assembly, 2018) thanks to the support of the CISS NGO staff, allowed to confirm that malaria, respiratory infections and diarrhoea were always the three most common diseases.

About the disposal of solid waste, in the villages, the dumpsites had a horizontal surface between 20 m^2 and 200 m^2. The only exception was represented by village #1, which also had a bigger dumpsite in the village's core (horizontal surface greater than 400 m^2). Furthermore, villages #6 and #9 had very small dumpsites (< 20 m^2). Most of the dumpsites were located in central parts of villages, in some cases close to local markets to facilitate waste collection and/or disposal. None of the dumpsites had fences or other protections, making the place easily accessible by adults, children and animals. Indeed, farm animals were frequently noted during the field assessments.

In some cases, mainly in small villages, some households had their little dumpsite to use, a few meters from the house. People disposed of household waste, mostly consisting of organic waste, but plastic waste was common as well. Metals and glass were also noted, although in low quantity, probably because of the value people gave to such materials. Electronic waste and other assorted waste were rare. It was easier to find it in the larger villages of the survey, as previously noted by Agyarko et al. (2010) in other Ghana regions. Human faeces were sometimes noted in the dumpsites. In some cases, during the assessment of November 2019, children using dumpsites as an open defecation area were seen.

Waste open burning represented a common practice used by the population to reduce waste. In some cases, it was periodically conducted in dumpsites or where people buried their waste. In any case, waste open burning was practised inside the villages. It is essential to highlight that municipal solid waste open burning can lead to the production of hazardous compounds such as dioxins, Polycyclic Aromatic Hydrocarbons (PAHs), and Organic Compounds (Estrellan and Iino, 2010). Farm animals were often seen eating in these areas. The waste that people preferred to burn was plastic because, unlike the organic fraction, it does not degrade, but if accumulated, it continues to increase. However, also, the organic fraction was burned as well.

Uncontrolled burying of solid waste represented a practice mainly related to houses building. It was ascertained in three villages. However, it can be possible that the activity was also conducted in some other village. As shown in Table 16, the information was Not Available (NA) in most other communities. Figure 23 shows (a) pit filling phase and (b) pit full of waste. Especially during the pit filling phase, the hole can provide breeding and feeding sites for animals and insects, as witnessed during the field assessment in village #6, in which a pit close to a new house was used by poultries. Furthermore, the time needed to fully fill the pit was not directly related to the waste generated by people who use it. In many cases, people burned waste when the hole started to be full to reduce the occupied volume. As can be noted in Figure 2, the hole's size was usually not huge, because it is related to the soil needed for the house. The reuse of solid waste from dumpsites as compost by local farmers was confirmed only in village #5. In the other villages, it was not possible to find this information, and although in most of them the practice seems unlikely it could not be excluded at all, and further surveys would be needed. In village #5 farmers periodically took waste from some dumpsites located close to local markets, about two times per month. Waste disposed of in dumpsites were household waste and waste produced in the market. Consequently, there is a lot of organic fraction, a bit of plastic, metal, glass, paper, and other fractions to a lesser extent. Some inhabitants disposed of ashes obtained from the combustion of wood or coal used for cooking. People reported periodic fires, mostly generated accidentally, due to, for example, hot ashes. Considering the value that farmers gave to waste as compost, waste open burning was discouraged even from dumpsites. During the field assessment, farm animals, such as pigs and goats, were spotted eating in dumpsites. Furthermore, dumpsites were used for open defecation.

It is essential to highlight that farmers periodically collect all this waste from dumpsites. They sort the organic fraction from the rest by themselves (i.e., there is no separation of waste at source). As a consequence, the organic fraction will be plenty of other substances. Furthermore, farmers burn the remaining waste (i.e. the residues, mainly plastics) by themselves in areas close to their lands. Based on the information collected during the field visits and using data taken by scientific literature, health risk assessment matrices were made, and they are better discussed in the next chapter.

4 RESULTS AND DISCUSSION

As previously discussed, the PhD research can be divided into two steps. Indeed, a systematic review was carried out preliminarily to understand better the recent evidence available in the scientific literature regarding MSW practices and adverse health outcomes. Such work was crucial to implement adequately the MSWSP discussed in the second, and larger, part of the results.

4.1 Municipal solid waste management and adverse health outcomes: evidence in studies from the last 15 years (January 2005- January 2020)

In conducting the systematic review, a total of 253 studies, including 33 reviews and reports, were initially identified. After adjusting for duplicates, 236 studies remained. Of these, 37 studies were discarded after reviewing the abstracts because it appeared these papers did not meet the criteria. The full text of the remaining 199 publications was examined in more detail. A total of 170 studies did not meet the inclusion criteria previously described. 29 studies met the inclusion criteria and are included in the review. The PRISMA flow chart illustrating the process for determining study eligibility appears in Figure 24.

Unfortunately, no studies were found that met the inclusion criteria for health effects associated with proximity to transfer stations, recycling centres, composting plants, and anaerobic digesters. The results with respect to landfills, incinerators, and dumpsites/open burning sites are summarised below (Tables 18-20).

Nine studies related to landfills were identified and included in Table 18. Five of them were conducted in Europe, two in North America, one in Asia (China) and one in Africa (South Africa). This highlights that all of these studies were conducted in the most industrialised areas, even in Asia and Africa. It is probably because landfilling and incineration are more common in high- and upper-middle-income countries (Kaza et al., 2018); this makes it easier to find such case studies there. Five papers were retrospective cohort studies, and four were cross-sectional studies.

The overall evidence of health risks associated with residing near a landfill was mixed. It was found an increased risk of mortality for lung cancer (Mataloni et al., 2016), births with congenital anomalies (Palmer et al., 2005), and negative respiratory conditions in people aged < 14 years, considering both all respiratory diseases and only acute respiratory infections (Mataloni et al., 2016), forced vital capacity in children aged 6-12 years (Gumede and Savage, 2017), mucosal irritation and upper respiratory symptoms (Heaney et al., 2011), and other mild symptoms (Kret et al., 2018; Yu et al., 2018). Some evidence of worsening mental and social health conditions was found in particular alteration of daily activities or negative mood states (Heaney et al., 2011). However, in other cases, no evidence of mortality or adverse health effects was found. Mataloni et al. (2016) found no evidence of increased mortality and other specific cancers (i.e. colorectal, kidney, liver, pancreas, larynx, bladder, stomach, brain, and lymphatic tissue). They did not find increased mortality for cardiovascular, digestive, ischaemic heart, respiratory and urinary system diseases. Furthermore, Elliott et al. (2009) did not find evidence of increased congenital anomalies, while Jarup et al.

(2007) found no evidence of increased risk of birth with Down's syndrome. For specific cardiovascular diseases (i.e. cardiac, ischaemic, and cerebrovascular), Mataloni et al. (2016) did not find evidence of increased risk. Evidence of increased risk of asthma (Kret et al., 2018; Mataloni et al., 2016) nor gastrointestinal symptoms (Heaney et al., 2011) were found.

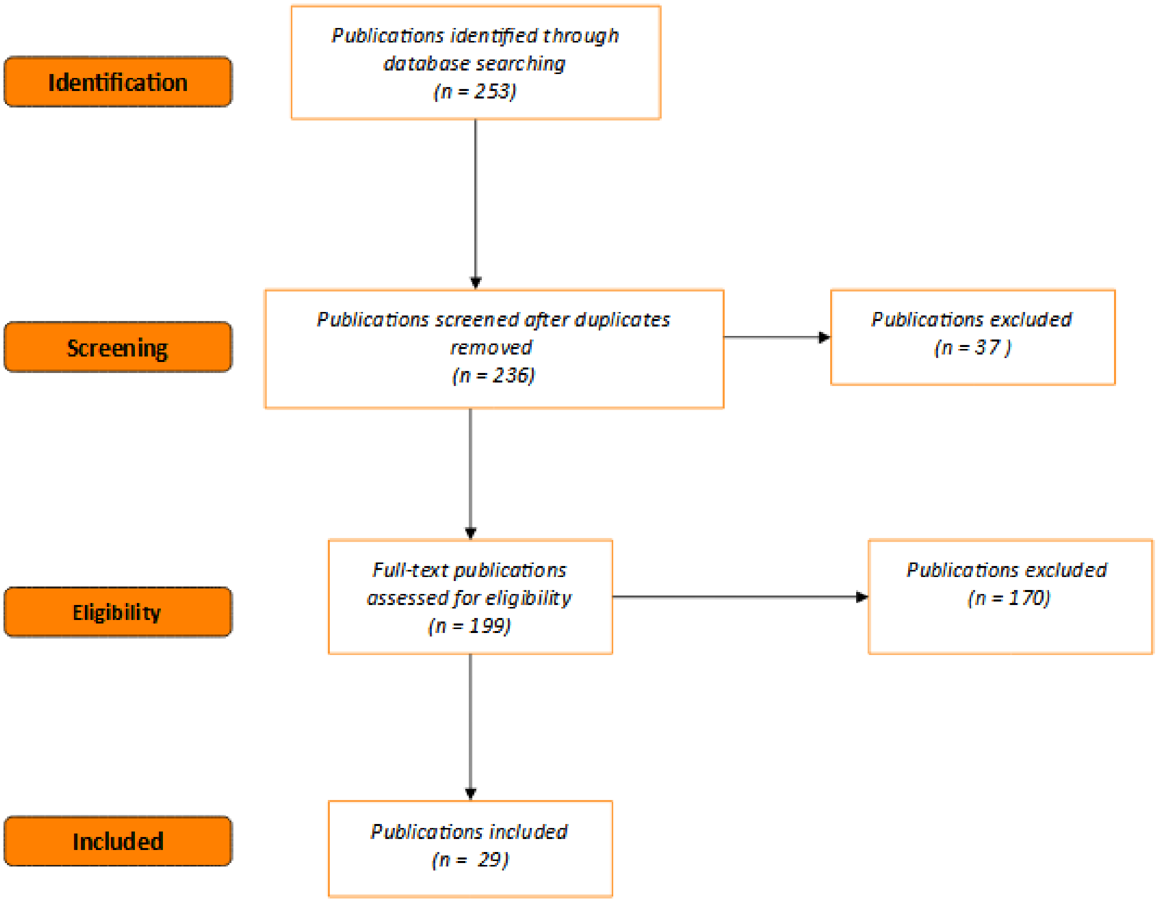

Figure 24: PRISMA flow diagram summarising the studies selection for the systematic review

Table 18: Health outcomes associated with landfills - Study Characteristics

Study location	Study design	Outcomes investigated	Main findings (e.g. estimated risk, CI, p-value)	References
Mortality				
Italy	Cohort study (retrospective)	The association between landfill H_2S exposure and mortality (both natural and cause-specific) and hospital admissions for cardiorespiratory	*Associations between H_2S (>75° quartile) and cause-specific mortality (hazard ratio (HR) and 95% Confidence Interval):* - natural cases: 0.98 (0.91, 1.05) - all cancers: 1.03 (0.91, 1.16) - specific cancers: - stomach: 0.88 (0.54, 1.42) - colorectal: 0.91 (0.64, 1.28) - liver: 0.76 (0.48, 1.2)	Mataloni et al. (2016)

		diseases was evaluated.	- pancreas: 0.73 (0.41, 1.32) - larynx: 0.26 (0.07, 0.95) - lung: 1.34 (1.06, 1.71), p<0.05[a] - bladder: 0.94 (0.5, 1.80) - kidney: 0.86 (0.41, 1.83) - brain: 1.76 (0.81, 3.81) - lymphatic and haematopoietic tissue: 1.12 (0.74, 1.17) - cardiovascular diseases: 0.91 (0.81, 1.02) - ischaemic heart diseases 0.78 (0.64, 0.95) - respiratory diseases: 1.30 (0.99, 1.70) - digestive diseases: 0.97 (0.69, 1.35) - urinary system diseases: 1.42 (0.84, 2.40)	
Adverse birth and neonatal outcomes				
England	Cohort study (retrospective)	The risk of congenital anomalies in relation to an index of geographic density of landfill sites (within 2 km from landfills).	Rates of congenital anomalies in the category with the highest exposure index (the 4th), for non-special or unknown waste sites (adjusted odd ratio (OR) and 95% Credible Interval): - all congenital anomalies (hypospadias and epispadias, cardiovascular defects, neural tube defects, abdominal wall defects): 1.02 (0.98, 1.07) - hypospadias and epispadias: 0.97 (0.89, 1.06) - neural tube defects: 1.04 (0.93, 1.18) - cardiovascular defects: 0.94 (0.82, 1.07) - abdominal wall defects: 1.11 (0.94, 1.32)	Elliott et al. (2009)
Denmark	Cohort study (retrospective)	Risk of congenital anomalies combined and congenital anomalies of the cardiovascular and nervous systems with maternal residence in function of distance from landfills.	Risk rate[b], comparing the closest zones with the others. When RR < 1.000 the risk is lower, compared to the closest zone: - combined congenital anomalies: 1.000 (closest zone), 0.991 (middle zone), 1.013 (farthest zone) - congenital anomalies in the cardiovascular system: 1.000 (closest zone), 0.926 (middle zone), 0.854 (farthest zone)	Kloppenborg et al. (2005)
England and Wales	Cohort study (retrospective)	The risk of giving birth to a child with Down	Relative risk (RR)[c] (95% Credible Interval) of Down's syndrome near landfill sites:	Jarup et al. (2007)

		syndrome associated with residence near landfill sites (within 2 km)	- considering both operating and closed sites (non-special waste): 1.000 (0.909, 1.095) - considering only operating sites (non-special waste): 1.011 (0.901, 1.126)	
Wales	Cohort study (retrospective)	The increased risk of births with at least one congenital malformation in population living within 2 km from landfill sites, comparing it with population living at least 4 km away	Ratio between risk of congenital anomalies (in live births) after and before opening of sites (95% Confidence Interval): 1.39 (1.21, 1.72), $p<0.05$[a]	Palmer et al. (2005)
Cardiovascular diseases				
Italy	Cohort study (retrospective)	The association between landfill H_2S exposure and mortality (both natural and cause-specific) and hospital admissions for cardiorespiratory diseases was evaluated.	*Associations between H_2S (>75° quartile) and cardiorespiratory morbidity (HR and 95% Confidence Interval):* - (all) cardiovascular diseases: 1.02 (0.97, 1.07) - cardiac disease: 1.04 (0.97, 1.11) - ischaemic heart diseases: 0.99 (0.88, 1.10) - cerebrovascular diseases: 0.98 (0.88, 1.10)	Mataloni et al. (2016)
Respiratory conditions				
Italy	Cohort study (retrospective)	The association between landfill H_2S exposure and mortality (both natural and cause-specific) and hospital admissions for cardiorespiratory diseases was evaluated.	*Associations between H_2S (>75° quartile) and cardiorespiratory morbidity (HR and 95% Confidence Interval):* - (all) respiratory diseases: 1.05 (0.99, 1.11) - acute respiratory infections: 1.07 (0.97, 1.18) - COPD (chronic obstructive pulmonary disease): 1.06 (0.90, 1.25) - asthma: 1.09 (0.90, 1.33) - (all) respiratory diseases (age ≤ 14 years): 1.11 (1.01, 1.22), $p<0.05$[a] - Acute respiratory infections (age ≤ 14 years): 1.20 (1.04, 1.38), $p<0.05$[a] - asthma (age ≤ 14 years): 1.13 (0.91, 1.41)	Mataloni et al. (2016)
South Africa	Cross-sectional study	Assessment of $PM_{2.5}$ concentration in indoor	Regression models expressing the association between a 24-h average indoor $PM_{2.5}$ exposure and lung function outcomes, in terms of slope coefficient	Gumede and Savage (2017)

		environments of the subjects involved in the study and its association with lung function patterns.	(95% CI): - $PM_{2.5}$ concentration level and forced expiratory volume in 1s (FEV_1): -0.60 (-1.23, 0.01) - $PM_{2.5}$ concentration level and forced vital capacity (FVC): -2.12 (-3.39, -0.85), $p < 0.05^d$ - $PM_{2.5}$ concentration level and FEV_1/FVC: -1.42 (-4.85, 2.01)	
Missouri (USA)	Cross-sectional study	Respiratory symptoms and diseases	Differences in the prevalence of diseases, between the 2 groups, in terms of significance: - $p > 0.05^e$: ever told asthma; asthma attack in last 12 months; ever told have chronic obstructive pulmonary disease (COPD); nasal allergies in last 12 months; wheezing, cough, eye irritation, fatigue (tiredness), headaches, nausea, trouble sleeping in the last 12 months; - $p < 0.05^e$: other respiratory conditions (the most commonly reported included pneumonia, sleep-related disorders, and bronchitis); - $p < 0.01^e$: attack of shortness of breath in the last 12 months	Kret et al. (2018)
China	Cross-sectional study	Association between air pollutants and respiratory health in exposed area, considering lysozyme and secretory immunoglobulin A (which are typically considered as the first line of defence from air pollutants and higher levels show good related health conditions)	Students in non-exposure areas had significantly ($p<0.05^f$) higher levels of lysozyme, secretory immunoglobulin A (SIgA), and better lung capacity than students in exposed areas	Yu et al. (2018)
North Carolina (USA)	Cross-sectional study	Relationships between H_2S, odour, and health outcomes in a community	Symptoms associated to odour (Odd Ratio (OR) and 95% Confidence Interval (CI)): - mucosal irritation 3.7 (2.0, 7.1), $p<0.05^a$	Heaney et al. (2011)

		living close to a landfill	- upper respiratory symptoms 3.9 (2.2, 7.0), p<0.05[a]	
Gastroenteritis				
North Carolina (USA)	Cross-sectional study	Relationships between H_2S, odour, and health outcomes in a community living close to a landfill	Symptoms associated to odour (Odd Ratio (OR) and 95% Confidence Interval (CI)): - gastrointestinal symptoms 1.0 (0.4, 2.6)	Heaney et al. (2011)
Mental and social health conditions				
North Carolina (USA)	Cross-sectional study	Relationships between H_2S, odour, and health outcomes in a community living close to a landfill	Symptoms associated to odour (Odd Ratio (OR) and 95% Confidence Interval (CI)): - alteration of daily activities: 9.0 (3.5, 23.5), p<0.05[a] - negative mood states: 5.2 (2.8, 9.6), p<0.05[a] - positive mood states: 0.6 (0.2, 1.5)	Heaney et al. (2011)

[a] p<0.05. Estimated in our systematic review on the basis of 95% Confidence Interval

[b] The sum of anomalies divided by the total proximal sum of births

[c] People living beyond the 2-km zone of all known landfill sites represented the reference population

[d] p< 0.05. Value from regression models.

[e] p-value for test of equality

[f] Multiple linear regression models were conducted by the authors to determine the associations between health end points and air pollutants

Table 19 summarises the health outcomes related to incinerators. A total of 13 studies were identified, ten of which were conducted in Europe and three in Asia (China and Taiwan). As already mentioned, this is probably because landfilling and incineration are more common in industrialised countries. In contrast, in low- and lower-middle-income countries, open dumping is the most common waste management practice (Kaza et al., 2018). Seven papers were retrospective cohort studies, one was a prospective cohort study, three were case-control studies, and two were cross-sectional studies.

Even in this case, the evidence of increased health risks from residing near an incinerator was mixed. Ranzi et al. (2011) reported an increased risk of mortality in women for various health outcomes, including cancer. In further studies evidence of adverse birth and neonatal outcomes, i.e., preterm births (Candela et al., 2013), spontaneous abortions (Candela et al., 2015), congenital heart defects, genital system defects and hypospadias (Parkes et al., 2020), urinary tract birth defects (Cordier et al., 2010) was found. Besides, in two human biomonitoring studies, a higher concentration of dioxins in residents near incinerators (Xu et al. 2019a, Xu et al. 2019b) was found. In other cases, no evidence of adverse health effects was found. Indeed, Viel et al. (2008) found no evidence of increased invasive breast cancer in women aged 20–59. The same authors found a significant reduction in invasive breast cancer in women aged 60 years and over. Ranzi et al. (2011) found no evidence of increased cancer diseases in both men and women. The same authors (Ranzi et al., 2011) found neither evidence of increased risk of cardiovascular diseases nor respiratory issues. Furthermore, several studies reported no evidence for some adverse birth outcomes

(Candela et al. (2013); Vinceti et al. (2008; 2009); Ghosh et al. (2019); Parkes et al., (2020); Lin et al. (2006); Cordier et al. (2010)).

Table 19: Health outcomes associated with incinerators - Study Characteristics

Study location	Study design	Outcomes investigated	Main findings (e.g., estimated risk, CI, p-value)	References
Mortality				
Italy	Cohort study (retrospective)	Health outcomes among people living close to incinerators (using a dispersion model for exposure assessment)	*Associations between heavy metals concentration and mortality in the highest exposed group using the lowest exposure category as the reference (Rate Ratio (RR) and 95% CI):* - all causes (men): 1.01 (0.86, 1.20) - all causes (women): 1.12 (1.00, 1.27) [a] - cardiovascular diseases (men): 0.98 (0.75, 1.29) - cardiovascular diseases (women): 1.32 (1.00, 1.72) - ischaemic heart diseases (men): 0.79 (0.51, 1.22) - ischaemic heart diseases (women): 1.14 (0.72, 1.82) - respiratory diseases (men): 1.01 (0.42, 2.45) - respiratory diseases (women): 0.53 (0.18, 1.56) - chronic pulmonary-diseases (men): 0.53 (0.15, 1.86) - chronic pulmonary-diseases (women): 0.27 (0.03, 2.06) *Associations between heavy metals concentration and cancer mortality in the highest exposed group using the lowest exposure category as the reference (Rate Ratio (RR) and 95% CI):* - all cancer (men): 0.85 (0.64, 1.12) - all cancer (women): 1.47 (1.09, 1.99) [a] - stomach (men): 0.85 (0.35, 2.03) - stomach (women): 1.86 (0.73, 4.75) - colon rectum (men): 2.05 (0.92, 4.58) - colon rectum (women): 2.15 (0.86, 5.37) - liver (men): 0.27 (0.03, 2.18) - liver (women): 5.10 (0.94, 27.80) - larynx (men): no cases - larynx (women): no cases - lung (men): 0.91 (0.53, 1.57) - lung (women): 0.96 (0.31, 2.97) - soft tissue sarcoma (men): no cases	Ranzi et al. (2011)

			- soft tissue sarcoma (women): no cases - breast (women): 2.00 (1.00, 3.99) - prostate (men): 1.57 (0.66, 3.74) - bladder (men): 1.48 (0.52, 4.22) - bladder (women): 3.06 (0.64, 14.70) - central nervous system (men): no cases - central nervous system (women): no cases - lymph. system (men): 0.42 (0.15, 1.23) - lymph. system (women): 1.78 (0.74, 4.25) - non-Hodgkin lymphoma (men): 0.52 (0.11, 2.45) - non-Hodgkin lymphoma (women): 2.03 (0.48, 8.67) - myeloma (men): no cases - myeloma (women): 4.28 (0.77, 23.80) - leukaemia (men): 0.67 (0.14, 3.16) - leukaemia (women): 1.31 (0.25, 6.95)	
Cancer				
Italy	Cohort study (retrospective)	Health outcomes among people living close to incinerators (using a dispersion model for exposure assessment)	*Associations between heavy metals concentration and cancer incidence in the highest exposed group using the lowest exposure category as the reference (Rate Ratio (RR) and 95% CI):* - all cancer (men): 0.87 (0.72, 1.06) - all cancer (women): 0.90 (0.73, 1.11) - stomach (men): 1.24 (0.64, 2.40) - stomach (women): 1.09 (0.49, 2.44) - colon rectum (men): 1.00 (0.57, 1.75) - colon rectum (women): 1.33 (0.71, 2.48) - liver (men): 0.26 (0.03, 2.01) - liver (women): 0.94 (0.20, 4.53) - larynx (men): 0.15 (0.02, 1.14) - larynx (women): 1.60 (0.15, 17.64) - lung (men): 0.96 (0.61, 1.52) - lung (women): 0.81 (0.27, 2.42) - soft tissue sarcoma (men): 0.84 (0.09, 8.06) - soft tissue sarcoma (women): no cases - breast (women): 0.76 (0.51, 1.13) - prostate (men): 1.27 (0.82, 1.99) - bladder (men): 0.78 (0.43, 1.42) - bladder (women): 2.30 (0.73, 7.24) - central nervous system (men): 1.35 (0.34, 5.39) - central nervous system (women): no cases	Ranzi et al. (2011)

			- lymph. system (men): 0.70 (0.38, 1.28) - lymph. system (women): 1.23 (0.65, 2.33) - non-Hodgkin lymphoma (men): 0.59 (0.23, 1.57) - non-Hodgkin lymphoma (women): 1.06 (0.39, 2.93) - myeloma (men): 0.61 (0.17, 2.13) - myeloma (women): 0.95 (0.26, 3.45) - leukaemia (men): 1.01 (0.36, 2.84) - leukaemia (women): 1.23 (0.33, 4.62)	
France	Case-control study	The association between dioxins emitted from a MSW incinerator (air exposure using a model) and invasive breast cancer risk among women residing in the area.	*Odds Ratio (OR) of invasive breast cancer by age bands and dioxin exposure categories (comparing very low with high exposure) (95% CI):* - women aged 20–59 years: 0.88 (0.43, 1.79) - women aged 60 years and over: 0.31 (0.08, 0.89)	Viel et al. (2008)
Adverse birth and neonatal outcomes				
Italy	Cohort study (retrospective)	Assessment of the effects of air emissions from MSW incinerators (simulated with a dispersion model) on reproductive outcomes	*Associations between modelled exposure levels to PM_{10} from the incinerators and reproductive outcomes, for the highest versus the lowest quintile exposure (Odd Ratio (OR), 95% Confidence Interval and significance):* - preterm births: 1.30 (1.08, 1.57)[b], $p<0.05$[c]; 1.44 (1.11, 1.85)[d], $p<0.05$[c] - sex ratio: 0.91 (0.83, 0.99)[b]; 0.88 (0.78, 0.99)[d]; - multiple births: 0.87 (0.57, 1.33)[b]; 1.12 (0.60, 2.08)[d]; - small for gestational age (SGA): 1.11 (0.96, 1.28)[b]; 1.06 (0.87, 1.29)[d];	Candela et al. (2013)
Italy	Cohort study (retrospective)	Assessment of the effects of air emissions from MSW incinerators (simulated with a dispersion model) on spontaneous abortions.	*Associations between modelled exposure levels to PM_{10} from the incinerators and miscarriages, for the highest versus the lowest quintile exposure (Adjusted Odd Ratio (OR), 95% Confidence Interval and significance p):* - spontaneous abortions: 1.29 (0.97, 1.72)[e]	Candela et al. (2015)
Italy	Cohort study (retrospective)	Rates of spontaneous abortion and	*Associations between modelled exposure levels of pollutants from the incinerator and reproductive outcomes,*	Vinceti et al. (2008)

		prevalence of birth defects among women living or working near a MSW incinerator, modelling incinerator emissions exposure	*in terms of Relative Risk computed as the ratio between observed and expected incidence, (95% Confidence Interval):* - Spontaneous abortion: - residents from both area A and B 1.00 (0.65, 1.48) - area A residents (highest exposure): 0.87 (0.22, 2.38) - area B residents (intermediate exposure): 1.03 (0.64, 1.56) - workers from both area A and B: 1.04 (0.38, 2.30) - area A workers: 0.00 (0.00, 1.46) - area B workers: 1.81 (0.66, 4.02) - Birth defects: - residents from both area A and B: 0.64 (0.20, 1.55) - area A residents: 0.00 (0.00, 4.41) - area B residents: 0.72 (0.23, 1.75) - workers from both area A and B: 2.26 (0.57, 6.14) - area A workers: 2.22 (0.37, 7.34) - area B workers: 2.27 (0.11, 11.21)	
Great Britain	Cohort study (retrospective)	Associations between modelled ground-level particulate matter from incinerators emission within 10 km and selected reproductive/birth outcomes	*Associations between modelled exposure levels of pollutants from the incinerator and reproductive outcomes (adjusted OR and 95% CI):* - stillbirths [f]: 0.99 (0.97, 1.00) - stillbirths [g]: 1.00 (0.99, 1.02) - neonatal mortality (pregnancy exposure) [f]: 0.99 (0.96, 1.02) - neonatal mortality (pregnancy exposure) [g]: 1.01 (1.00, 1.03) - post-neonatal mortality (pregnancy exposure) [f]: 1.02 (0.96, 1.07) - post-neonatal mortality (pregnancy exposure) [g]: 0.99 (0.97, 1.02) - post-neonatal mortality (birth to death of case exposure) [f]: 1.01 (0.98, 1.04) - multiple births [f]: 0.99 (0.99, 1.00) - multiple births [g]: 1.00 (0.99, 1.00) - sex ratio [f]: 1.00 (1.00, 1.00) - sex ratio [g]: 1.00 (1.00, 1.00) - preterm delivery [f]: 0.99 (0.97, 1.01) - preterm delivery [g]: 1.00 (0.99, 1.00) - terms small for gestational age (SGA) [f]: 0.99 (0.98, 1.00) - terms SGA [g]: 1.00 (0.99, 1.01)	Ghosh et al. (2019)

England and Scotland	Cohort study (retrospective)	Associations between modelled ground-level particulate matter from incinerators emission within 10 km and selected reproductive/birth outcomes	*Adjusted odds ratio (OR) (95% CI):* - all congenital anomalies [f]: 1.00 (0.98, 1.02) - all congenital anomalies [g]: 1.02 (1.00, 1.04) - all congenital anomalies excluding chromosomal [f]: 0.99 (0.97, 1.01) - all congenital anomalies excluding chromosomal [g]: 1.02 (1.00, 1.04) - nervous system [f]: 0.97 (0.92, 1.02) - nervous system [g]: 0.97 (0.93, 1.02) - congenital heart defects [f]: 0.99 (0.93, 1.05) - congenital heart defects [g]: 1.04 (1.01, 1.08), $p<0.05$[h] - abdominal wall defects [f]: 1.00 (0.92, 1.08) - abdominal wall defects [g]: 1.00 (0.94, 1.07) - oro-facial clefts [f]: 1.00 (0.94, 1.07) - oro-facial clefts [g]: 0.99 (0.94, 1.05) - limb defects [f]: 1.01 (0.94, 1.08) - limb defects [g]: 1.02 (0.97, 1.08) - digestive system [f]: 1.00 (0.92, 1.09) - digestive system [g]: 1.00 (0.95, 1.06) - urinary system [f]: 1.00 (0.94, 1.07) - urinary system [g]: 1.02 (0.97, 1.06) - genital system [f]: 1.03 (0.95, 1.13) - genital system [g]: 1.07 (1.02, 1.12), $p<0.05$[h] - neural tube defects (from congenital anomaly sub-groups (CAS)) [f]: 1.00 (0.92, 1.07) - neural tube defects (from CAS) [g]: 0.97 (0.91, 1.03) - severe congenital heart defects (from CAS) [f]: 1.03 (0.97, 1.10) - severe congenital heart defects (from CAS) [g]: 1.02 (0.97, 1.07) - gastroschisis (from CAS) [f]: 1.04 (0.94, 1.15) - gastroschisis (from CAS) [g]: 0.97 (0.89, 1.05) - cleft palate (from CAS) [f]: 1.02 (0.92, 1.13) - cleft palate (from CAS) [g]: 0.98 (0.90, 1.06) - cleft lip with or without cleft palate (from CAS) [f]: 1.00 (0.93, 1.08) - cleft lip with or without cleft palate	Parkes et al., 2020

			(from CAS) [g]: 1.00 (0.94, 1.07) - limb reduction defects (from CAS) [f]: 1.02 (0.91, 1.14) - limb reduction defects (from CAS) [g]: 0.98 (0.90, 1.08) - oesophageal atresia (from CAS) [f]: 1.04 (0.88, 1.22) - oesophageal atresia (from CAS) [g]: 0.92 (0.80, 1.05) - anomalies of the renal system (from CAS) [f]: 1.02 (0.95, 1.10) - anomalies of the renal system (from CAS) [g]: 1.00 (0.93, 1.07) - obstructive defects of renal pelvis (from CAS) [f]: 0.97 (0.90, 1.04) - obstructive defects of renal pelvis (from CAS) [g]: 1.03 (0.97, 1.10) - hypospadias (from CAS) [f]: 1.00 (0.90, 1.12) - hypospadias (from CAS) [g]: 1.07 (1.01, 1.12), $p<0.05$ [h]	
Taiwan	Cohort study (retrospective)	The relationships between exposure to elevated PCDD/Fs concentration generated by a MSW incinerator (using a model), and various birth outcomes	*Difference of birth outcomes between higher exposure and control areas in 1997 (adjusted OR and 95% CI):* - birth weight: 1.06 (0.71, 1.57) - gestation weeks, in 1997: 1.22 (0.97, 1.52) - gender, in 1997: 0.90 (0.78, 1.05)	Lin et al. (2006)
Italy	Case-control study	Examining the relation between exposure to the emissions from an MSW incinerator and risk of birth defects, modelling incinerator emissions exposure	*Prevalence (odds ratio) for congenital anomalies according to maternal exposure to air emissions from the incinerator (95% Confidence Interval), with low exposure area as reference:* All congenital anomalies: - area B (medium exposure) [i]: 1.55 (0.67, 3.56) - area B [j]: 1.10 (0.39, 3.06) - area B [k]: 3.17 (0.65, 15.46) - area C (high exposure) [i]: 0.67 (0.25, 1.77) - area C [j]: 0.41 (0.11, 1.61) - area C [k]: 1.30 (0.29, 5.82) Cardiovascular anomalies: - area B [i]: 0.94 (0.27, 3.31)	Vinceti et al. (2009)

			- area C [i]: 0.58 (0.14, 2.45) - area B [j]: 0.59 (0.14, 2.49	
France	Case-control study	Association between the risk of urinary tract birth defects and living near MSW incinerators, using a model to predict the exposure to dioxins	*Risk of urinary tract birth defects, in terms of OR (with 95% CI), for not exposed group versus exposed above the median:* - considering atmospheric dioxins: 2.84 (1.32, 6.09) [h] - considering dioxin deposits: 2.95 (1.47, 5.92) [h] - considering metals: 0.73 (0.45, 1.19) - considering consumption of local food and dioxin deposits: 1.88 (0.55, 6.35)	Cordier et al. (2010)
Cardiovascular diseases				
Italy	Cohort study (retrospective)	Health outcomes among people living close to incinerators (using a dispersion model for exposure assessment)	*Associations between heavy metals concentration and hospitalization for specific causes in the highest exposed group using the lowest exposure category as the reference (Rate Ratio (RR) and 95% CI):* - acute myocardic infarction (men): 0.81 (0.51, 1.28) - acute myocardic infarction (women): 1.40 (0.66, 2.98) - chronic heart failure (men): 0.78 (0.46, 1.33) - chronic heart failure (women): 1.48 (0.90, 2.46)	Ranzi et al. (2011)
Respiratory conditions				
Italy	Cohort study (retrospective)	Health outcomes among people living close to incinerators (using a dispersion model for exposure assessment)	*Associations between heavy metals concentration and hospitalization for specific causes in the highest exposed group using the lowest exposure category as the reference (Rate Ratio (RR) and 95% CI):* - chronic obstructive pulmonary disease (men): 1.43 (0.89, 2.31) - chronic obstructive pulmonary disease (women): 0.63 (0.35, 1.14) - acute respiratory diseases (men): 0.89 (0.63, 1.27) - acute respiratory diseases (women): 1.29 (0.94, 1.78) - asthma (men): 1.16 (0.36, 3.71) - asthma (women): 1.01 (0.40, 2.55)	Ranzi et al. (2011)
Human biomonitoring [l, m, n]				
China	Cross-sectional study	PCDD/F levels in blood and their associated health impacts.	Blood PCDD/Fs levels comparing exposed group with control group: - TEQΣPCDD/Fs: 0.40 vs. 0.28 pg TEQ/g wet weight, $p < 0.05$ [o]	Xu et al. (2019a)

China	Cross-sectional study	Body burden of PCDD/Fs and PCBs in the breast milk of mothers. Estimated daily intake (EDI) level of these pollutants in infants was assessed.	PCDD/Fs and PCBs levels in breast milk comparing exposed and control groups: - TEQΣ(PCDD/Fs + DL-PCBs): 0.28 vs. 0.16 pg TEQ/g wet weight, $p < 0.05$ [p] *Mean EDI level in infants comparing exposed and control groups:* 22.0 vs. 13.0 pg TEQ/kg bw day, $p < 0.05$ [p]	Xu et al. (2019b)
Spain	Cohort study (perspective)	To monitor PCDD/Fs and PCBs levels in blood samples in the different exposed groups.	Concentrations of PCDD/Fs, expressed as pg TEQ/g fat in whole blood samples in exposed/non-exposed (Matarò)/non-exposed (Arenys de Mar): - 1995: 13.0/13.1/Not Measured (NM) - 1997: 15.9/16.4/NM - 1999: 17.8/18.1/18.7 - 2002: 15.1/18.2/16.0 - 2005: 11.7/12.3/17.9 - 2008: 14.6/12.6/14.5 - 2012: 12.9/13.3/12.5	Parera et al., 2013

[a] The authors indicated the level of significance only when p-value was lower than 0.05.

[b] period 2003-2010

[c] p<0.05. Test conducted by the authors for trend across categories of exposure to incinerator emissions

[d] period 2007-2010

[e] The authors reported a p-value of 0.042, for testing the trend of groups 1 and 5 (the highest versus the lowest quintile). It can be noted a significant trend for increases in spontaneous abortions with greater PM exposure.

[f] Per doubling of PM_{10}

[g] Proximity to the nearest MWI, calculated as a continuous measure of linear distance (km)

[h] p<0.05. Estimated in our systematic review on the basis of 95% Confidence Interval

[i] Entire study period

[j] Operation period: from December 1 1998 to October 31 2002 and from April 1 2006 to December 31 2006

[k] Shut-down period: from February 1 2003 to December 31 2005

[l] In terms of dioxins, whose long-term exposure increases the risk of cancer and other negative health outcomes including reproductive, developmental and neurodevelopmental effects (IARC, 2012; WHO, 2019c).

[m] Values expressed in terms of Toxic Equivalence (TEQ) were assessed. Indeed, TEQs are calculated values that allow to compare the toxicity of different combinations of dioxins and dioxin-like compounds; in order to calculate a TEQ, a toxic equivalent factor (TEF) is assigned to each member of the dioxin and dioxin-like compounds category. TEFs have been established through international agreements and currently range from 1 to 0.0001 (US EPA, 2016b).

[n] EFSA et al. (2018) considered a threshold value in serum of 7.0 pg/g fat. Furthermore they established a Tolerable Weekly Intake (TWI) of 2 pg TEQ/kg bw per week. WHO (2019) indicates a provisional tolerable intake of 70 pg/kg bw per month for PCDDs, PCDFs and coplanar PCBs expressed as TEFs. It has to be noted that although several studies showed a positive association with cancer, there was no clear dose-response relationship between exposure and cancer development (EFSA et al., 2018); at the same time, WHO (2019) noted since dioxins induce tumours and likely other effects via a receptor-mediated mechanism, tolerable intake guidance based on non-cancer end-points observed at lower doses is considered protective for carcinogenicity.

[o] $p < 0.05$. When data fit the normal distribution, two independent sample t-tests were performed by the authors to compare the mean levels of the two groups. Otherwise, the Mann–Whitney U testwas performed.
[p] $p<0.05$. If the data fitted the normal distribution, two independent sample t-tests were performed by the authors to compare the mean levels of the two groups. Otherwise, the non-parametric test was performed.

In Table 20, the effects of residing near dumpsites and open burning areas are summarised. Seven studies met the criteria mentioned above and were included. One study was carried on in Latin America (Brazil), two in North America and four in Africa (Ghana, Nigeria, Sierra Leone, Swaziland). It has to be born in mind that open dumping represents the most common practice in low- and lower-middle-income countries. It is more common in Sub-Saharan Africa (Kaza et al., 2018). As a consequence, the higher number of African studies that were found should not surprise. Three were retrospective cohort studies and four cross-sectional studies.

The evidence of adverse health effects from the exposure was mixed. Still, it appears clear that the health risks associated with dumpsites should be higher, considering the lower protection level that such sites offer if compared with landfill and incinerators. However, the results show some evidence of increased risk. In particular, residing near dumpsites resulted associated with an increased risk of adverse birth or neonatal outcomes in terms of low birth weight (Gilbreath and Kass, 2006a). In any case, most studies found no evidence of adverse health effects, including cancer (Gouevenia and Prado, 2010) and congenital malformations (Gilbreath and Kass, 2006b). All the studies that analysed infectious and vector-borne diseases were found in Africa and they were cross-sectional (Abul, 2010; Babs-Shomoye and Kabir (2016); Sankoh et al., 2013; Suleman et al., 2015). Considering gastroenteritis, the results were mixed and not statistically significant. The same four studies reported on gastroenteritis also reported malaria, and the evidence suggested that there might be an increased risk of malaria for nearby residents. However, none of these results was statistically significant.

Table 20: Health outcomes associated with dumpsites and open burning - Study Characteristics

Study location	**Study design**	**Outcomes investigated**	**Main findings**	**References**
Cancer				
Brazil	Cohort study (retrospective)	To evaluate the association between living close to a solid waste landfill and occurrences of cancer and congenital malformations.	*Standardized mortality ratios (SMRs) for areas of 2 km around the solid waste landfill sites (95% CI):* - bladder cancer: 0.98 (0.79, 1.21) - liver cancer: 1.00 (0.86, 1.16) - leukaemia in adults: 0.92 (0.77, 1.10) - leukaemia in children: 0.84 (0.54, 1.31)	Goueveia and do Prado, 2010
Adverse birth and neonatal outcomes				
Alaska	Cohort study (retrospective)	To evaluate adverse birth outcomes (low and very low birth	*Adjusted odds ratios (95% CI) describing the relations between low and high hazard*	Gilbreath and Kass (2006a)

		weight, preterm birth, and intrauterine growth restriction (IUGR)) in infants born close to dumpsites	*exposure categories and incidence of low and very low birth weight, preterm birth, and intrauterine growth retardation:* - low birth weight: 2.06 (1.28, 3.32), $p<0.05$ [a] - low birth weight adjusted for gestation: 2.20 (1.26, 3.85), $p<0.05$ [a] - very low birth weight: 1.17 (0.37, 3.67) - preterm birth: 1.24 (0.89, 1.74) - intrauterine growth retardation: 3.98 (1.93, 8.21), $p<0.05$ [a]	
Alaska	Cohort study (retrospective)	To evaluate the rates of adverse pregnancy outcomes as foetal death, neonatal death, congenital anomalies, close to dumpsites	*Adjusted rate ratios (95% CI) describing the relationships between lower and higher hazard exposure categories and incidence of foetal and neonatal death and congenital anomalies:* - all deaths: 0.65 (0.34, 1.27) - foetal deaths: 0.75 (0.28, 1.99) - neonatal deaths: 0.55 (0.22, 1.38) - all congenital anomalies (CA), (listed separately in the categories below): 1.37 (0.92, 2.04) - central nervous system CA: 2.36 (0.37, 14.71) - circulatory/respiratory CA: 1.42 (0.39, 5.42) - gastrointestinal CA: 0.58 (0.14, 2.40) - urogenital CA: 2.71 (0.67, 10.95) - musculoskeletal/integumental CA: 1.61 (0.79, 3.29) - others CA: 1.38 (0.77, 2.39) - multiple CA: 1.33 (0.34, 5.20)	Gilbreath and Kass (2006b)
Brazil	Cohort study (restrospective)	To evaluate the association between living close to a solid waste landfill and occurrences of cancer and congenital	*Standardized mortality ratios (SMRs) for areas of 2 km around the solid waste landfill sites (95% CI):* - congenital malformation: 0.86 (0.72, 1.03)	Goueveia and do Prado (2010)

		malformations.		
Gastroenteritis				
Swaziland	Cross-sectional study	To determine the health effects of a dumpsite on the surrounding human settlement	*Diseases which affected residents:* - diarrhoea: 16% of closer residents vs. 5% of further away residents *Reasons for hospitalization among the interviewed:* - diarrhoea: 16% of closer residents vs. 26% of further away residents - cholera: 12% of closer residents vs. 0% of further away residents	Abul (2010)
Ghana	Cross-sectional study	To determine the health effects of dumpsites on the surrounding human population	*Diseases which affected residents:* - cholera: (a) 67%; (b) 33%; (c) 0% (out of a total of 6 people affected) - typhoid fever: (a) 75%; (b) 25%; (c) 0% (out of a total of 12 people affected) Where (a), (b), (c) refer to distances between people and disposal sites (i.e. less than 5 minutes; 5-10 minutes; 11-15 minutes respectively).	Suleman et al. (2015)
Sierra Leone	Cross-sectional study	To determine the health effects of a dumpsite on the surrounding human population	*Diseases which affected residents:* - diarrhoea: about 10% of closer residents vs. about 12% of further away residents - cholera: about 11% of closer residents vs. about 15% of further away residents	Sankoh et al. (2013)
Nigeria	Cross-sectional study	To determine the health effects of a dumpsite on the surrounding human population	*Diseases which affected residents[b]:* - cholera and diarrhoea: 10 closer households vs 5 further away households reported 1-2 cases; 0 closer households vs 0 further away households reported 3-4 cases; 0 closer households vs 0 further away households reported at least 5 cases.	Babs-Shomoye and Kabir (2016)
Vector-borne diseases				

Swaziland	Cross-sectional study	To determine the health effects of a dumpsite on the surrounding human population	*Diseases which affected residents:* - malaria: 36% of closer residents vs. 13% of further away residents *Reasons for hospitalization among the interviewed:* - malaria: 44% of closer residents vs. 18% of further away residents	Abul (2010)
Ghana	Cross-sectional study	To determine the health effects of dumpsites on the surrounding human population	*Diseases which affected residents:* - malaria: (a) 73%; (b) 25%; (c) 2% (out of a total of 103 people affected) Where (a), (b), (c) refer to distances between people and disposal sites (i.e. less than 5 minutes; 5-10 minutes; 11-15 minutes respectively).	Suleman et al. (2015)
Sierra Leone	Cross-sectional study	To determine the health effects of a dumpsite on the surrounding human population	*Diseases which affected residents:* - malaria: about 40% of closer residents vs. about 35% of further away residents	Sankoh et al. (2013)
Nigeria	Cross-sectional study	To determine the health effects of a dumpsite on the surrounding human population	*Diseases which affected residents* [b]*:* - malaria: 20 closer households vs 24 further away households reported 1-2 cases; 4 closer households vs 8 further away households reported 3-4 cases; 0 closer households vs 1 further away households reported at least 5 cases.	Babs-Shomoye and Kabir (2016)

[a] $p<0.05$. The authors indicated the p-value when it was lower than 0.05

[b] The authors categorized counts of reported cases into groups for each health outcome and then used a chi-square test to test for differences. No significant differences were found

Summarising, there is a general lack of evidence, with no studies for specific exposures and outcomes. It is particularly true in mental health and social health conditions and biomonitoring, and for most health outcomes associated with dumpsites and open burning. Only in the case of adverse birth and neonatal outcomes at least one study from each type of exposure was found. The results are mixed. There was evidence to suggest an increased risk of adverse birth and neonatal outcomes for all kinds of MSW sites. Still, there was either a lack of evidence for one or more MSW site type and varied evidence of health effects for different MSW sites. There was also some evidence of health outcomes for landfills and incinerators compared to dumpsites or open burning areas, but this can be due to the higher number of studies related to landfills and incinerators and the lower quality of research related to dumpsites. Indeed most of the studies about dumpsites were cross-sectional.

In future, in addition to epidemiological studies, more biomonitoring research should be conducted. Indeed, focusing on the burning of solid waste (both in incinerators and through uncontrolled open burning) most general population exposure to dioxins is through ingestion of contaminated foods of animal origin, as noted by WHO (2019). Approximately 90% of the total exposure is via fats in fish, meat and dairy products (FAO and WHO, 2018). In general, the concentration of dioxins in the air is shallow, except close to sources such as inefficient incinerators or waste open burning areas. But the continuous release in the air ends up contaminating soil and aquatic sediments. It can lead to bioaccumulation and bioconcentration through food chains (WHO, 2019c). As aforementioned, it is essential to highlight that dioxins decompose very slowly in the environment, remaining in it for very long periods (FAO and WHO, 2018). Thus, the biomonitoring of dioxins and other dangerous persistent pollutants in farm animals and their derivatives would be very useful. In particular nearby incinerators and waste open burning areas. Some valuable works in this field already exist, and it can be taken as a reference for further research. For example, Cordier et al. (2010) analysed the association between local food consumption, dioxin deposits generated by MSW incinerators and risk of urinary tract congenital birth disabilities. And more recently, Xu et al. (2019a) analysed contamination in eggs close to an incinerator in China. The biomonitoring studies should also be extended to other waste practices, as recently done by Scaramozzino et al. (2019). The authors conducted the first proposal for a standardised protocol for farm animal biomonitoring useful for both environmental risk assessment and human exposure preliminary assessment. Scaramozzino et al. (2019) measured the concentration in milk and eggs of contaminants nearby three potential sources of contamination in Italy, i.e. a landfill, a waste incinerator, and a secondary aluminium smelter.

It is also important to note that none of the 29 studies identified investigated the health effects associated with transfer stations, recycling centres, composting plants, and anaerobic digesters. It is probably the literature's major gap since transfer and treatment facilities are widespread and could pose health risks, including exposure to toxins, particulate or infectious agents via direct or indirect contact. Consequently, future research must also address this gap.

4.2 The health risk assessment matrices

As aforementioned, from this section, the MSWSP is addressed. As noted, to rank the hazards can be essential to establish priorities and most appropriate control measures. Therefore, making good quality health risk matrices is fundamental. Semi-quantitative health risk assessment matrices were made, considering the heterogeneity of the possible hazards and hazardous events. The matrices are discussed hereafter. As previously noted, although the case studies in Serbia and Ghana have common elements related to solid waste management practices and possible risks, there are also significant differences.

As anticipated, a vital element for the successful implementation of the MSWSP is formal commitment and adoption by one or more local stakeholders. Besides, assembling a team with the necessary skills is crucial to develop well-pondered matrices.

The current work represents a first step on the way of MSWSP, which does not exist yet. That is the main reason to explain why the initial push did not come from local authorities or other stakeholders for both the case studies. The pandemic contributes to making more difficult contacts and expressions of interest by potential beneficiaries.

As aforementioned, semi-quantitative health risk assessment matrices took inspiration from both the SSP and the WSP. In particular, with a semi-quantitative health risk assessment approach, the team can calculate a priority score for each hazard, and there are several approaches to ranking risk. The scale used and the risk definitions conceived for the matrices of this thesis are available in Tables 3 and 4 (Chapter 2). Such desciptions are the results of exchanging opinions and points of view with the MSWSP teamì. Furthermore, the weight to give in terms of likelihood and severity to the hazardous events was derived from the technical knowledge and expertise of all the team members and literature data from similar contexts and relevant guidelines.

When assessing the severity of the hazardous events, the contents and concentration of pollutants in the waste and the magnitude of associated health outcomes should be considered (WHO, 2015). However, the team may choose to develop its definitions for likelihood and severity. They should consider aspects related to the potential health impact, regulatory elements, and effects on community perceptions (WHO, 2015).

When direct data from the case studies were available, they were used to weigh the risk and fill the health assessment matrices in terms of concentration of pollutants in the environment (soil, water, air, biota). Indeed, the best scenario is when quantitative data about the level of pollution in the local context exist. They can be compared with legislation and scientific knowledge about the adverse health effects on humans. Unfortunately, remote areas in developing countries are often characterized by a lack of such information (Tilt, 2018), as witnessed among the rural villages in Ghana. Furthermore, the impossibility of carrying out a second field mission was not allowed. In Serbia, although no field missions were conducted, more quantitative information was available. Furthermore, useful data from similar contexts were searched in the scientific literature, and a conservative approach was used.

In general, when a specific activity was not performed in a particular location, a related risk assessment was not conducted. While if it was not possible to assert the presence, likelihood and/or severity of a specific activity, it was included in the matrix but with the acronym NA (Not Available).

Then, control measures will be discussed in section 4.5 for those events whose risk level resulted in high or very high

4.2.1 The case study in Novi Sad (Serbia)

Regarding the case study in Novi Sad, after the phase of data collection, it was necessary to understand the SWM situation in Novi Sad. It was decided to focus only on the municipal landfill of Novi Sad.

A series of reasons led to this choice. First of all, much more detailed information was available concerning the landfill. Furthermore, the landfill is more similar to a dumpsite, determining many potential environmental and health risks. The size of the landfill, and the environmental factors surrounding the area contribute to giving priority to the site.

As anticipated, in compiling the health risk assessment matrix related to the case study in Serbia, when it was not possible to assert the presence, likelihood, and/or severity of a specific hazardous event, it was included in the matrix the acronym NA (Not Available).

Table 21 shows the risk assessment matrix related to the municipal landfill of Novi Sad. Then, each event and its level of risk are discussed.

Table 21: Disposal of solid waste in the municipal landfill of Novi Sad – risk assessment matrix

Hazardous event	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk Level**[a]
Leaking of leachate in groundwater	Groundwater contamination (and human consumption)	3	16	48	**VH**
Spread of leachate in surface water	Contamination of surface water (and human use)	2	2	4	L
Waste combustion	Inhalation, ingestion and/or dermal contact with contaminants by inhabitants	2	16	32	**H**
Waste combustion	Inhalation, ingestion and/or dermal contact with contaminants formal by waste workers	NA	NA		
Waste combustion	Injuries (including burning injuries) by formal waste workers	2	16	32	**H**
Waste combustion	Inhalation, ingestion and/or dermal contact with contaminants by informal waste workers	NA	NA		
Waste combustion	Injuries (including burning injuries) by informal waste workers	NA	NA		
Free movement of farm animals in the landfill	Ingestion of contaminants by inhabitants (through the food	NA	NA		

	chain)				
Movement of formal waste workers in the landfill	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA		
Movement of formal waste workers in the landfill	Injuries	NA	NA		
Movement of informal waste workers in the landfill	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA		
Movement of informal waste workers in the landfill	Injuries	NA	NA		
Feed for rodents and other animals (including insects)	Spread of infectious and vector-borne diseases	3	4	12	M
Spread of contaminants in the air (excluding waste combustion)	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	**H**
Spread of contaminants into the soil (excluding waste combustion)	Inhalation, ingestion and/or dermal contact with contaminants	1	8	8	M

[a] Risk Level: L (Low), M (Medium), H (High), VH (Very High)

Regarding the event "**leaking of leachate in groundwater**" associated to the hazard "**groundwater contamination (and human consumption)**", it refers to leachate that can reach groundwater, if it is not adequately managed, with a potentially significant health risk to consumers. The information collected allowed to define the event, in terms of likelihood, as possible, following a conservative approach. The risk refers to people living in the closest zone and in the direction of the groundwater flow (i.e., from north to south). Indeed, although it seems that the population from the closest zones to the landfill is partially aware of the contamination of the first aquifer and the related risks in case of human consumption, many people own wells, and there are no official restrictions in terms of use of groundwater. At maximum people have to ask for permission to the local administration to built a well. Still, there are no official administrative indications aimed at limiting the aquifer's use for safety reasons. As previously discussed, much quantitative information related to leachate flow and physicochemical characteristics in the Novi Sad landfill was collected. The statement highlighted a leachate flow towards the underlying aquifer. As anticipated, the Novi Sad landfill has much in common with dumpsites. Indeed, there is no waterproof layer at the bottom; neither leachate treatment is conceived. It is also interesting to note that concentration of pollutants in leachate from the landfill's peripheral canals was of the same order of magnitude of the concentration of the same substances in the groundwater located under the landfill (Djogo et al., 2017). Although data about physiochemical characteristics in the groundwater in the landfill correspondence are available, unfortunately, the parameters measured were not very useful in conducting a health risk assessment.

However, the concentration of three inorganic compounds measured by Djogo et al. (2017) in the groundwater below the Novi Sad municipal landfill was studied. The compounds were taken as indicators because they overstepped the Serbian hygienic drinking water standards (Serbian Official Gazette, 2019). The compounds considered were B, Mg, K, because they were above the Serbian limits for drinking water. The flow and the decrease in the concentration of these contaminants were studied up to 600 m away from the contamination source (i.e., the landfill of Novi Sad). The objective was to understand if the concentration of the chemicals would be above the national legislation limits for drinking water at the point of exposure. With a conservative approach, the following boundary conditions were considered, similarly to as already done in Vaccari et al. (2018):

- Diffusion and dispersion phenomena but not degradation of contaminants.
- Continuous release of leachate from the landfill toward the groundwater.
- Homogeneous aquifer properties.
- One dimensional groundwater flow.

The available data did not allow the accurate calculation of the aquifer's thickness involved in the contamination below the landfill. However, considering the absence of a waterproof layer at the bottom, the proximity of the water table with the bottom of the landfill, and the groundwater thickness (i.e. 30-35 m), it was followed a conservative approach. Therefore, it was assumed that, below the landfill, the aquifer's entire thickness was affected by contamination. Besides, this is in line with the results of a previous study we conducted related to the risk posed by leaching of leachate to groundwater from dumpsites in developing countries ((Vaccari et al., 2018). As a consequence, the equation for Dilution Attenuation Factor (DAF) was (APAT, 2008):

$$\frac{1}{DAF} = \exp\left[\frac{x}{2\alpha_x} \times \left(1 - \sqrt{1 + \frac{4\lambda_i \alpha_i R_i}{v_e}}\right)\right] \times \left[erf\left(\frac{S_w}{4\sqrt{\alpha_y x}}\right)\right]$$

Where:

- DAF: Dilution Attenuation Factor.
- x: the distance between the source of release and the point of exposure = 600 m.
- α_x = longitudinal dispersivity (calculated as α_x = 0.1 x) (m).
- α_y = transverse dispersivity (calculated as α_y = 0.33 α_x) (m).
- λ = first order degradation rate constant (1/d).
- R_t = time delay coefficient (-).

- v_e = pore velocity (m/s).
- S_W = source width perpendicular to groundwater flow direction (m) = 800 m.

Furthermore, the absence of specific laboratory or field tests to assess the site-specific biodegradation situation is frequent. In such cases, λ can be conservatively assumed equal to 0 (APAT, 2008).

The following equation has to be used to obtain the concentration of contaminants at the point of exposure:

$$C_X = C_0/DAF$$

Where:

- C_X = concentration of the contaminant at the point of exposure considered.
- C_0 = initial concentration of the pollutant in the groundwater.

However, DAF resulted in 1.01, highlighting that, with the conservative approach aforementioned, at 600 m from the source of release, the contaminants' dilution would be almost negligible. Consequently, the groundwater quality of the first aquifer would be below the Serbian drinking water standards taken as a reference (Serbian Official Gazette, 2019).

Besides, a similar approach was followed to evaluate the health risks related to some contaminants. As anticipated, unfortunately, the groundwater parameters (Djogo et al., 2017) were not very useful in conducting a health risk assessment. As a consequence, in the absence of specific indicator contaminants that can be used for this purpose, with a conservative approach, a recent review on characteristics of leachate from landfills and dumpsites (Vaccari et al., 2019a) was taken as a reference, and the average leachate concentration was assumed as the same of the groundwater. In particular, the concentration of Cd, Cr and Pb were considered. Although when the leachate flux reaches and mixes with the underlying aquifer contaminants present in the leachate are at least a bit diluted (Vaccari et al., 2018), following a conservative approach the dilution was not considered, mainly for two reasons:

- The distance between the bottom of the landfill and the aquifer's water table is minimal, and at some point, it seems there is no distance at all.
- As aforementioned, the concentration of the chemicals measured in the peripheral channels around the landfill was of the same order of magnitude measured in the groundwater below the landfill (Djogo et al., 2017).

The average concentration of Cd, Cr and Pb was taken into account, both in landfills and dumpsites from the review mentioned before (Vaccari et al., 2019a) and always resulted above the WHO (2017) guidelines for drinking water quality, even more than an order of magnitude. It is important to note that the adverse health outcomes of Cd, Cr and Pb include neurodevelopmental effects and adverse birth outcomes (WHO, 2017a).

Consequently, the severity was assumed as catastrophic, leading to a very high level of risk. However, even a major severity (that is of a lower level) would have led to a high risk level. In both the cases, control measures should be conceived. Control measures will be discussed next, in section 4.5 and, in addition to capital works, also operational interventions and behavioural measures will be proposed.

The event **"spread of leachate in surface water"** and the related hazard **"contamination of surface water (and human use)"** were considered taking into account the Danube River, which is about 5 km south from the landfill. As previously discussed, a system of non-waterproof channels surrounds the landfill and data about water quality in the vicinity of the landfill are available (see Chapter 3). However, the use of water from the channels for human purposes appears "unlikely", stating that for the collect ed information people in the surrounding area typically do not use such water. Consequently, the primary contact with leachate from the channels can happen where the water reaches the Danube River. Indeed, people swim and fish in the Danube. However, the incidence of the pollution of the Danube River due to leachate is reduced by many factors:

- Channels are not waterproof; as a consequence, a portion of leachate leaches into the ground.
- The flow across the channels is more substantial during rainy days. But rain contributes to the dilution of pollutants, increasing the amount of clean water and the concentration of contaminants decrease in space and time (Parsaie and Haghiabi, 2017).
- As previously discussed, wastewater from households and factories of Novi Sad is discharged in the Danube River without any treatment. As a consequence, wastewater from home and factories has a higher incidence in terms of health risk for the human population that use the Danube River.

The hazardous event **"waste combustion"** was included, considering the phenomena of self-combustion in the landfill, as mentioned before. In this case, **six different hazards** were initially analysed:

- Inhalation, ingestion and/or dermal contact with contaminants by inhabitants.
- Injuries (including burning injuries) by inhabitants.
- Inhalation, ingestion and/or dermal contact with contaminants by formal waste workers.
- Injuries (including burning injuries) by formal waste workers.
- Inhalation, ingestion and/or dermal contact with contaminants by informal waste workers.
- Injuries (including burning injuries) by informal waste workers.

However, injuries by inhabitants were removed, taking into account the distance from houses and buildings was excessive, and no previous fires that reached the residences have been documented.

As previously discussed, big fires affect the landfill at least once per year, but small fires are almost continuous. Both the categories are mainly due to the biogas production in the landfill, which is not collected and adequately treated, making the combustion phenomena easier. Fire is one of the more severe risks that a landfill faces through its life (ISWA, 2019). Fires are common at dumpsites, but relatively infrequent at well-managed landfills.

Although it was impossible to conduct any field visit and pose direct questions to waste workers, risks related to waste burning in terms of injuries and damage were scored as high, with a conservative approach. Indeed, the big fires can cause loss of life among waste workers (i.e., catastrophic in terms of severity), but they represent unlikely events. Furthermore, as noted by Tot et al. (2019) analysing landfills' status in Serbia and the risks of injuries and damaged for waste workers, some fires might be characterised by a shallow collapse, where operators of heavy machinery (i.e., compactors and bulldozers) may fall.

As can be noted in the matrix, the event "inhalation, ingestion and/or dermal contact with contaminants by waste workers" was not calculated. Indeed, although it is possible that in the landfill of Novi Sad such risks for waste workers are relevant, more detailed data were necessary. A field mission was initially scheduled, also having the objective to pose some direct questions to waste workers, but the pandemic made it impossible. It is worth to mention that Covid-19 is an infectious disease very contagious, and to meet many people in areas affected by the pandemic was not recommended (WHO, 2020).

Furthermore, the risk associated with informal waste workers was not evaluated. Although it seems that some waste pickers are still going to the landfill, to take precious materials, it was not possible to make the questions initially conceived for those who frequent the landfill (i.e., formal and informal waste workers). It was not possible to collect information through some field surveys as well. As aforementioned, the pandemic hindered this activity. The result was considered too misleading due to the limited information currently available, and it was defined as Not Available (NA).

For the hazard **"inhalation, ingestion and/or dermal contact with contaminants by inhabitants"** related to the event **"(uncontrolled) waste combustion"**, detailed information about the concentration of pollutants in the air during open burning in Novi Sad are not available. Furthermore, epidemiological studies related to such a practice have been found, neither in Novi Sad nor elsewhere. It is probably because the open burning of waste is more common in developing countries or in contexts where collecting detailed information is not easy. It is perhaps also due to the illicit nature that often characterizes such a practice. However, studies about the concentration of pollutants generated during open burning of MSW have been conducted in the last years. Such research highlighted the elevated concentration of POPs (such as dioxins) and other toxic and carcinogenic compounds (Estrellan and Iino, 2010; Zhang et a., 2011). Furthermore, the level of pollutants in smokes from incineration plants is well known, and many epidemiological and human biomonitoring studies have been conducted (Candela et al., 2013; 2015; Ghosh et al., 2019; Parkes et al., 2020; Xu et al., 2019a; 2019b). As a consequence, it was assumed that:

- The pollutants flow related to the big fires from the landfill of Novi Sad is not constant but last at least two days per year.
- Compounds that can bioaccumulate are spread as well.
- There is no treatment of smokes, and the flow would be in any case higher than that from the incinerators of the studies aforementioned.

As a result, a significant risk was assigned. Indeed, with a precautionary approach, for people who live closest to the landfill the event was considered unlikely (i.e., if the current local context makes it possible at least once per year) but catastrophic (indeed it can be associated with cancer and birth defects).

The event **"free movement of farm animals in the landfill"** and the hazard **"ingestion of contaminants by inhabitants (through the food chain)"** were not evaluated because of the lack of data. Indeed, farm animals had been seen in the past. But in the last years, the realization of a fence around the landfill should have hindered their presence. At the same time, some photographs received showed a couple of cows in the landfill. However, it was not possible to establish the pictures' year, and it was not possible to interview enough waste workers about it. As a result, information about the event was considered Not Available (NA).

The event **“free movement of inhabitants in the landfill”** and the following related hazards were not considered:

- Inhalation, ingestion and/or dermal contact with contaminants.
- Injuries.

Indeed, the information collected allowed to exclude the presence of inhabitants in the landfill. Unfortunately, it was impossible to evaluate the risks related to “movement of workers in the landfill” both for formal and informal waste workers. Although it seems likely there are risks for legal waste workers, more detailed information, questionnaires and field visits would be necessary. The pandemic hindered such a survey. About informal waste workers (such as waste pickers), the risk related to their activities are common to their category. Still, it is not clear the frequency, and the kind of activities informal waste workers conduct in the landfill. It initially seemed that none of them frequented the landfill, but some photographs raised doubts about such an assumption. Also, in this case, more detailed information, questionnaires, and field visits would be necessary. As a result, information about these events was considered Not Available (NA).

A further event was “feed for rodents and other animals (including insects)”, and it was associated with the hazard “spread of infectious and vector-borne diseases”. As discussed in Chapter 1, inadequate solid waste accumulation is often assumed as a risk factor for infectious and vector-borne diseases because it may provide breeding and feeding sites for animals and insects (Krystosik et al., 2020). It is necessary to consider that, except for the supermarket and some factories that are about 300 m from the landfill (see Figure 9, section 3.3.5), both the legal and illegal houses are at least 600 m from the site. The constraints due to the pandemic hindered questionnaires among the area residents, which were initially conceived to understand the most common infectious diseases in the territory. However, some cross-sectional studies can be taken as a reference to evaluate this risk. In particular, Abul, (2010), Babs-Shomoye and Kabir (2016) and Suleman et al. (2015) reported a higher incidence of gastroenteritis in people living closer to dumpsites. The threshold distance between one group and another were 200 m in Abul (2010) and 250 m in Babs-Shomoye and Kabir (2016). Suleman et al. (2015) compared the distance in terms of time necessary to reach the dumpsite; consequently, the linear distance was not well defined. In Novi Sad, using a precautionary approach, the risk for people living close to the landfill was assumed as moderate (e.g. acute illness such as diarrhoea) and possible (i.e., the current local context makes the event possible at least once per month). It resulted in a medium level of risk.

The hazardous event **“spread of contaminants in the air (excluding waste burning)”** and the hazard **“inhalation, ingestion and/or dermal contact with contaminants”** were considered as well. The paper of Petrovic et al. (2018) was taken into account. As previously discussed, the authors measured air concentration of organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs) in the landfill of Novi Sad. Then, they conducted a health risk assessment using the methodology suggested by US EPA, founding no risks associated with these pollutants in the landfill (Petrovic et al., 2018). However, only the gaseous phase was analysed, while the particulate matter was not considered, leading to a possible underestimate of the overall risk. Simultaneously, people living in illegal houses north of the landfill complain about bad smell from the landfill; and also in Klisa suburb people are affected by bad smells (Stojanović, 2017). As a result, the risk was analysed for residents living in the two areas, taking into account some epidemiological studies as well. In particular, in a cohort study, Mataloni et al. (2016) found a higher incidence of all respiratory diseases and acute respiratory infections in young people under the age of 15 living close to sanitary landfills. Furthermore, analysing people living within 1.2 km from a landfill, in a cross-sectional study, Heaney et al. (2011) found mucosal irritation and upper respiratory issues as symptoms associated with odour. As a consequence, with a precautionary approach, the risks for residents in Klisa suburb and in the illegal houses north of the landfill, both about 600 m from the sites, was assumed as moderate in terms of severity (i.e., event potentially resulting in moderate temporary health effects, such as upper respiratory illness) and likely in terms of likelihood (i.e., the current local context makes it possible at least once per week). The risk resulted as high.

The last event considered was **"spread of contaminants into the soil (excluding waste burning)"**, and it was associated with **"inhalation, ingestion and/or dermal contact with contaminants"**. In this case, taking into account the absence of any geomembrane or layer to avoid direct contact of solid waste with soil, the whole ground in which the landfill is placed is undoubtedly contaminated by pollutants. At the same time, the collected information showed that it could be assumed residents usually do not go into the landfill. Furthermore, soil and waste from the landfill are not used for other purposes (such as compost). Indeed, if the landfill's contaminated soil would be used in agriculture, it could favour the spread of contaminants through the food chain. In that case, also dermal contact and inhalation of contaminants by farmers should be taken into account. Fortunately, it was not the case. Consequently, the risk was assumed as very unlikely in terms of likelihood, and major in terms of severity. The overall result led to a medium level of risk.

4.2.2 The case study in Ghana: nine rural villages in the Savannah ecological zone

As previously discussed, the case study in Ghana was very different compared with that in Serbia. As a consequence, for the health risk assessment matrix, four SWM practices were considered. Furthermore, in Ghana, nine rural villages were assessed. The four matrices below (Tables 22-25) summarises the risks in each village in the function of the following SWM practices analysed:

- Disposal of solid waste in dumpsites.
- Open burning of waste.
- Uncontrolled burying of solid waste.
- Reuse of solid waste from dumpsites as compost by local farmers.

As can be noted, the scores in terms of likelihood, severity and risk were not included in the matrices, to avoid huge tables with an excessive amount of information. Only the level of risk was included in each matrix. However, the complete nine health risk assessment matrices, specific for each village, are available in Annex 3.

As done in the previous case study, a risk assessment was not conducted if a specific activity not occurred in a particular community. When it was not possible to state about the presence, likelihood and/or severity of a specific activity, it was included in the health risk assessment matrix using the acronym NA (Not Available).

Table 22: Disposal of solid waste in dumpsites – risk assessment matrix

Hazardous event	**Hazard**	**Risk level [a] in each village**								
		#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**
Leaking of leachate into groundwater	Groundwater contamination	M	-	M	NA	M	M	M	NA	M
Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	**H**	-	**H**	**H**	**H**	**H**	**H**	**H**	M
Free movement of people in the dumpsite	Injuries	M	-	M	M	M	M	M	M	M
Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA	-	NA	NA	NA	NA	NA	NA	NA
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	**VH**	-	**VH**	**H**	**VH**	**H**	**VH**	**H**	**H**
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	**H**	-	M	M	M	M	M	M	M
Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	M	-	M	M	M	M	M	M	M

[a] Risk Level: L (Low), M (Medium), H (High), VH (Very High)

Table 23: Open burning of waste - risk assessment matrix

Hazardous event	**Hazard**	**Risk level [a] in each village**								
		#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**	**#9**
Leaking of leachate into groundwater	Groundwater contamination	L	L	L	NA	L	L	L	NA	L
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	**VH**	**VH**	**VH**	**VH**	**VH**	**VH**	**VH**	**VH**	**VH**
Proximity to open fires	Injuries (including burning injuries)	M	M	M	M	M	M	M	M	M

[a] Risk Level: L (Low), M (Medium), H (High), VH (Very High)

Table 24: Uncontrolled burying of solid waste - risk assessment matrix

Hazardous event	Hazard	Risk level [a] in each village								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Leaking of leachate into groundwater	Groundwater contamination	NA	NA	NA	NA	-	M	M	NA	M
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA	NA	NA	NA	-	**VH**	**VH**	NA	**VH**
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	-	M	M	NA	M
Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	-	M	M	NA	M

[a] Risk Level: L (Low), M (Medium), H (High), VH (Very High)

Table 25: Reuse of solid waste from dumpsites as compost by local farmers - risk assessment matrix

Hazardous event	Hazard	Risk level [a] in each village								
		#1	#2	#3	#4	#5	#6	#7	#8	#9
Leaking of leachate into groundwater	Groundwater contamination	NA	NA	NA	NA	M	NA	NA	NA	NA
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA	NA	NA	NA	NA	NA	NA	NA	NA
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	M	NA	NA	NA	NA
Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	**H**	NA	NA	NA	NA

[a] Risk Level: L (Low), M (Medium), H (High), VH (Very High)

Table 22 analyses the risks related to the SWM practice **"disposal of solid waste in dumpsites".** As already discussed in Chapter 3, dumpsites were noted in all the communities, except for village #2. The hazardous event **"leaking of leachate into groundwater"**, associated with the hazard **"groundwater contamination (and human use)"** reached a medium level of risk in all the villages having dumpsites, except for villages #4 and #8. Indeed, in these two villages, it was not possible to ascertain wells and groundwater, and the event was classified as Not Available. In assigning the scores in the remaining six villages, it was taken into account the low annual rainfall characterizing all the areas, as shown in Table 17 of Chapter 3. Furthermore, Aljaradin and Persson (2013) stated that for the water balance of a landfill for regions where the annual precipitation is less than 400 mm, virtually all rain leaves the system through evapotranspiration. In the areas involved in the study, except for the year 2019, the annual rainfall was in most cases about 400-500 mm. In addition to the almost arid climate of the Savannah zone and the elements aforementioned, the small size characterizing the dumpsites contributed to reducing further leachate generation and leaching. Values from a similar Ghanaian context were taken as a reference to evaluate the severity of the event since it was not possible to measure the concentration of pollutants in groundwater and the soil of the case studies. Indeed, Agyarko et al. (2010) measured the concentration of heavy metals and metalloids in the ground and plants in a dumpsite from a Ghanaian rural village of about 2,400 inhabitants (Ghana Statistical Service, 2014). The authors found concentrations of Cd, Hg, Pb, Fe, Ni, Cu, Zn, Mo, As not at hazardous levels but higher than background samples taken in about 1 km from the dumpsite. As a consequence, considering the dilution and dispersion phenomena, the small generation of leachate in the case study, the low concentration of pollutants but the proximity with open wells used by people, following a precautionary approach, the severity was assumed as moderate, and the likelihood as unlikely, leading to the medium level of risk aforementioned.

The hazardous event **"free movement of people in the dumpsite"** was associated with the two following hazards:

- Inhalation, ingestion and/or dermal contact with contaminants.
- Injuries.

Injuries caused no more than a medium level of risk in all the villages. The likelihood was always assumed as likely, except for village #9, in which it was assumed as possible. The lower value in village #9 was given because of the observations during the field visit and the question posed to inhabitants. However, the generally high frequency of the event was due to the absence of any fence and that children can go freely in the dumpsites and if they stumble they can have some injuries. But the kind of waste that were observed did not result sharp. Indeed, most of the waste was organic and plastic. At the same time, glass and aluminium were few representing valuable materials in a small fraction, making the amount of this waste shallow in the dumpsites of such rural villages.

The level of the risk related to **"inhalation, ingestion and/or dermal contact with contaminants"** resulted high in all the villages with dumpsites, except #9. The severity was assumed as moderate (i.e., acute illness such as diarrhoea or upper respiratory illness) in all the villages. Indeed, the organic fraction of solid waste was observed as the preponderant kind of refuse. It is important to note that during the surveys children were usually observed in such dumpsites. Children played and sometimes used the sites as open defecation areas. As a consequence, the study mentioned above of Agyarko et al. (2010) was taken as a reference to make a simulation of the rate of ingestion of some metals and metalloids (i.e., Cd, Hg, Pb, As) by children. The pollutants were chosen among those that the authors found at higher levels in about 1 km from the dumpsite. In particular, four compounds having toxic or carcinogenic effects by ingestion were analysed. However, it is necessary to highlight that the study was used as a first approximation because the authors measured the concentration of pollutants in a dumpsite soil in a small rural village in Ghana. The following equation was used to estimate the daily assumption rate of contaminated soil by children per kilogram of body weight (APAT, 2008):

$$EM = \frac{IR \times FI \times EF \times ED}{BW \times AT \times 365}$$

Where (APAT, 2008)

- IR = ingestion rate = 200 mg/day.
- FI = soil fraction ingested = 1.
- EF = exposure frequency = 350 d/year.
- ED = exposure duration = 6 year for children.
- 30 year for adults.
- AT = averaging time = ED for non carcinogenic compounds; average value between childhood and adult age for carcinogenic compounds.
- BW = body weight = 15 kg.

The obtained values were multiplied for the concentration of pollutants in the soil. The resulting values, in terms of µg/(kg x time interval) for all the four compounds (i.e., Cd, Hg, Pb, As) were found to be more than an order of magnitude below the tolerable daily (or weekly, or monthly) intake given by WHO (2007; 2019a; 2019b; 2019d). Consequently, the adverse health outcomes related to ingestion of soil with metals and metalloids were not considered. However, as aforementioned (Chapter 3), also faeces were disposed of in dumpsites, and the biological risk was assumed as relevant. Indeed, the survey confirmed that diarrhoea was among the most common diseases in the villages. The frequency was posed as that as the previous event (i.e., likely except for village #9). Indeed, there were no fences, and children could go in the sites without restrictions.

About the event **"free movement of farm animals in the dumpsite"** associated to **"ingestion of contaminants by inhabitants (through the food chain)"** unfortunately it was not possible to assign any level of risk. Many farm animals were observed in the dumpsites. It seems plausible bioaccumulation of POPs in their body can cause adverse health outcomes to people who eat farm animals and their derivatives. However, the related field of research is still novel, and the results are partially discordant. For example, Scaramozzino et al. (2019) made the first proposal for a standardised protocol for farm animal biomonitoring to be used for environmental risk assessment and human exposure preliminary assessment. The authors measured the concentration in milk and eggs of some contaminants, but they did not find a significant difference between a landfill and a control area. Instead, Pius et al. (2020) measured dioxins and furans in soils around a municipal dumpsite in Tanzania. In this case, the authors considered pollutants' levels high enough to accumulate in free-range chickens, causing harmful effects to humans, especially residents nearby. However, the excessive uncertainty led to assess the risk Not Available.

Considering **"feed for rodents and other animals (including insects)"** and the hazard of **"infectious and vector-borne diseases"**, associated with the presence of dumpsites, the risk always resulted high or very high. In all the villages the severity was assumed as major because in Ghana malaria is endemic. It is one of the countries with the highest incidence of malaria globally (Riveron et al., 2016). The surveys confirmed that it was common also in the villages involved in the study. Furthermore, some cross-sectional studies conducted in Africa found a higher incidence of malaria close to dumpsites (Abul, 2010; Sankoh et al., 2013; Suleman et al., 2015). The likelihood was assumed as likely or almost certain, considering the high incidence of this disease.

The event **"spread of contaminants in the air"** associated with the hazard **"inhalation, ingestion and/or dermal contact with contaminants"** always resulted as a medium, except for village #1 which had a high risk. In particular, in the two villages with the smallest dumpsites (i.e., villages #6 and #9) this hazardous event was evaluated as possible. In contrast, in the remaining villages, the hazardous event was evaluated as likely. A severity of minor was assigned in all the cases, taking into account the low level of POPs and other toxic or carcinogenic compounds. But in village #1, following a precautionary approach, a moderate severity was assigned. In assigning this score in village #1, the study of Hoffmeyer et al. (2014) was taken into account. Indeed, the authors found a higher incidence of chronic bronchitis in former compost workers. Even if the study of Hoffmeyer considered composting plants, there are interesting elements in common with the dumpsite of village #1. Indeed, in the dumpsite, the organic fraction represented a high percentage of waste. It was larger than the other dumpsites, and it was close to households, leading to a high level of risk.

The event **"spread of contaminants into the soil"** and the hazard **"inhalation, ingestion and/or dermal contact with contaminants"** can be due to different activities. When people dispose of waste in dumpsites, considering the absence of any geomembrane the waste is in direct contact with the soil, and pollutants can easily contaminate it. And even if the contaminants would not move further, when people touch the ground in the area they can absorb pollutants through dermal contact, ingestion or even inhalation. However, as previously discussed, the daily assumption rate of contaminated soil by children considering the metals and metalloids concentration in the ground given by Agyarko et al. (2010) did not pose a relevant risk. However, with a precautionary approach, the severity was assumed as moderate (e.g. acute illness such as diarrhoea or upper respiratory illness), given the presence of organic waste and faeces. In this case, based on the surveys, the likelihood was assumed as possible. The level of risk resulted as a medium in all the villages with dumpsites.

Table 23 analyses the risks related to the SWM practice "open burning of waste", verified in all the nine villages. Unlike the case study in Serbia, here, waste burning was considered an activity in itself since it is a widespread practice regardless of the presence of landfills. In fact, in several cases during the field missions in Ghana, it was also verified outside the dumpsites. Furthermore, as discussed above, in Serbia, the focus was on a single site.

The event **"leaking of leachate into groundwater"** and the hazard **"groundwater contamination (and human consumption)"** were considered because, after combustion, ashes remain in the soil and during rainy events, or when people use water to put out fires, the liquid can enrich of the contaminants generated and leach into groundwater. This risk was evaluated in all the villages, except for villages #4 and #8. Indeed, in these two villages, it was not possible to verify wells and groundwater. However, considering the low level of precipitation in the area, and the consequent low level of pollutants that can reach the groundwater, the event was assumed as unlikely, and the severity as minor, leading to a low level of risk.

Regarding **“spread of contaminants in the air”** and the hazard **“inhalation, ingestion and/or dermal contact with contaminants”**, the risk always resulted very high. In terms of likelihood, the event was assumed as possible or likely, based on information collected during the surveys. Furthermore, some studies about the concentration of pollutants generated during open burning of MSW have been conducted in the last years, highlighting the elevated concentration of POPs (such as dioxins) and other toxic and carcinogenic compounds (Estrellan and Iino, 2010; Zhang et a., 2011). Furthermore, many epidemiological cohorts (Candela et al., 2013; 2015; Ghosh et al., 2019; Parkes et al., 2020) and human biomonitoring studies (Xu et al., 2019a; 2019b), have been conducted in the last years, focusing on MSW incineration plants. In some cases, evidence of increased risk of adverse health outcomes was found. For instance, Candela et al. (2015) found an increased risk of adverse birth outcomes, and Parkes et al. (2020) found some increased risk of congenital anomalies. As a consequence, the severity was assumed as catastrophic, taking into consideration the following elements:

- Waste burning of waste is a common practice that was conducted close to households.
- Household waste burning can generate carcinogenic or toxic compounds (Estrellan and Iino, 2010), even in MSW from rural settlements (Zhang et al., 2011).
- POPs, such as dioxins and furans, can bioaccumulate through food chains (WHO, 2019c).
- Up to 90% of the total exposure to dioxins is via fats in fish, meat and dairy products (FAO and WHO, 2018).
- People from the villages were mostly farmers who eat local food.
- Unlike incineration plants, in open burning of waste, there is no treatment of the fumes generated.

“Proximity to open fires” associated with the hazard **“injuries (including burning injuries)”** resulted always having a medium risk. The likelihood was always assumed as possible (i.e., the current local context made it possible at least once per month), based on the surveys conducted in all the villages. The severity was evaluated as moderate, because it generally resulted in small fires that people can control, and burn injuries were locally described by people as not very dangerous.

It must be highlighted that the hazardous event **“feed for rodents and other animals”** was not considered because burning waste decreases its bioactivity, and animals are less likely to feed, breed and transmit pathogens (Cook and Velis, 2020).

Table 24 focuses on **“uncontrolled burying of solid waste”**. As previously discussed, in the villages, it is usually related to the construction of new houses, in which soil is used. As a consequence, people use the holes they made to bury solid waste. The practice was observed in only three villages (i.e., #6, #7, #9). But in most of the other villages, it was not possible to verify this practice.

“Leaking of leachate into groundwater” and the related hazard **“groundwater contamination (and human consumption)”** always resulted in a medium risk. Likelihood and severity assumed the same values given to the equivalent event in the case of “disposal of solid waste in dumpsites”. Indeed, the characteristics of the sites were pretty similar, and when the holes were full, they were not covered.

The hazardous event **"feed for rodents and other animals (including insects)"** and the hazard "**infectious and vector-borne diseases"** always resulted in a very high risk. As already discussed in the case of dumpsites, the severity was assumed as major because malaria is endemic in Ghana. It is one of the countries with the highest incidence of malaria globally (Riveron et al., 2016) and mainly during the filling phase of the hole, a lot of animals and insects can be attracted by the waste, in particular by the organic fraction. Indeed, as noted by Krystosik et al. (2020), solid waste accumulation may provide breeding and feeding sites for animals and insects. Presence of animals and insects was observed during the surveys in some holes. Furthermore, the holes were usually a few meters from the houses. As a consequence, the likelihood was assumed as "almost certain". It is important to remember that some cross-sectional studies conducted in Africa found a higher incidence of malaria close to dumpsites (Abul, 2010; Sankoh et al., 2013; Suleman et al., 2015) and as already noted the burying sites had a lot in common with dumpsites.

The event **"spread of contaminants in the air"** and the related hazard **"inhalation, ingestion and/or dermal contact with contaminants"** resulted in a medium level of risk in all the three villages. Indeed, based on the surveys, the likelihood was assumed as likely. The severity was assumed as minor (temporarily irritation or headaches from the smell).

The event **"spread of contaminants into the soil"** and the hazard **"inhalation, ingestion and/or dermal contact with contaminants"** led to a medium level of risk in all the three villages. As in the previous event, the likelihood was assumed as possible, given that children were not observed in such sites, causing a lower frequency of contact with contaminants. The severity was assumed as moderate, also considering the soil analysis conducted by Agyarko et al. (2010) and the concentrations of pollutants based on the daily assumption rate of contaminated soil by children (APAT, 2008).

Table 25 refers to **"reuse of solid waste as compost by local farmers"**. As anticipated, such a practice was only confirmed in village #5.

The event **"leaking of leachate into groundwater"** and the resulting hazard **"groundwater contamination (and human consumption)"** resulted in a medium risk. Indeed, the condition was assumed similar to the case of disposal of solid waste in dumpsites. As a consequence, taking as a reference the low annual rainfall, the frequency was assumed as unlikely. The severity of such an event was evaluated as moderate, considering the dilution and dispersion phenomena of water, and the small generation of leachate in the case study.

Unfortunately, the event **"feed for rodents and other animals (including insects)"** related to the hazard **"infectious and vector-borne diseases"** was not evaluated (NA). It was due to the lack of available information from the field, literature, and the high specificity the topic required.

The event **"spread of contaminants in the air"** and the hazard **"inhalation, ingestion and/or dermal contact with contaminants"** resulted in a medium level of risk. Indeed, it must be taken into account that local farmers collect waste from dumpsites about two times per month, then they separate by themselves organic fractions and plastic. Finally, they use the organic fraction as compost in the soil. As a consequence, the likelihood of the event was assumed as possible (i.e., at least one time per month). However, contaminants can spread in the air during the collection, the waste sorting, the use of compost in the soil, and even later (e.g., diffusion of contaminated vapours from the soil). The severity was assumed as minor (i.e., temporary symptoms like irritation, nausea, headache) because it has not appeared as a very dangerous event.

Figure 25: Dumpsite in village #5 whose waste are periodically collected by farmers (photo Giovanni Vinti, November 2019)

"Spread of contaminants into the soil" and the hazard **"inhalation, ingestion and/or dermal contact with contaminants"** resulted in a high risk. In terms of likelihood, also this event was assumed as possible. But in terms of severity, it was considered major. Indeed, as aforementioned, there is no waste separation at the source, and farmers separate the organic fraction from the rest. As shown in Figure 25, the quality of the mixed waste is very low. As a consequence, even after separation, biowaste would be plenty of pollutants. Furthermore, sometimes there are unintentional fires in such dumpsites, that can generate POPs such as dioxins. It is important to note that Fiani et al. (2013), when considered open burning of MSW, identified the emission factor to land in terms of release of PCDD/PCDF in the ashes as 5-10% of the emission factor in air. This highlight that when farmers use such a waste as compost for their crops, it would also have dioxins that can bioaccumulate in the environment.

4.3 The link between the health risks and the number of people affected

Concerning the health risks evaluated as high or very high, as anticipated in the Methods chapter, it is important to estimate the number of people that can be affected by each hazardous event. However, it is essential to note that it was very challenging to have a clear idea about how many people could be reached by a particular event in some cases. For instance, the rural villages in Ghana required at least a second field mission to get more in-depth information related to some aspects. Unfortunately, the pandemic (Covid-19) hampered such a second on-field investigation that was initially conceived. Similarly, in Serbia, some questionnaires among the residents and the waste workers would be necessary, to have a more definite idea of the number of human receptors potentially affected by the diverse hazardous events. Still, the pandemic hindered a field mission in Serbia. However, on the one hand, in most cases, it was possible to have an order of magnitude of the number of people potentially reached by the hazardous events, on the other hand, further investigations will be discussed later in the thesis.

4.3.1 The case study in Serbia

As already discussed, in Novi Sad three hazardous events resulted in high risk and one in very high risk. However, the number of human receptors potentially reached by each of such hazards was different.

Starting with the hazard **"groundwater contamination (and human consumption)"**, the only one resulting in a very high risk, it can involve residents downstream of the groundwater flow that passes through the landfill. As will be discussed later, further investigations are needed, but the probably contaminated groundwater may reach people from the Klisa and Veliki Rit suburbs. Figure 26 shows the two areas.

Figure 26: Novi Sad landfill, Klisa suburb and Veliki Rit suburb (from Google Earth - modified)

Although the groundwater flow mainly gets Veliki Rit, the phenomena of diffusion and dispersion of contaminants in the aquifer (Domenico, 1987) can cause an expansion of the area involved. This fact led conservatively to consider also Klisa. As aforementioned, about 16,000 people live in Klisa. After talking with professor Batinic, 5,000 residents were assumed in Veliki Rit suburb. It was estimated that between 10% and 50% of those people use groundwater from the first aquifer through private wells, i.e. between 2,100 and 10,500 residents. As will be discussed in the cost analysis section, such an assumption is conservative because, in reality, people usually use the water network instead of groundwater wells. The investigations discussed later will be crucial in understanding it. However, considering that the groundwater flow continues in the city centre's direction, further inhabitants using such aquifer could be affected.

Regarding **"waste combustion"** and the related hazard **"injuries (including burning injuries) by formal waste workers"**, it is an event that would involve the personnel of the landfill. Unfortunately, it was not possible to receive detailed information about the workers at that site. As a consequence, further investigations will be needed, and they are discussed in the section 4.4. Still, considering both landfill workers and administrative staff in the landfill building, between 50 and 100 people are employed (IMG, 2016). However, it should be evident that the human receptors directly affected by such an event will be much less than in the previous case.

The other hazard directly related to **"waste combustion"** but that involved the residents in Novi Sad was **"inhalation, ingestion and/or dermal contact with contaminants by inhabitants"**. As previously discussed, on average, the big fires in the landfill was assumed to happen 1-2 times per year. In this case, the human receptors will not depend on the water flow, that always has the same direction, but on the wind direction. However, most people potentially involved live south and south-west to the landfill, which must be added a few other hundred who live in the north. Consequently, the most exposed group would be represented by those living in the areas of Figure 26, and a few thousands more. However, when waste combustion occurs, human receptors in the area can mainly absorb contaminants through inhalation of the air and ingestion of contaminated food, through the food chain. Indeed, according to WHO (2019c), most general population exposure to dioxins related to waste combustion is through ingestion of contaminated foods of animal origin. Further investigations will be needed in Novi Sad to have a clearer idea of the problem's magnitude. They are discussed in the next subchapters. Still, even 100,000 residents in Novi Sad could currently be affected by such a health risk.

The last hazardous event with high risk was the **"spread of contaminants in the air (excluding waste combustion)"**, associated with the hazard **"inhalation, ingestion and/or dermal contact with contaminants"**. In this case, people can be affected by a threat with a higher frequency than waste combustion, but that does not generate further by-products. People most affected could be assumed as those of Figure 26, and some other thousand, for a total of about 25,000. However, as will be discussed later, further investigations are needed.

4.3.2 The case study in Ghana

As previously discussed, the Ghana case study was very different than the Serbian one. As a consequence, to estimate the number of people potentially reached by hazardous events with high and very risk appeared very challenging. And further investigations will be needed. New field missions were conceived, but the pandemic (Covid-19) has hampered them. Furthermore, looking at Tables 22-25, it can be noted that in some cases the villages were not reached by the same level of risk or some events were not identified. However, the information collected during the mission carried out in Ghana at the end of 2019 allowed the estimate of the order of magnitude of the people affected.

Starting with the SWM practices of **"disposal of waste in dumpsites"**, three hazardous events were evaluated having high or very high risk. The first consisted of **"free movement of people in the dumpsite"** and the related hazard **"inhalation, ingestion and/or dermal contact with contaminants"**. It reached seven out of nine villages. The number of people living in each village was already shown in Table 16. Considering that there are no restrictions at the movement of people in the dumpsites, all the villagers from those seven communities can conservatively be assumed involved, for a total of 28,982.

The second hazardous event associated with the **"disposal of waste in dumpsites"** was the **"feed for rodents and other animals (including insects)"** related to the hazard **"infectious and vector-borne diseases"**. It resulted in a high or very high risk in all the villages, except one (village #2). It can be assumed that all the villagers are affected by that, given the dumpsites' vicinity with the houses. It means a total of 29,204 people.

The last hazardous event was the **"spread of contaminants in the air"** related to the hazard **"inhalation, ingestion and/or dermal contact with contaminants"**. However, it was evaluated with high risk only in village #1, while the risk was lower in the other villages. At the centre of village #1, there was a dumpsite bigger than those also assessed in the other settlements. Probably to assume that all the inhabitants of village #1 can be affected by this hazardous event it is excessive, and further investigations are needed. Still, following a precautionary approach and considering the small size of the settlement, the risk can be considered for all the villagers, i.e. reaching 5,919 people.

"Open burning of waste" was assumed as a practice leading to a very high risk related to the hazardous event of **"spread of contaminants in the air"**. It was identified in all the nine villages. Besides, such a spread of contaminants can reach all the people without limitations of existing obstacles that could reduce the exposition. Probably some people could be less affected, but further field missions would be needed. Consequently, with a precautionary approach, all the villagers were assumed reached by this threat, for a total of 30,904 inhabitants.

As regards of the SWM practice **"uncontrolled burying of solid waste"**, the only hazardous event identified with very high risk was **"feed for rodents and other animals (including insects)"**. It was only identified in three villages (i.e. #6, #7, #9). It is necessary to highlight that the related hazard, i.e. the spreading of **"infectious and vector-borne diseases"** probably does not represent a risk for all the inhabitants. Indeed, it has to be considered the small size and the limited amount of such holes. Further investigations would be needed. However, some infectious diseases, such as the plague related to rodents and solid waste (Agamuthu et al., 2009), can also be transmitted from one infected person to another (WHO, 2017b).

Consequently, with a conservative approach, and in the absence of more detailed information, all the people from the three villages can be assumed potentially reached, directly or indirectly, by such a hazardous event, i.e. 5,504 villagers.

As previously discussed, the SWM practice of **"reuse of solid waste from dumpsites as a compost by local farmers"** was only identified in village #5. A high risk resulted for the hazardous event of **"spread of contaminants into the soil"** associated with the hazard **"inhalation, ingestion and/or dermal contact with contaminants"**. Even in this case, further investigations would be needed to find the number of people affected by such a threat. However, most villagers feed on local agricultural products. Consequently, with a precautionary approach, all the inhabitants can be assumed as exposed to such a risk, i.e. 8681 people. Furthermore, if the farmers also sell their products to other communities, human receptors could be even more.

4.4 How to deal with uncertainty and the lack of detailed data

As aforementioned and shown in Tables 21-25, some events was classified as NA (Not Available). However, it does not mean the related risks were low. The uncertainty was due to the lack of available data or knowledge about the current situation. Consequently, a series of activities should be conceived to evaluate the risk as soon as possible. For the hazardous events that resulted in high or very high risk, preliminary monitoring was suggested when uncertainty was identified in the evaluation process. They are discussed below.

4.4.1 The case study in Serbia. The events with Very High and High risk

For the landfill of Novi Sad, **very high risk** was only associated with the **"leaking of leachate in groundwater"** and the consequent **"groundwater contamination (and human consumption)"**. However, as was previously discussed, some uncertainties have been identified. Taking into account that control measures to reduce such a risk could be very expensive and challenging to achieve, they should be anticipated by preliminary monitoring activities discussed here below.

The first activity to conceive is the realization of wells for monitoring the groundwater upstream and downstream of the landfill. A document to take as a reference can be the Italian decree of waste landfills (D.Lgs. 36/2003), which corresponds to the implementation of the EU Landfill Directive (1999/31/EC). Indeed, Serbia is a candidate to join the European Union, Chapter 27 of the negotiation is on "Environment", and SWM is one of the main components (IMG, 2016).

The monitoring's objective is to promptly detect any situations of groundwater pollution that is certainly due to the landfill. Representative and significant monitoring points must be identified. To do that at least one well upstream (at a sufficient distance from the site to exclude direct influences) and two wells downstream must be placed. The two downstream wells must take into account the direction of the water table. In Figure 27, the three monitoring wells' proposed position is shown, in which U_W, D_W 1, D_W 2 stand for Upstream Well, Downstream Well 1, Downstream Well 2, respectively. However, if some existing wells would be identified in the area, they could be used for the monitoring depending on their position and actual condition. For instance, Djogo et al. (2017) mentioned a well they used for their sampling campaign in 2014-2015, that should be close to D_W 1.

Figure 27: Proposed position of the three monitoring wells for the groundwater of Novi Sad (from Google Earth - modified)

The groundwater level must be measured at the identified monitoring points. Given the water table's limited depth, it is better to install a probe for continuous detection of the groundwater level. However, the detection should be conducted at least once per month. The monitoring plan should include at least the parameters listed in Table 26 (D.Lgs.36/2003). Given the possible risks that the landfill seems to pose, some non-fundamental parameters mentioned in the Italian decree of waste landfills were included.

Table 26: Parameters for the analysis of groundwater through the monitoring wells

pH
Temperature
Electric Conductibility
Chlorides
Sulfates
Fe
Mn
Ammonia nitrogen
Nitrites (NO_2^-)
Nitrates (NO_3^-)
Escherichia Coli
Polycyclic Aromatic Hydrocarbons (PAH)
As
Cu
Cd
Cr_{total}
Cr VI
Hg
Ni
Pb
Mg
Zn
Phosphorus pesticides and total pesticides

It will be crucial to carry out all the analytical measurements referred to Table 26, at least once per year. The best scenario would consist of quarterly analysis.

However, for groundwater quality, the Serbian rulebook (Serbian Official Gazette, 2012) defines values only for nitrates and pesticides, and not for other chemicals. Consequently, the results should be compared with Serbian legislation for drinking water (Serbian Official Gazette, 2019), which considers many parameters, as well as WHO (2017) guidelines for drinking water.

Through a comparison upstream and downstream, taking Figure 27 as a reference, if the measurements confirm groundwater contamination, the next step should consist of a survey among residents living south to the landfill, i.e., in the groundwater flow direction. The minimum area to involve in such an activity is that previously shown in Figure 26.

As will be discussed later, although some controls measures to reduce the risk could be more effective than others, some of them appeared too expensive and would require excessive efforts. To overcome such issues and think about more sustainable proposals, a punctual investigation involving all the people living in the area identified can represent a strategic choice, preliminary and functional to the appropriate control measures discussed later (section 4.5).

Such a survey will conceive two phases. Initially, all the area households will be interviewed, taking a cue from the simplified questionnaire shown in Table 27. However, some people may be reluctant to answer because they consume water from a well not officially registered. Consequently, it should always be highlighted the beneficial scope of the interview, namely that the quality of the surface aquifer could pose severe risks for the health of the people. In this way, the investigation would be affected by less bias.

Table 27: Questions for inhabitants

General information	
Address	
Number of family members	
Specific questions	
1. Does your family have or use a nearby well connected to the surface aquifer?	
2. If yes, how do you use such a water? Select all the voices that fit	• Drinking • Cooking • Irrigation • Cleaning • Other (please specify) ___________________

Such a simplified questionnaire has the scope to quickly identified people to whom the contamination could pose health risks. Then, investigations aimed at assessing the wells' water quality used by those families should be conducted. The parameters shown in Table 26 should be monitored. The results will allow defining the control measures needed at the household level. As will be discussed in section 4.5 (Control measures), the current uncertainties did not permit to prescribe specific water treatments for each polluted well, but filtration could be enough. In some cases, it might be necessary to forbid water consumption, or only allow it for specific uses.

Regarding the events evaluated with high risk, even in this case, some uncertainties have been identified. It must be noted that the spread of contaminants in the air can cause the hazard **“inhalation, ingestion and/or dermal contact with contaminants”** through the diffusion of pollutants in the air both with and without waste combustion. Control measures to reduce the risks are discussed in section 4.5. But they should be anticipated by preliminary monitoring activities. The foul smell noted by residents south of the landfill (Stojanović, 2017) deserves further investigations. As previously discussed, Petrovic et al. (2018) monitored the atmospheric air of Novi Sad's landfill. The analysis only involved some POPs, excluding common landfill compounds such as CH_4, H_2S, NH_3 (Themelis and Ulloa, 2007). At the same time, further studies (Vujic et al., 2012) highlighted that the landfill's biogas wells are only used for monitoring, i.e., no gas drainage and treatment system exists. As a consequence, considering the hazardous event **“spread of contaminants in the air (excluding waste combustion)”**, the first activity to conceive is the realization of landfill gas monitoring points at some distance from the landfill. The Italian decree of waste landfills

(D.Lgs. 36/2003) can be taken as a reference. It is advisable to provide at least two monitoring points along the main direction of the dominant wind at the time of sampling, upstream and downstream of the landfill. A control unit for the detection of weather data (sensor for wind direction and speed, and rain sensor) have to be installed in the landfill if, as it appeared, such a unit does not exist. At least a monitoring point should be placed in the same area of Figure 25 previously discussed, taking into account the complaints expressed by the nearest resident population (Klisa suburb) (Stojanović, 2017). The parameters showed in Table 28 (D.Lgs. 36/2003) have to be measured. To broader monitoring, in Table 28, $PM_{2.5}$ and PM_{10} were added.

Table 28: Parameters for the analysis of gas emissions from the landfill of Novi Sad

CH_4
CO
O_2
H_2
H_2S
NH_3
Mercaptans
$PM_{2.5}$
PM_{10}

For the implementation of the investigation, the use of fixed control units could represent the right solution. It has to be equipped for monitoring air quality with the following devices:

- An automatic CH_4 analyser.
- An automatic CO analyser.
- An automatic O_2 analyser.
- An automatic H_2 analyser.
- An automatic H_2S analyser.
- An automatic NH_3 analyser.
- An automatic mercaptans analyser.
- A sequential gravimetric sampler for $PM_{2.5}$.
- A sequential gravimetric sampler for PM_{10}.

A further investigation could entail adverse health outcomes monitoring. The study of Mataloni et al. (2016) can be taken as a reference. As previously shown (see Table 18, section 4.1), the authors (Mataloni et al., 2016) evaluated the association between landfill H_2S exposure and adverse health outcomes of people in function of the distance from the landfill. In conducting such analysis, experts from the Faculty of Medicine (University of Novi Sad) should be involved.

However, as will be discussed in section 4.5 (Control Measures), given people's complaints about bad smells, some not very expensive interventions can be conceived even before completing these preliminary monitoring.

Additionally, it should be considered that groundwater contamination could contribute to the spread of contaminants in the air. In particular, those volatile compounds that reach the groundwater with the leachate can, in turn, pass through the soil and spread into the atmosphere as vapours (APAT, 2005; 2008). For this reason, it would be useful to measure the concentrations of a series of volatile and dangerous substances in the groundwater (such as benzene, toluene, ethylbenzene, xylenes phenols, ammonia (Christensen et al., 2001)). The same monitoring points of Figure 27 can be used (D_W 1). By measuring the wind speed and direction, it will be possible to calculate through existing models both the groundwater volatilization factor and the air dispersion factor to evaluate the transport of contaminants into the atmosphere up to the point of exposure (APAT, 2008).

Also, the hazard of **“injuries”** for waste workers associated with **“waste combustion”** at the landfill requires preliminary monitoring. Indeed, it could even cause death. In particular, if the big fires that break out at least one time per year are considered. The procedure followed by the landfill personnel in such occasions must be analysed, and the PPE used by workers checked. First of all, the existence of fire prevention and control plan must be verified. Currently, also taking into account the frequency of the fires, it seems such procedures are not put in place, or in any case, they do not work adequately. Indeed, as highlighted in the Landfill Operational Guidelines (ISWA, 2019), landfills need to have an established and maintained fire prevention and control plan. In such a program, important issues related to the landfill have to be included such as site characteristics, fire fighting resources, fire alert levels, fire response actions and responsibilities, fire fighting methods, PPE (ISWA, 2019). It must be verified that site personnel is aware of the plan and received training about it. Taking the ISWA (2019) Guidelines as a reference, during the investigation, the checklist of Table 29 can be applied, to assess the actual situation and identify possible gaps. For working face is meant the portion of the land where solid waste is discharged, spread, and compacted before the placement of cover material. However, some control measures can already be conceived, given the currently significant risk caused by waste combustion. They will be discussed in section 4.5.

Table 29: Checklist to verify the risk of waste combustion at the landfill (from ISWA, 2019 - modified)

Check for buildings in the landfill	
Are emergency exit signs adequately illuminated?	Yes/No
Are fire alarms and fire extinguishers visible and accessible?	Yes/No
Are fire extinguishers serviced annually?	Yes/No
Are corridors and stairways kept free of	Yes/No

obstructions and not used for storage?	
Are the roads that lead to the buildings clear and accessible to the fire engine?	Yes/No
Check about training	
Is there a specific training program for fire prevention and extinguishment?	Yes/No
Are new employees given basic fire training?	Yes/No
Is all personnel familiar with the emergency evacuation plan?	Yes/No
Is training documentation current and accessible?	Yes/No
Are the guests of the landfill informed that have to follow the staff's instructions?	Yes/No
Check related to the landfill body	
Is there a sufficient stockpile of the earth close to the working face?	Yes/No
Is there an adequate supply of water under pressure for fire-fighting purposes?	Yes/No
Is there a water storage tank for fire-fighting purposes?	Yes/No
Is fire-fighting equipment readily available?	Yes/No
Are record-keeping procedures for all fires available?	Yes/No
Is there suitable access road for the fire engine to reach the working face and the burning mass?	Yes/No
Are all the equipment maintenance procedures followed?	Yes/No
Are all flammable materials appropriately stored?	Yes/No
Are the most dangerous locations of the landfill for fire signed properly?	Yes/No
Is there an adequate network of lightning conductors for protection from a lightning strike?	Yes/No
Is there a biogas collection system in the landfill?	Yes/No
Is the biogas collection system properly operating?	Yes/No
Is there a biogas treatment system?	Yes/No
Is the biogas treatment system properly operating?	Yes/No

About the hazardous event **“waste combustion”**, and the related hazards for residents, in general, it should be evaluated in function of typical by-products generated during waste combustion, such as dioxins, PAHs, and Organic Compounds (Estrellan and Iino, 2010). The same monitoring points downstream of the wind mentioned before can be used for such measurements. However, if the prevalent wind would not be in the direction of Klisa suburb, it would be necessary to conceive a fixed control unit point also in such a suburb. In addition to the compounds of Table 28, some PCDD/Fs and PAHs should be measured.

It would be beneficial to conduct biomonitoring studies as well, to evaluate the concentration of some compounds in the blood of people in function of their distance from the landfill. A control group should be considered, as well. The studies of Xu et al. (2019a; 2019b) and Parera et al. (2013) refer to incinerators but can be taken as references. As shown in Table 19 (paragrah 4.1), the authors analysed PCDD/Fs levels in people's blood at different distances from the incinerators. Besides, the rate of same adverse health outcomes could be evaluated, taking as a reference the studies of Candela et al. (2013; 2015), Ghosh et al. (2019), Parkes et al. (2020).

Additionally, a detailed investigation about the presence of farm animals breeding sites and crop growing sites would be strategical in identifying of other risks. In such research, the questions of Table 30 should be posed.

Table 30: Investigation related to farm animals and crops near the landfill

Questions	**Answers**
• Are there farm animals or crop cultivations close to the landfill? If possible, please specify the kind of animals and crops.	
• How far are there from the dumpsite?	
• Can you give the following information? Size of animal breeding sites.	
• Can you give the following information? Size of crop growing sites.	
• Can you give the following information? Characteristics of the sites (including the presence of).	

It would also be helpful to involve some experts from the Faculty of Medicine (University of Novi Sad) in conducting such analysis. It must be noted that the biomonitoring, as well as the adverse health outcomes investigation, could be excessively challenging, though very useful. In any case, control measures to reduce the risk related to uncontrolled waste combustion appear necessary, given the well-known threats they can cause. Such control measures will be discussed in section 4.5, and they should be taken promptly.

4.4.2 The case study in Serbia. The Not Available (NA) events

As anticipated, in the Novi Sad landfill, the events classified as NA could pose some risks, but the lack of data did not allow to go more profound such circumstances. Monitoring programmes to better evaluate the risks are described below.

Regarding **"waste combustion"** associated with the hazard **"inhalation, ingestion and/or dermal contact with contaminants by formal waste workers"**, it needs more direct investigations. Unfortunately, the pandemic caused the cancellation of a field mission initially scheduled. In evaluating the risk, a series of questions have to be posed to waste workers (e.g., where they eat, what PPE they use during fires, how much time do they spend outdoor and indoor in the landfill). Furthermore, analysis of the air during fires should be carried out to evaluate pollutants' level in those occasions. A fixed control unit to measures the same compounds of Table 28 can be used in such a study. Furthermore, the compounds mentioned in section 4.4.1, referring to waste combustion and health risks for residents have to be measured. If the company that manages the landfill would allow it, common diseases among waste workers should be investigated. The rate of some diseases, or the level of pollutants in the blood of waste workers, could be compared with other workers. The study of Rachiotis et al. (2012) can be taken as a reference; in that case, the authors assessed the prevalence of a specific disease through a biomonitoring study, considering two groups: waste workers and municipal gardeners. For Novi Sad's case, the concentration of some compounds generated during waste burning (e.g., dioxins and furans) could be measured in the blood of waste workers and compared with the level in an unexposed group of workers.

A similar approach should be followed regarding both the hazard **"inhalation, ingestion and/or dermal contact with contaminants by informal waste workers"** associated with **"waste combustion"**. However, the initial investigation should ascertain the presence of such a category of workers in the landfill. Indeed, as aforementioned, their group was sure in the past. Currently, guards and fences seem to have reduced it. Notwithstanding waste pickers were observed in the streets of Novi Sad collecting waste from containers. As a consequence, some field surveys at the landfill would help to understand the actual situation better. The following questions should be posed to formal waste workers (Table 31).

Table 31: Questions for formal waste workers at the landfill, about the presence of informal waste workers

Questions	Answers
1. In the last year, have you seen waste pickers or other informal waste workers at the landfill?	
2. If yes, how often (every day, week, seldom)?	
3. How many informal waste workers do you see per week at the landfill?	
4. Do they use PPE? What?	
5. Are there effective fences or barriers to avoid that someone goes inside the landfill, or are fences damaged at some point?	

If informal waste workers were seen during the field surveys, it would be useful to ask them some direct questions. For example, how many hours they stay at the landfill every day and how many days per week; what kind of activity they carry out at the landfill; what kind of materials they look for; what diseases they usually suffer; experiences with burn injuries. Indeed also the hazard **"injuries by informal waste workers"** should be investigated. The best scenario would be represented by informal waste workers willing to answer and undergo biomonitoring analysis, for example taking as a reference some research conducted in the last years at the E-waste site of Agbogbloshie in Ghana (Srigboh et al., 2016; Wittsiepe et al., 2017). However, questionnaires with self-reported data seem to be the most common in the case of informal waste workers (Black et al., 2019).

As anticipated, also the event **"free movement of farm animals in the landfill"** and the hazard **"ingestion of contaminants by inhabitants (through the food chain)"** were not evaluated because of the uncertainties. Indeed, farm animals had been seen in the past. Currently, it is not sure about their presence and frequency, and field investigations are needed. With this in mind, it can be useful to spend at least one week in the landfill, to increase the possibility to see some cows or other animals if they periodically go in the site. Besides, the questions of Table 32 should be posed to waste workers.

Table 32: Questions for formal waste workers at the landfill regarding the presence of farm animals

Questions	Answers
1. In the last year, have you seen farm animals at the landfill?	
2. What species?	
3. If yes, how often (every day, week, seldom)? If possible, distinguish it per species.	
4. How many farm animals do you see per week? If possible,	

distinguish it per species.	
5. Have you seen farm animals while feeding on waste in the landfill?	
6. Are there effective fences or barriers to avoid that farm animals go inside the landfill, or are fences damaged at some point?	

If it would be ascertained the presence of farm animals, even biomonitoring analysis for some of the animals could be conceived, taking as a reference the research of Scaramozzino et al. (2019). However, the investigation could be challenging to carry out in such a context, given the animals' owners' possible reluctance and the specific skills required.

The event "**movement of formal waste workers in the landfill**" and the hazard **"inhalation, ingestion and/or dermal contact with contaminants"** required more detailed data that was not possible to collect because of the pandemic. Field missions are needed. Such an event could be evaluated in the future through questionnaires aimed at waste workers of the landfill. The questionnaires should be used to investigate workers' habits (e.g., where they eat, if they use PPE all the time, how much time they spend outdoor and indoor in the landfill). Furthermore, the analysis of air should be carried out, at least monitoring the parameters of Table 28. Also, dioxins and PAHs in the air should be monitored. If the company that manages the landfill would allow it, common diseases among waste workers should be investigated. The rate of some diseases, or the level of pollutants in the blood of waste workers, could be compared with that of other workers, as previously suggested for the case of waste combustion. For a more general investigation, not only related to waste burning, more chemicals could be monitored and diseases associated with bioaerosols. The review of Pearson et al. (2015) can be taken as a reference. Indeed, although the authors focused on composting facilities, there are many elements in common with the landfill of Novi Sad, which daily receive a significant amount of organic waste. Also, the study of Athanasiou et al. (2010) can be taken as a reference. Indeed the authors evaluated the respiratory health of 104 MSW workers of Keratsini (Greece) and used 80 office employees in the same municipality as a control group. A similar comparison could be made in Novi Sad's case, involving both waste workers from the landfill and other office employees in the same municipality.

"Injuries" associated with the **"movement of formal waste workers in the landfill"** should be evaluated through questionnaires addressed to them during field missions. The rate of damages should be compared with that of other categories of workers. The use of PPE by waste workers should be monitored and the presence of sharp waste in the landfill. Furthermore, the frequency and kind of accidents that occurred in the landfill in the past should be investigated. As noted by Tot et al. (2019), accidents could be related to the lack of specific training operators in the landfill. Also, internal transport with different vehicles can be associated with accidents (Tot et al., 2019). If safety protocols are identified, they should be analysed.

The investigations about movement in the landfill discussed for formal waste workers can be extended to informal waste workers. However, it will be necessary to verify the presence of informal waste workers in the landfill. In doing that, the questions showed in Table 31 can be used. Such questions have to be posed to formal waste workers. If informal waste workers were seen during the investigation, it would be useful to ask them questions. For example, how many hours they stay at the landfill every day and how many days per week; what kind of activity they carry out at the landfill; what kind of materials they look for; what diseases they usually suffer. It could be necessary to deal with reluctance from informal workers. Indeed, in such an illegal context, they could prefer not to answer to any question. A solution could consist in guaranteeing the anonymity of the interviewees. Biomonitoring could be carried out to obtain more reliable results. Waste pickers (or other categories of informal waste workers) could be persuaded because of the usefulness of such analysis through which specific health risk could be observed in advance.
After conducting the investigations mentioned above, it should be possible to fill the health risk assessment matrix of Table 21. Such activities could be carried out when the pandemic slow down significantly.

Additional investigations will be necessary **for the six shops and factories** shown in Figure 9. Indeed, they are the closest working sites not directly related to the landfill, but that may pose high risks for people operating there. The first action should consist in look for the information summarised in Table 33.

Table 33: Investigation for shops and factories located close to the landfill

Questions	Answers
1. Kind of activities conducted on the site.	
2. Kind of workers operating on the site.	
3. Number of workers.	
4. Hours of work per day.	
5. Days of work per week.	
6. Does the shop (or factory) use to pump water from the surface aquifer? If yes, what is the use of such water?	
7. Bad smells coming from the landfill	

Then, if the use of water from the surface aquifer will be confirmed, the parameters of Table 26 have to be analysed. If some contamination is observed, the control measures that will be discussed in section 4.5.1, related to groundwater contamination, have to be extended to such shops as well. Also, the air quality parameters of Table 28 should be considered in modelling their concentration in the proximity of the six shops and factories discussed. Furthermore, given the vicinity with the landfill, a specific epidemiological investigation could be carried out involving workers in the six sites of Figure 9. The study of Mataloni et al. (2016) can be taken as a reference. In that case, the authors (Mataloni et al., 2016) evaluated the association between landfill H_2S exposure and people's adverse health outcomes related to the distance from the landfill. As aforementioned, to conduct such analysis, experts from the Faculty of Medicine (University of Novi Sad) should be involved.

4.4.3 The case study in Ghana. The events with High and Very High risk

In Ghana, as previously noted, the situation appeared very different. The case study involved nine rural villages, and a field assessment was carried out in November 2019. Notwithstanding, in Novi Sad (Serbia), more quantitative data were available. However, the Ghanaian situation is typical for such contexts, in which communities often appear isolated and challenging to reach, and staff shortages represent a common issue (Lehmann et al., 2008). It is crucial to remember that an estimated 45% of the world population lived in rural areas in 2018, representing about two-thirds of the people in LMICs (World Bank, 2017). It highlights the strategic role of the research for this large segment of the human population.

As previously discussed, three hazardous events resulted in a **very high risk**. Similarly to Novi Sad, given the uncertainties, more detailed information would be necessary before starting with the interventions aimed to reduce the level of risk. However, at least two peculiarities have to be taken into account:

- Difficulty in conduct many field assessments in all the nine villages (even in the absence of Covid-19), due to the isolation that characterize the places.
- Difficulty in finding detailed information, also due to the lack of specialized personnel present in the areas.

Furthermore, unlike the interventions needed in Novi Sad, the control measures that can be proposed in Ghana appeared on a smaller scale, making them both less expensive and challenging. As Tables 22-25 showed, different communities resulted in a distinct level of risk. Therefore, it has to be taken into account that the proposed investigations discussed below are probably less essential but more challenging to achieve than those required for the dangerous events identified in Novi Sad.

Both in the case of dumpsites and uncontrolled burying of solid waste, the very high risk was identified for the hazardous event **"feed for rodents and other animals (including insects)"** and the related hazard **"infectious and vector-borne diseases"**. However, higher accuracy can be useful. Indeed, such a high risk was based on previous cross-sectional studies conducted in Africa that found a higher incidence of malaria for people living closer to dumpsites (Abul, 2010; Sankoh et al., 2013; Suleman et al., 2015). It has to be considered that malaria is endemic in Ghana (Riveron et al., 2016), and it was one of the most common diseases in all the villages visited. As a consequence, a cross-sectional study involving the people from all the villages could be instrumental. Given the small number of people in many selected locations, such an investigation should not be too challenging. Furthermore, it could represent an interesting scientific work, given the paucity of available data in such a field. With this in mind, the exact location and size of all the dumpsites should be defined. Then, through some satellite images (e.g., by Google Earth), all the houses' position could be determined, and a more detailed survey could be carried out.

Regarding the open burning of waste, the event **"spread of contaminants in the air"** and the related hazard **"inhalation, ingestion and/or dermal contact with contaminants"** were evaluated as very high. In the evaluation, most of the population was made up of farmers was taken into account. Indeed, this causes a higher density of farm animals, and it would increase the risk of bioaccumulation of POPs in humans climbing the food chain. However, more detailed investigations could be useful. For example, to measure the concentration of POPs and other by-products in the air during waste burning would be crucial. Possibly, the concentration of such pollutants in all the environmental matrices at different distances from the source should be measured. Indeed, dioxins and other contaminants present in the smoke tend to deposit in soil and plants' surface at some distance. Studies related to waste burning and bioaccumulation of pollutants in the blood ad urine of people was already conducted in Ghana, but mostly focusing on the E-waste at the site of Agbogbloshie in Ghana (Srigboh et al., 2016; Wittsiepe et al., 2017). A comparison with a control group, involving people in which waste burning is not practised could be made. Furthermore, bioaccumulation of pollutants in farm animals could be evaluated and taken as a reference to Scaramozzino et al. (2019) research.

However, in particular regard to waste burning, it could be complicated to carry out the local context's mentioned investigations. In any case, some control measures to reduce the risks did not appear too challenging and expensive, and they are discussed in section 4.5.

Concerning the events with **high risks**, two of them were associated with solid waste disposal in dumpsites and one to the reuse of mixed waste as compost by local farmers. A further event (i.e., feed for rodents and other animals) had a high risk in some dumpsites. But it was already discussed in the case of very high risk; consequently, the same investigations are suggested.

Regarding the hazardous event **"free movement of people in the dumpsite"**, further surveys would be useful; in particular, to evaluate the frequency of children in the dumpsites. A mapping using GPS coordinates should be conducted to verify the effective presence of faeces in each dumpsite. Such an activity would only require a smartphone. Furthermore, waste characterisation on some samples should be carried out to understand the waste composition in each village better. These are not particularly challenging activities but, as already mentioned, excessive efforts in such contexts may be required to verify risks almost sure for those who attend dumpsites and above all for those who play (i.e., children). Consequently, even if it is hoped that such detailed monitoring will be carried out, to maintain good effectiveness and speed of intervention for people's health, some control measures will already be proposed in section 4.5.

In village #1, referring to the bigger dumpsite, the hazardous event **"spread of contaminants in the air"** was evaluated having high risk. Such a situation requires a prompt intervention even in the absence of more in-depth investigations. If it were possible to carry out detailed monitoring quickly, it would be advisable to evaluate the composition of the waste in the dumpsite by samples to have more certainty of the various components and pollutants. It would also be useful to carry out air quality monitoring not only in terms of $PM_{2.5}$ and PM_{10}, as already done during the November 2019 mission. It would be optimal to measure the composition of various volatile compounds, such as PAHs and PCBs, taking inspiration from the study done by Petrovic et al. (2018). Furthermore, bioaerosol exposures can cause infectious, toxic, and allergenic effects (Hoffmeyer et al., 2014). The bacterial and fungal diversity of aerosols can be analysed using Bru-Adan et al. (2009) as a reference.

As anticipated, such interventions would improve the quality of the control measures and make a better scale of priorities. If such investigations were carried out in each community's dumpsite, it would allow the realisation of a series of risk matrices even more site-specific. However, these are investigations that should not be seen as a priority, having noted the local situation, which is very tough. Regarding village #1 in particular, it would be essential to act through the control measures discussed below, precisely because these are generally already known risks.

Finally, regarding the SWM activity **"reuse of solid waste from dumpsites as compost by local farmers"** in village #5, as already discussed, **"spread of contaminants into the soil"** was the only hazardous event having a high risk. In such a context, it would be beneficial to measure the concentration of some pollutants in the soil and the crops involved, taking as a reference the work of Agyarko et al. (2010). Also, metals' transfer factor in soil-plant systems could be evaluated (Lato et al., 2012). In village #5, it would also be appropriate to try to carry out questionnaires to assess the spread of diseases among people who use the soil's products with contaminated compost, comparing them with those who use products not coming from those soils. Even in this case, however, the need for prompt intervention is already evident and will be discussed in section 4.5 (Control Measures).

4.4.4 The case study in Ghana. The Not Available (NA) events

In Ghana, some events defined as Not Available followed a path different than the Serbian case study. Indeed, for some hazardous events in Serbia, it was impossible to verify its existence given the impossibility to conduct a field mission. In Ghana, though a field mission was carried out, in some cases, it was not possible to evaluate the risk because of the lack of quantitative data, or because of scientific literature gaps that not allowed to assess it. Further surveys were needed in some circumstances, but they were hindered by the pandemic (Covid-19).

It is crucial to highlight a standard uncertainty, i.e., the lack of site-specific information about waste composition in all the nine villages. It is a constraint quite common in such contexts, but it deserves specific surveys. A preliminary analysis of waste composition and production rate per inhabitants started during the field mission in November 2019. It confirmed the strong predominance of organic waste. However, it was just a preliminary survey, given operational difficulties and the short time available during such a mission. More detailed investigation to carry out in further field missions was conceived, but they were hindered by the pandemic (Covid-19). As a consequence, one of the first activities to carried out during subsequent field investigations should consist of such analysis. However, in the framework of the Sustainable Livelihoods project, we have recently launched a call (CISS, 2020b), by which a Ghanaian researcher will be selected to carry out some field activities in the area of solid waste, including waste characterisation in the villages involved in the project. In this way, the gap will be filled soon.

Regarding the SWM practise defined as **"disposal of solid waste in dumpsites"**, it was not possible to evaluate the risk associated with the **"leaking of leachate in groundwater"** in villages #4 and #8. Indeed, during the first field mission in Ghana, no wells for groundwater were observed, and more detailed surveys were needed. Unfortunately, the pandemic

(Covid-19) has not allowed to carry out a further mission in Ghana, initially scheduled. Consequently, the first step for future missions should consist of investigating the presence of wells used by people, that would confirm the existence of groundwater.

However, more detailed information about the physicochemical characteristics of groundwater and boundary conditions (i.e., hydrogeological characteristics) would be necessary. In the monitoring, existing wells can be used (ARPA Valle d'Aosta, 2020). In this way, cost and time needed to carry out investigations in such isolated areas would be reduced. The parameters showed in Table 26 of section 4.4.1 can be taken as a reference. Besides, microbiological contaminations should be monitored (e.g., Escherichia Coli). Similarly to as proposed in Novi Sad, monitoring wells should be found both downstream and upstream dumpsites, to evaluate the possible level of pollution caused by them. Such investigations should be extended to all the villages. Indeed, as previously noted, although risk associated with the leaking of leachate in groundwater did not appear high, uncertainties remain about it in all the villages, except village #2 in which no dumpsites were observed. A further useful investigation would consist in geolocate via GPS coordinates the positions of all the wells used by people. Such activity should be easy to achieve. Indeed, nowadays, even a smartphone may be sufficient.

The other event that was not possible to evaluate in dumpsites was **"free movement of farm animals in the dumpsite"**. As aforementioned, farm animals were observed in dumpsites during the field surveys in November 2019. The animals were eating food waste, grasses and plants in the sites. The sites did not have a fence to prevent the presence of animals. Furthermore, sometimes waste was burned in dumpsites. However, the current status of international knowledge related to such events is still limited, and it did not allow to determine the health risks for people. In the future, biomonitoring studies should be conducted, monitoring some contaminants in tissues of animals that spend time in dumpsites. In the choice of pollutants, Scaramozzino et al. (2019) study can be taken as a reference, and some of the contaminants shown in Table 34 analysed.

Table 34: Parameters to monitor in farm animal tissues

Polychlorinated dibenzo-p-dioxins (PCDDs)
Polychlorinated dibenzofurans (PCDFs)
Dioxin-like polychlorinated biphenyls (dl-PCBs)
Pb
Cd
Cr
Mn
As
Zn
Ni
Hg

Also, the study of Xu et al. (2019a) provides useful information. Indeed, although the authors investigated the accumulation of PCDD/Fs in children living nearby an incinerator in

China and the related health risks, the methods they used could be applied to the event discussed here. In particular, the authors also investigated the concentration of such pollutants in eggs and compared a control group. However, it must be noted that such investigations could be too challenging, expensive and time-consuming in the rural villages of the Ghanaian case study. Probably, the authors of the study aforementioned (Scaramozzino et al., 2019; Xu et al., 2019a) could be contacted and involved in such research.

Regarding the SWM practise **"open burning of waste",** the only event whose information was considered Not Available was **"leaking of leachate into groundwater"** in villages #4 and #8. The reasons and the proposed investigations are alike those discussed for the same event related to "disposal of solid waste in dumpsites".

Considering the SWM practice **"uncontrolled burying of solid waste",** it resulted Not Available in five out of nine villages. In villages #6, #7 and #9 it was confirmed, while in village #5 resulted as an activity that people did not conduct. It was not possible to ascertain such activity in the five remaining villages, and further investigation would be needed. More time to spend in each village would probably represent the best scenario to collect more information about the burying of waste. In particular, it could be instrumental in posing specific questions to people living close to such sites. As previously discussed, the uncontrolled burial of solid waste is characterised by a pit filling phase and a pit full of waste phase (i.e., when the hole is full of waste and is not used anymore as a place in which dispose of trash). As a consequence, some of these sites could be challenging to find, and the knowledge of inhabitants will be crucial. The sites should be geolocated via GPS coordinates. Such activity should not be too difficult. Indeed, even a smartphone could be sufficient. The size of each site should be evaluated. Furthermore, soil and groundwater analysis would be instrumental. But it appears that in such contexts it would be challenging to collect these data. However, at least for groundwater analysis, the investigation discussed for the case of dumpsites should be conducted.

The last SWM activity with many events evaluated as Not Available was the **"reuse of solid waste from dumpsites as compost by local farmers"**. It was only ascertained in village #5. All the other villages will require further investigations. It must be noted that it appeared as a relatively uncommon activity, tough with many potential benefits discussed in section 4.5 (Control Measures). Both in village #5 and in the other villages where such an activity will be confirmed, soil analysis should be conducted. In particular, in terrains where the (contaminated) compost is used. Besides, it would be beneficial to measure the concentration of some pollutants in the crops involved, taking as a reference the work of Agyarko et al. (2010). Also, metals' transfer factor in soil-plant systems could be evaluated (Lato et al., 2012). However, as already noted, soil and plants analysis to assess contamination level, comparing it with control areas, could be excessively challenging in Ghanaian rural villages.

Finally, the event **"feed for rodents and other animals (including insects)"** related to the hazard **"infectious and vector-borne diseases"** was not even evaluated (NA) in village #5. It was due to the lack of scientific knowledge about such a risk. Future field missions could aim at cross-sectional studies to evaluate the spread of malaria and other infectious diseases in the function of the distance from areas in which the compost is used. Such investigations would allow overcoming the literature gap of knowledge in this field. Previous cross-sectional studies can be taken as a reference (Abul, 2010; Babs-Shomoye and Kabir, 2016; Suleman et al., 2015), although the authors examined the risk based on the presence of dumpsites.

4.5 Control measures

As illustrated in section 2.2.7, control measures are actions, activities and processes having the scope to prevent or minimise hazards identified (Davison et al., 2005). Proposed control measures are analysed below for the highest risks emerging from the health risk matrices, both in Serbia and Ghana. Such interventions have to be preceded by the investigations described in section 4.4. It is crucial for the case study in Novi Sad (Serbia), whose control measures are more expensive and challenging. Indeed, keeping in mind the concept of appropriate technologies previously discussed, it appeared that Novi Sad could manage interventions more advanced than those in the Ghanaian rural villages. Diverse kinds of control measures were identified, i.e., capital works, operational interventions, and behavioural measures introduced in section 2.2.7. Priority has to be given to Very High and High risk events.

4.5.1 The case study in Serbia

A **Very High risk** event characterised the case study of Novi Sad, i.e., the **"leaking of leachate in groundwater"** and the consequent hazard "groundwater contamination (and human consumption)". As a consequence, if the investigation discussed in section 4.4 will confirm it, priority has to be given to such an event, and the control measures provided below have to be implemented. However, as it will be seen, the current level of knowledge has allowed to accurately define neither the number of people to involve nor the best technological solution.

- **The final top cover of landfill section III.** Based on Figure 11, in which Novi Sad landfill sections are shown, and using Google Earth software, it was estimated the area of Section III, i.e. the only that is currently closed. It resulted in about 64,000 m^2. As already mentioned, the only material used as a top cover of this section is a soil of 20 cm thickness (Vujic et al., 2012). Consequently, an adequate final top cap would be crucial to control percolation due to rainfall in underlying waste (Albright et al., 2004). It would contribute to reducing the leachate flow from the landfill to the groundwater. Considering that negotiations between Serbia and the European Union also include SWM (IMG, 2016), the Italian legislation (D.Lgs. 36/2003) for the design of the final top cover of a landfill was taken as a reference. Indeed, such regulations are based on European Directives. Therefore, the layers of the top cover should be the following: (1) surface covering layer with a thickness of at least 1 m; (2) drainage layer with a thickness of at least 0.5 m; (3) compacted mineral layer with a thickness of at least 0.5 m; (4) gas drainage layer with a thickness of at least 0.5 m; (5) regularization layer for the correct implementation of the overlying layers. Although such an intervention could not be very useful in the short term, it is a crucial element in reducing the phenomenon's scale in the long term. Furthermore, it will have to be implemented in the other landfill sections for their proper closure.

- **Water treatment systems at the household level.** Decentralised approaches to supplying water are spread in many parts of the world, including developing countries (Peter-Varbanets et al., 2009). Such solutions may cover both quality and quantity problems, and include different approaches; for example, the direct use of groundwater or rainwater, household water treatment systems, dual tap water treatment (Peter-Varbanets et al., 2009). After the investigation discussed above, the inhabitants for whom water contaminated will need a household water treatment system to use it for drinking purposes safely. Depending on the water analysis results, the use for irrigation purposes could be forbidden as well. Currently, it is not possible to establish the number of households that will require water treatment. Also, the treatment necessary is unknown because it will depend on the results of the analysis. However, in the first approximation, the people potentially involved in Klisa and Veliki Rit suburbs were discussed in section 4.3, and a cost analysis is presented in section 4.6. In general, appropriate solutions to implement at the household level could consist of filters of different nature. Indeed, many systems are available in function of the kind of contaminants to deal with (Carrière et al., 2011; Siwila and Brink, 2019; Yu et al., 2019). Consequently, a general idea of the most appropriate solutions will be agreed at the end of the investigations aforementioned.

- **Awareness campaigns and related actions.** The public utility company and the municipality of Novi Sad promote an information campaign having multiple purposes. The first objective will be to make aware the whole population of Novi Sad about the health risk of consuming water from the surface aquifer. Consequently, the local authority has to enact a ban on the use of such water bodies for drinking purposes. Depending on the investigation results mentioned in section 4.4, even a ban on the use for irrigation purposes could be declared. Simultaneously, for those who wish to use such water, also for private purposes, a physicochemical analysis will be required, including at least the parameters of Table 26. Authorities must point out the health risk to use such waters without any investigation at the point of exposure. With the aims to deal with the possibility that people who own illegal wells do not report themselves to the authority, it could be useful to find an agreement with the municipality to do not sanction them. After analysing water quality of their wells, people have to report the values to the municipality that will certify its safety or the need for some treatments before to consume it. If some risks are observed, the municipality will take charge of the actions needed to guarantee safety conditions (e.g., providing filters for water treatment at the point of use).

The hazardous event **"waste combustion"** was associated with two hazards having high risk, i.e., **"injuries (including burning injuries) by formal waste workers"** and "inhalation, ingestion and/or dermal contact with contaminants by inhabitants". As a consequence, some control measures will be the same for both hazards. Starting with waste combustion and risks for waste workers, the following control measures are given.

- **Implementation of a collection, transport and treatment system of biogas.** It is necessary to consider that one of the two significant constituents of landfill biogas is methane. Methane is explosive in concentrations ranging from 5% to 15% by volume in air, while at concentrations above

15% by volume is flammable (ISWA, 2019). Cases of spontaneous biogas explosions and fires may occur (ISWA, 2019). That makes the biogas' collection, transport, and treatment system essential in reducing many of the risks above discussed. As previously noted, in the Novi Sad landfill, some wells for biogas are already put in place. However, the wells are not connected with any transport system. As a consequence, they can be used at a maximum for some monitoring activities. Furthermore, many wells were damaged.

Starting from the collection, this is a forced action that arises from an applied depression, through which the biogas produced in the landfill body is conveyed through preferential lanes. If there is no vacuum applied, we speak of exhalation, and the displacement of the gases occurs mainly due to the difference in pressure inside the landfill (i.e., the case of Novi Sad). Sometimes, an element born with exhalation's function can be transformed into a collection element, once connected to the forced collection network that determines the depression. Sometimes the collection is implemented only at the end of the disposal of waste in landfills. This choice is not recommended both from an environmental and energy point of view. However, it must be admitted that during the landfill cultivation phases, the collection efficiencies are limited, and the presence of an extraction and transport network can complicate the disposal (Magnano, 2010). Still, it is advisable to overcome these difficulties and anticipate the collection operations as much as possible.

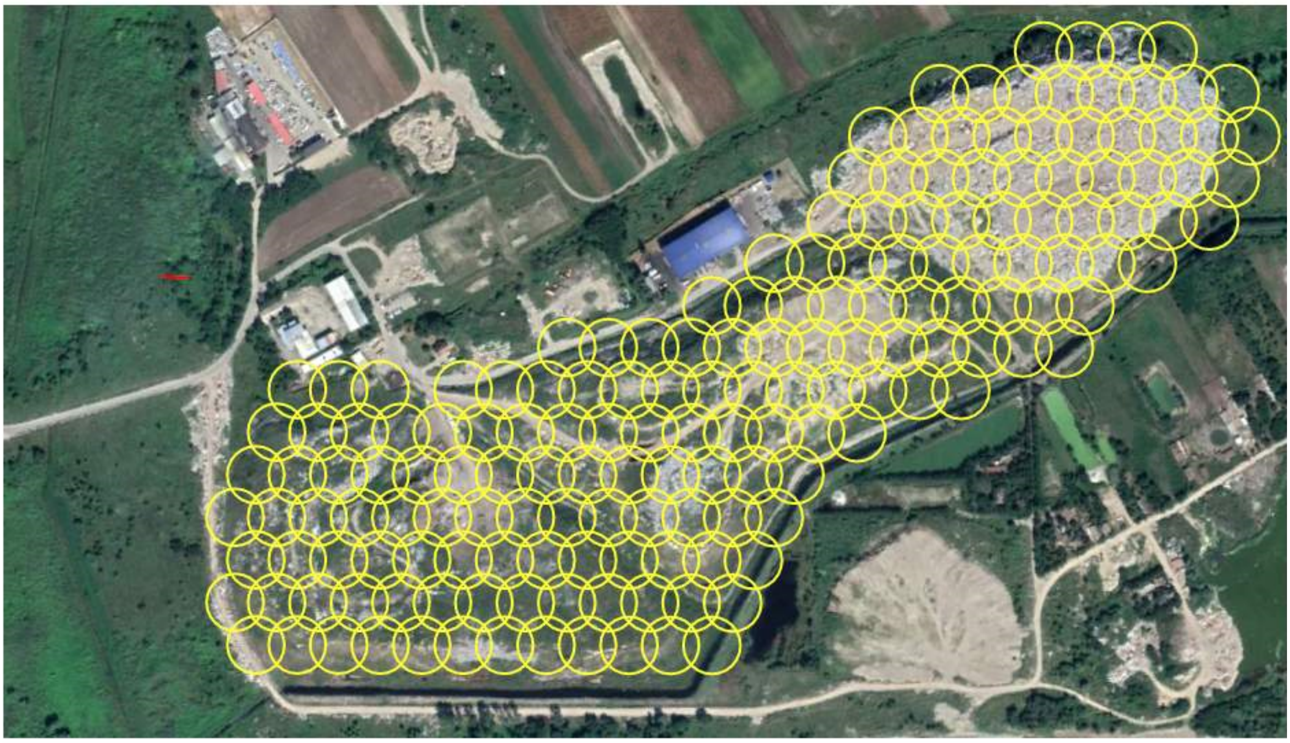

Figure 28: Proposed distribution of wells for biogas extraction, with a ROI of 25 m

One of the most used criteria for the sizing of a collection network is based on the range of influence, i.e. the distance within which the well, through the applied depression, maintains the ability to develop its collection action effectively. The concept is to associate an imaginary cylinder with each well. Its radius will correspond to the radius of influence (ROI) and the height to that of the well. Based on this, by superimposing the circles generated by the influence rays on a satellite image of the landfill, the collection network was designed, as shown in Figure 28. A total of 172 wells was estimated. However, the condition and the possible use of the existing well must be investigated. Some of them could be used. The areas of influence of the various circles must be superimposed, to avoid areas not covered and excessive biogas dispersion. Following this principle, a triangular lattice was created where the wells' distances were slightly less than the sum of the two radii. An ROI of 25 m has been set to have a design indication. Indeed, the sector literature suggests not to exceed this value (Magnano, 2010). The wells will consist of a probe coaxial to the drain (in HDPE) and a drain with vertical development (consisting of gravel).

The biogas thus captured will be transported to a torch. For this transport to take place, there must be depression. A hybrid system is envisaged to overcome the complexity that the network could have. The course will consist of secondary lines connected to the wells and a primary line. In practice, several secondary lines are connected to the primary line. This biogas transport network will be made of HDPE, a material suitable to resist the biogas' chemical aggressiveness and able to maintain its characteristics for a long time.

Finally, as regards the treatment of biogas, combustion through a high-temperature torch is envisaged. Such a torch will allow burning the biogas at high temperatures thanks to refractory insulation. The temperature can reach 1000 °C. The torch will permit obtaining a high combustion efficiency and consequently, shallow emission values, considerably below the limits required by European regulations (Magnano, 2010).

- **Daily cover of waste.** The regular application of daily cover represents a simple, robust control on many of a landfill's critical effects. It is an essential requirement at any well-managed waste disposal site (ISWA, 2019). Indeed, areas with poor daily cover practices are often subjected to many problems, including fires (ISWA, 2019). In general, daily waste coverage reduces the inflow of air to the waste, isolates the trash from the surface and reduces the potential for accidental or deliberate fires being started (ISWA, 2019). The simplicity of application needs to be taken into account when selecting the type of daily cover. As aforementioned, waste coverage is seldom practised at the Novi Sad landfill. As a consequence, it will be necessary to induce landfill managers to conduct such activity daily. The surface upon which the daily cover is applied needs to be adequately compacted and free from depressions; otherwise, a higher amount of daily cover will need to be used (ISWA, 2019).
- **Implementation of safety and training programmes for waste workers**. After the investigations aforementioned and applying the checklist of Table 29, the need for safety and training programmes could emerge. Indeed, accidents can be minimized by the implementation of such activities (ISWA, 2019). Employees have to be trained in the safety aspects. The basic rules of Table 35, derived from the ISWA (2019), can be taken as a reference. Training in site safety measures will have to become a regular activity. The Landfill Manager will be responsible for the initiation and maintenance of accident prevention programmes. Site safety preparation should include the following actions (ISWA, 2019): eliminating debris, levelling the ground, filling of holes, cutting tree roots, and make a mark of gas, water, and electric pipelines.

Table 35: Primary safety rules at the landfill (from ISWA 2019 - modified)

• Do not allow those under the influence of alcohol or controlled substances to work on or use the site.
• Do not permit horseplay or idle time in the tipping area.
• Do not make the first compacting pass over deposited wastes with the tractor or compactor in reverse.
• Do not consent trucks to discharge waste within three meters of others.
• Consider that complete separation of mechanical discharging trucks from those which must be hand unloaded increases safety and decreases the area of tipping face required. To take into account that hand unloading will require less space between trucks but requires a great deal more time to unload.
• Only allow drivers to enter the disposal area. The spotter must not be distracted by external activity.
• Smoking at the tipping face or exposed surface has to be prohibited and considered a violation of safety rules.
• If salvaging is allowed on-site, it should not result in tipping face activity or the deposit of salvaged material on the deposited waste, especially near the active working face.
• All site personnel should be required to log in and log out each time they arrive or leave the site.

As anticipated, the other hazard related to **"waste combustion"** was the **"inhalation, ingestion and/or dermal contact with contaminants by inhabitants"**. Two control measures discussed above can also be applied here to deal with it and reduce the risk. Indeed, both the implementation of a **"collection, transport and treatment system of biogas"** and the **"daily cover of waste"** would effectively reduce the risk for inhabitants living nearby the landfill.

- A further control measure has to consist of **setting up a fast and efficient emergency population warning system**. Indeed, the public and particularly vulnerable groups should be aware of the air quality, allowing actions to be taken in the case of an increased level of pollution (Kelly et al., 2011). The local authorities' first communication activities have to be carried out through local media (i.e., radio and television). Furthermore, an air pollution alert service will be implemented, with the aims to alert registered users of imminent pollution events proactively. In this way, the most vulnerable people will be directly warned about the hazardous situation, rather than leaving them up to find the information elsewhere (Kelly et al., 2011). People included in the alert service will receive a registered message by phone.

The last hazardous event with high risk for inhabitants was the **"spread of contaminants in the air (excluding waste combustion)"** and the related hazard **"inhalation, ingestion and/or dermal contact with contaminants".** Two control measures previously mentioned could be implemented to reduce such a risk, i.e., "collection, transport and treatment system of biogas" and the "daily cover of waste". Besides, the control measure below should be realised.

- **Air filters at the household level.** Air filters have been proven efficient for reducing air pollution, and their effectiveness in reducing adverse health daily symptoms has been shown in many studies (Guan et al., 2016; Vijayan et al., 2015). Indoor air filtration can be provided in different ways. For instance, whole house filtration, particulate sleep zone air filtration, and portable filter-based air cleaners with high-efficiency have appeared to provide benefit (Sublett, 2011). The most appropriate and inexpensive solution identified consisted of portable filter-based air cleaners. Air cleaners should be placed where the most vulnerable occupants spend a lot of time. In particular, the areas mostly occupied by children, elders and asthmatics will have to be considered (US EPA, 2018). Suppose the analysis will confirm the high level of air pollution-related to the landfill. In that case, air filters should be distributed by the local authority at least to people living in the Klisa and Veliki Rit suburbs (see Figure 26), i.e., about 21,000 people. Taking Table 8 as a reference, the average number of people per household in Novi Sad is 2.22. That make about 9,460 households that should receive a portable air filter. Such action will improve air quality at the household level, reducing adverse health outcomes related to air pollution. Such a move would also benefit national health service and social care which can be strongly affected by air pollution (Pimpin et al., 2018).

Table 36: Risk matrix with the control measures conceived

Hazardous events	Hazards	Level of Risk	Control measures
Leaking of leachate in groundwater	Groundwater contamination (and human consumption)	**VH**	• The final top cover of landfill section III • Water treatment systems at the household level • Awareness campaigns and related actions
Waste combustion	Injuries (including burning injuries) by formal waste workers	**H**	• Implementation of a collection, transport and treatment system of biogas • Daily cover of waste • Implementation of safety and training programmes for waste workers
Waste combustion	Inhalation, ingestion and/or dermal contact with contaminants by inhabitants	**H**	• Implementation of a collection, transport and treatment system of biogas • Daily cover of waste • Setting up a fast and efficient emergency population warning system
Spread of contaminants in the air (excluding waste combustion)	Inhalation, ingestion and/or dermal contact with contaminants	**H**	• Implementation of a collection, transport and treatment system of biogas • Daily cover of waste • Air filters at the household level

The control measures related to the disposal of solid waste in dumpsites discussed above are summarised in the last column of Table 36. An estimate of the costs associated with these interventions is presented in section 4.6 (cost analysis).

4.5.2 The case study in Ghana

Similarly to the Serbian case, also in Ghana, priority will be given to the events with the highest risks. Furthermore, some interventions can have beneficial effects on several dangerous events at the same time.

Starting with the SWM activity **“disposal of solid waste in dumpsites”**, as already discussed, the hazardous event **“feed for rodents and other animals”** resulted in a high or very high risk in all the communities with dumpsites. Actually, it appears to be an almost inevitable hazard for people living closer to the dumpsites. With this in mind, the following control measures have been identified:

- **To reduce the organic fraction of waste disposed of in dumpsites.** Such an objective can be achieved through the introduction of composting bins at the household level. It is an activity already conceived in the framework of the Sustainable Livelihoods project (Vinti et al., 2020b). Notwithstanding difficulties caused by the pandemic (Covid-19), the dissemination of composting bins will start in 2021. In this way, it will be possible to reduce at least two-thirds the amount of waste disposed of in dumpsites. It is necessary to consider that inadequate solid waste accumulation often represents a risk factor for infectious and vector-borne diseases because it may provide breeding and feeding sites for animals and insects (Krystosik et al., 2020). As a consequence, reducing the waste to dispose of in dumpsites, also reducing the organic fraction, will contribute to reducing the health risks. As previously discussed, site-specific information about waste composition and generation rate is currently lacking. However waste characterisation activities are conceived within the Sustainable Livelihoods project, and they will be carried out by local researchers during 2021 (CISS, 2020b). In a first approximation, the total number of composting bins needed in each village can be estimated based on the number of households per village, assuming to distribute a composting bin per family.

Table 37: The number of composting bins required in each village

Village	Number of inhabitants	Number of households	Number of composting bins required
#1	5919	769	769
#2	1700	221	221
#3	6000	780	780
#4	4000	520	520
#5	8681	1128	1128
#6	350	46	46
#7	2932	381	381
#8	1100	143	143
#9	222	29	29

The area's average household size was deemed as 7.7 persons/family (Ghana Statistical Service, 2013). On this basis, the total number of composting bins needed in each village is showed in Table 37. However, such an activity needs to be integrated with the others discussed below. In particular, in village #5 composting bins will not be used, but simple bins will substitute them for weekly collection of biowaste. Indeed, as it was anticipated, in such village farmers use mixed waste to make compost, and a separate waste collection at the source would improve the quality of compost. It will be discussed later.

- **To locate dumpsites further away.** Conceiving dumpsites at the edge of each village, ceasing to use those currently located near houses, will reduce many health risks. If possible, dumpsites should be placed at least 1000 m from residences and 500 m from agricultural areas (Simsek et al., 2014). As aforementioned, the amount of organic waste disposed of need to be reduced. Simultaneously, taking into account that places too far away to dispose of waste could discourage the population from using them (Coffey and Coad, 2010), the involvement of waste pickers in the collection service at the village level could represent the most suitable solution. In particular, animal carts can be useful in waste collection for distances up to 5 km, and donkeys, mules, horses and buffaloes have been used for pulling loads in many countries, including rural areas (Coffey and Coad, 2010; Shah et al., 2019). In Ghana, previous experiences related to waste collection and transportation with donkeys were documented (Bellwood-Howard, 2012; Obirih-Opareh and Post, 2002). It appeared an appropriate solution for the rural villages involved in the study. A research recently conducted in Pakistan (Shah et al., 2019) found that a typical donkey cart transports on average 1100 kg waste per day, including non-recyclable and recyclable waste. Although site-specific information related to the waste composition and generation rate is not available, it is possible in a first approximation to consider the research of Mieza et al. (2015). In Tamale, Northern Region, the authors found an average waste generation rate of 0.33 kg/(person x day). The organic fraction represented about 60% of the waste. The households in each village were already shown in Table 37. As a consequence, taking such values as a reference, it was possible to estimate the number of donkey carts that would be needed per village. Assuming that the organic waste was used at the household level to make compost, the remaining fraction's waste generation rate would be 0.13 kg/(person x day). Table 38 shows the weekly waste generation rate in each village, with and without the organic fraction.

Table 38: Total waste generation per week in each village

Village	Total waste generation per week (including the organic fraction) [kg/week]	Total waste generation per week (without the organic fraction) [kg/week]
#1	5469.16	2187.66
#2	1570.80	628.32
#3	5544.00	2217.60
#4	3696.00	1478.40
#5	8021.24	3208.50
#6	323.40	129.36
#7	2709.17	1083.67
#8	1016.40	406.56
#9	205.13	82.05

The following equations were used:

$$A = B \times C \times 7$$

$$D = B \times C \times E \times 7$$

Where:

A = Total waste generation rate per village per week.

B = Daily waste generation rate per capita.

C = Number of inhabitants in each village.

D = Total waste generation rate per village per week, excluding the organic fraction.

E = 0.4, i.e. the waste fraction excluding biowaste.

Then, a door-to-door collection with donkey carts was chosen. The time spent by carts in collecting waste in each family was conservatively assumed as 10 minutes (i.e., the time usually considered for loading a container (Coffey and Coad, 2010)). The best scenario was represented by a collection that not involved organic waste, whose fate would consist of composting bins, as discussed at the previous point. As a consequence, in each household, a weekly waste collection would not cause the spread of bad smells, usually associated with the organic fraction. The number of donkey cart needed in each village was estimated, and it is shown in Table 39. In doing that, the number of families of Table 37, a maximum of 8 hours (i.e., 480 minutes) of work per day, and five days of work per week (2400 minutes) were assumed. Every integer was assigned by excess. In each village, an additional donkey cart was added, to reduce the risk of management problems.

Table 39: Number of donkey cart needed in each village

Village	Donkey carts needed
#1	4
#2	1
#3	4
#4	3
#5	5
#6	1
#7	2
#8	1
#9	1

Such results would entail not operational problems due to excessive loads that the animals have to support (Coffey and Coad, 2010), for example, because of the unpaved roads' bad quality. Indeed, the number of donkeys shown in Table 39 would guarantee a capacity transport per donkey cart that not exceeds 130 kg per day, far below the aforementioned operative values of Shah et al. (2019). Furthermore, the time needed to reach dumpsites with donkey carts should not affect the number of animals required, because one round-trip per day should be sufficient. Indeed, the distance with the site have not to be excessive, and the waste generation rate resulted on average very low. Besides, a waste bin for mixed waste should be provided to every household, based on the amounts of Table 37. Such a solution would require a low number of waste pickers and donkey carts in the smallest villages and no more than five donkey carts in the biggest location. As it will be better discussed in the cost analysis section, the highest cost per household resulted in the smallest villages (i.e. villages #6 and #9). Consequently, no additional donkey carts with waste workers were conceived to avoid to affect excessively such an economically fragile system. It has to be considered that most of the villagers are poor, and a series of meeting will need to be scheduled to define the best payment for the waste collectors. An attractive solution could be represented by compensation with community-based livelihood products. But at least funds for the purchase of bins for families, PPE for waste workers, and the donkey carts have to be found. Furthermore, as it will be better discussed later, in village #5 a different strategy will be followed, considering farmers who currently use biowaste from dumpsites as a compost.

Unfortunately, it must be noted that in the short-term it appears very difficult to imagine the construction of a sanitary landfill in which dispose of waste. Indeed, such a system entails great economic, construction and management efforts, and it does not seem currently implementable. Consequently, at least during the first phase, the sites will have neither a waterproof layer at the bottom nor a leachate treatment system. Biogas will not be collected and treated, as well. However, the anaerobic degradation of the organic component of waste that leads to biogas generation is influenced by chemical, physical and biological phenomena. The waste composition is crucial in the production phenomenology, especially organic substances that produce biogas (Magnano, 2010). Indeed, landfill gas is generated in landfills where organic waste is disposed of (ISWA, 2019). As a consequence, if the distribution of composting bins previously discussed will be achieved, biogas production in such sites should not be very high. Such unsanitary landfills, more similar to dumpsites, will be located in areas far from wells, and possibly in soils with low hydraulic conductivity. Indeed, taking as a reference the Italian decree of waste landfills (D.Lgs. 36/2003), corresponding to the implementation of the EU Landfill Directive (1999/31/EC), a natural geological barrier should be identified, below the landfill. Its geological and hydrogeological conditions have to be sufficient to avoid contamination risks to the soil, surface waters and groundwater. The base and sides of the landfill have to consist of a natural geological formation that meets the requirements of permeability and thickness at least equivalent to the following (D.Lgs. 36/2003):

- Hydraulic conductivity $k \leq 1 \times 10^{-7}$ m/s
- Thickness greater than or equal to 1 m.

According to the Italian decree (D.Lgs. 36/2003), if the geological barrier does not naturally satisfy the above conditions, it can be artificially completed through an appropriately constructed confinement barrier system that provides equivalent protection. However, as anticipated, the artificial barrier seems not to be applicable in the rural Ghanaian villages. Besides, the conditions required above for the soil could not be found near all the villages. Even in such a case, the construction of these unsanitary landfills at least 1000 m from dwellings will drastically reduce the inhabitants' health risks. Under a hydrogeological point of view, the sites must be located downstream of the inhabited centres, and in areas that are not at risk from floods (D.Lgs. 36/2003).

- **Awareness campaigns to improve hygiene habits related to solid waste.** Such activity has already been conceived in the framework of the Sustainable Livelihoods project (Vinti et al., 2020b). Covid-19 partially hampered the implementation, but it had already started, as shown in Figure 29 (CISS, 2020a). Awareness campaigns to change behaviour are crucial for increasing the enactment of particular actions known to promote health (Briscoe and Aboud, 2012). To be more effective, such best practices to reduce environmental and health risks have to be promoted involving community organizations and schools (Briscoe and Aboud, 2012, Leclert et al., 2018). As a consequence, at least one school per village will be involved, and children will receive brochures with figures. The objective will be to make people aware of the adverse health outcomes due to bad practices associated with waste management. Furthermore, through the campaign, the correct waste separation of two waste categories, i.e., biowaste and the others, will be promoted. It will be beneficial for a fair composting process using composting bins, to reduce the waste to dispose of in dumpsites, and to optimize waste collection with donkey carts.

Figure 29: WASH campaign to also improve hygiene habits related to solid waste among the rural villages involved in the project in Ghana (from CISS, 2020a)

- **Waste daily cover.** As discussed for Novi Sad, sites for waste disposal with inadequate daily cover are often subjected to many problems. Among the benefits, the daily cover allows to prevent or reduce the risk for infestation by flies and vermin and birds from scavenging (ISWA, 2019). Consequently, such activity will play a crucial role in contrast to the spread of infectious and vector-borne diseases. The soil cover layer will have a minimum of 10 cm thick, as suggested by ISWA (2019) to be incisive in this regard. The best scenario would be represented by a daily cover of 20 cm to be very useful in control vermin for a while (ISWA, 2019). However, given the boundary conditions characterizing the rural villages, the 10 cm coverage would represent a good result if carried out at least three times per week. To achieve such objective, readily available inert soil near the dumpsite can be used. Volunteers among residents in each village should be found. Each volunteer will have to receive PPE such as a mask, gloves, boots, a shovel, a wheelbarrow. They will also attend a safety and training programme. The size and new location that will be agreed for every dumpsite will determine the required number of people to involve. It could be ambitious to find many volunteers for such activity, but it appears more straightforward than regularly paying someone to do it. However, the action and the "call for volunteers" will be discussed during meetings with local stakeholders in each village to find the most appropriate solution to this challenge. It is important to note that waste cover can allow reducing other risks as well. As a consequence, it is strongly recommended to carry it out.

Another event for which control measures have been conceived was the "**free movement of people in the dumpsite**" and the related hazard "**inhalation, ingestion and/or dermal contact with contaminants**". Indeed, in most communities, it was scored with high risk. For such an event, many of the control measures discussed above would also have benefits. Indeed, **"waste coverage"** would reduce the direct contact with contaminants for people that walk in the landfill. **"Awareness campaign to improve hygiene habits related to solid waste"** can induce people to pay attention when they go to dumpsites and discourage children from playing in there. Besides, **"locate dumpsites further away"** may represent another intervention able to reduce the presence of people, and children in particular, within dumpsites. An additional control measure is discussed below.

- **To build a fence around each dumpsite**. A fence represents an access control system. It makes clear boundaries and limits of a site; it needs channels access and egress and provides visual barriers (APTA, 2010). It has the aims to support security and safety, and deter or at least make difficult and delay intrusion and trespassing.

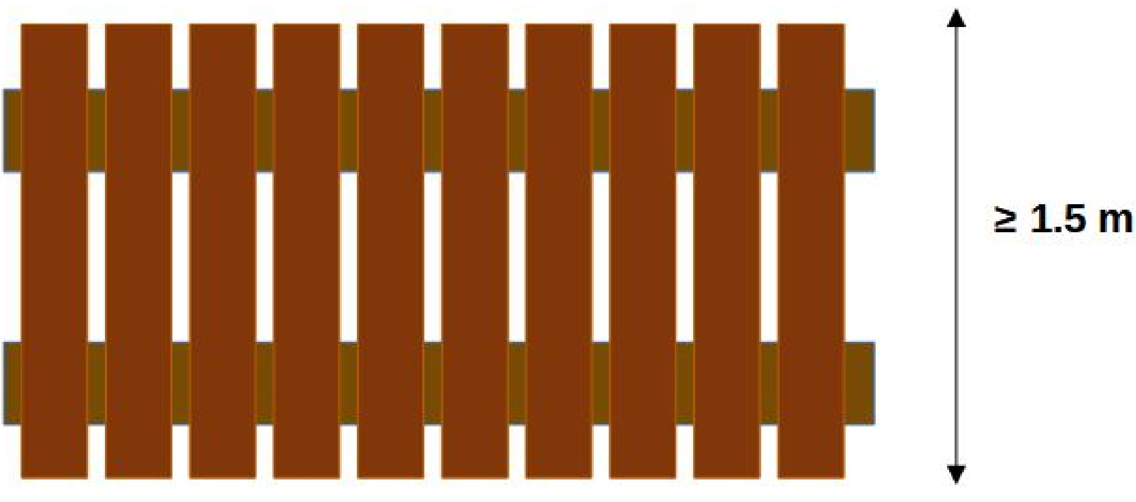

Figure 30: Wooden fence to protect dumpsites

Fencing system material, construction, installation method and fencing design are crucial to determining the most appropriate fencing system selection for a specific context (APTA, 2010). For the Ghanaian villages involved in the research, a wooden fence around each dumpsite was planned. The total length of the borders will be related to the size of each dumpsite, but they should be helpful to prevent the entry of both children and farm animals. As a consequence, as shown in Figure 30, a minimum height of 1.5 meters is suggested. Furthermore, the distance between the two axes should not be more than 5 cm to prevent poultry crossing.

"**Spread of contaminants in the air**" was the last hazardous event associated with the "disposal of solid waste in dumpsites" that was evaluated having high risk; but just in village #1, where a bigger dumpsite in the core of the inhabited centre was placed. Many of the control measures discussed above can be implemented to reduce such a risk. In particular, **"locate dumpsites further away"** with all the related activities, represent the first more effective intervention. Furthermore, **"waste coverage"** carried out at least two times per week will reduce the spread of contaminants in the air and will contribute to controlling the odours (ISWA, 2019). Besides, **"to reduce the organic fraction of waste disposed of in dumpsites"** through the activities aforementioned will allow producing a less amount of biogas. Indeed, biogas is generated in landfills and dumpsites, where organic waste is disposed of (ISWA, 2019). As already shown, it consists mainly of methane and carbon dioxide, but it contains many other chemicals, such as nitrogen, oxygen, sulphides, mercaptans, VOCs, ammonia, carbon monoxide, and many others (ISWA, 2019). As a consequence, the distribution of composting bins among people will play a crucial role in reducing the amount of organic fraction disposed of in the dumpsite.

Table 40: Risk matrix with the control measures conceived for the disposal of solid waste in dumpsites among the Ghanaian rural villages

Hazardous events	Hazards	Level of Risk	Control measures
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	**VH**	• To reduce the organic fraction of waste disposed of in dumpsites • Locate dumpsites further away • Awareness campaigns to improve hygiene habits related to solid waste • Waste daily cover
Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	**H**	• Locate dumpsites further away • Awareness campaigns to improve hygiene habits related to solid waste • Waste daily cover • To build a fence around each dumpsite
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	**H**	• To reduce the organic fraction of waste disposed of in dumpsites • Locate dumpsites further away • Waste daily cover

The control measures related to the disposal of solid waste in dumpsites discussed above are summarised in the last column of Table 40. The level of risk shown in the Table is the maximum identified among the nine villages. An estimate of the costs associated with these interventions is presented in section 4.6 (Cost Analysis).

Considering the SWM practice defined as **"open burning of waste"**, only a dangerous hazardous event was identified, i.e., "spread of contaminants in the air", associated with the hazard **"inhalation, ingestion and/or dermal contact with contaminants"**. However, the risk resulted very high in all the nine villages. The following control measures were identified to reduce it.

- **Awareness campaigns against waste combustion.** Such activity will be essential in stopping the harmful practice of open burning of waste. The field survey carried out in November 2019 highlighted that inhabitants burn waste because it appears the simplest way to obtain waste volume and mass reduction. As previously discussed waste collection by local authorities is not adequate, also taking into account the isolation and inaccessibility that characterizes most of the rural villages, and waste tends to accumulate in inhabited areas. Not by chance, waste burning is more common in areas where waste collection services are not comprehensively provided (Cook and Velis, 2020). People are usually unaware of the health risk waste combustion will bring. Accordingly, specific awareness campaigns will be carried out in all the nine villages. In such activity, chiefs of the communities and other strategical stakeholders will be involved. The awareness campaigns will be characterized by workshops, distribution of leaflets and posters placed around the villages. During such activities, people will be explained not to burn waste, not even in dumpsites, deepening the risks they would face following the combustion of waste. As shown in Figure 29, some activities already started, following the making of a manual (Vinti et al., 2020b) whose Annex included a series of best practices to reduce environmental and health risks. However, on the one hand, such awareness campaigns were hampered by the pandemic (Covid-19); on the other hand, some future workshops should focus on waste combustion. However, as discussed in the next control measures, awareness campaigns alone risk being less effective if they are not combined with practical interventions to reduce the generation of waste that should be disposed of.

- **To reduce the organic fraction of waste.** Such control measure was already discussed in the relation of the SWM activities disposal of solid waste in dumpsites. The methodology to follow will be the same, and the reasons will be similar. The principle is to reduce the generation of waste to make people feel less of the need to burn it to reduce its volume. As previously discussed, organic fraction represents roughly two-thirds of the total amount of waste produced at the household level. As a consequence, it would be strategical to reuse it as compost. However, plastic waste plays a crucial role, as it is discussed in the next control measure.
- **Identify specific solutions to discourage the burning of plastic waste.** It must be noted that people tend to burn a lot of plastic waste because, unlike biowaste, it does not biodegrade. Unfortunately, plastic waste may generate dangerous contaminants such as dioxins (Zhang et al., 2017) and hydrocarbons (Simoneit et al., 2005). Therefore, a strategy to reduce the burning of plastic is needed. In the short-term, the first action should consist of encouraging people to dispose of plastic waste in a dumpsite in which it is forbidden to burn trash. Even if plastic waste represents less than 10% of waste generated at the household level (Miezah et al., 2015), it tends to

accumulate because of its persistence in the environment excessively. As a consequence, in the long-term, appropriate solutions have to be found. Recycling of waste could represent a strategical choice, but it could be very challenging at the level of rural villages. Probably, a systematic collection of waste involving all the villages at the district level could be the winning choice, also taking into account that plastic waste usually does not generate foul odours. However, as aforementioned, the initial activity will induce people to dispose of plastic waste in dumpsites, banning waste burning activities.

Table 41: Risk matrix with the control measures conceived for the open burning of waste among the Ghanaian rural villages

Hazardous events	Hazards	Level of Risk	Control measures
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	**VH**	• Awareness campaigns against waste combustion. • To reduce the organic fraction of waste • Identify specific solutions to discourage the burning of plastic waste

The control measures related to the open burning of waste discussed above are summarised in the last column of Table 41. An estimate of the costs associated with these interventions is presented in section 4.6 (Cost Analysis).

The SWM activity **"uncontrolled burying of solid waste"** was identified in three out of nine villages. However, except for village #5, it was not possible to establish the presence or absence of such activity in the other inhabited areas, as a consequence, the risk was not evaluated (NA). The control measures to deal with the hazardous event **"feed for rodents and other animals (including insects)"** and the hazard **"infectious and vector-borne diseases"** are discussed below, taking into account the risk was evaluated as very high.

- **Awareness campaigns to discourage the burial of waste**. Such a practice is similar to that of disposing of waste in dumpsites. However, it was noted very close to houses because usually, people built traditional houses using soil. As a consequence, they make a hole to exploit the terrain as a building material. Examples were already shown in Figure 23. In particular, during the filling phase, the risk of spread infectious and vector-borne diseases appears very relevant. People need to be made aware of the risk. However, it must be admitted that burning waste decreases bioactivity, and animals are less likely to feed, breed, and transmit pathogens (Cook and Velis, 2020). But it would be contradictory to discourage burning waste in a control measure and promote it in another one. Moreover, as already discussed, uncontrolled burning of waste can cause other adverse health outcomes. As a consequence, even if tempting, during the awareness campaign, the burning of waste in holes must be discouraged as well. Such a campaign must be necessarily conducted in the three villages where the activity was observed (villages #6, #7 and #9). In the other villages, it would be advantageous as well, both because currently it is not known if it is conducted and to discourage such activity in the future.

- **Waste daily cover**. In places in which such an event is currently happening, the daily waste coverage must be promoted. Indeed, it minimises the availability of the food source for birds (ISWA, 2019). Furthermore, regular placement of cover soil can prevent the emergence of flies (ISWA, 2019). But a minimum of 10 cm of coverage is suggested (ISWA, 2019). To achieve such objective, readily available inert soil from nearby can be used.

The control measures related to the open burning of waste discussed above are summarised in the last column of Table 42. An estimate of the costs associated with these interventions is presented in section 4.6 (Cost Analysis).

Table 42: Risk matrix with the control measures conceived for the uncontrolled burying of solid waste among the Ghanaian rural villages

Hazardous events	Hazards	Level of Risk	Control measures
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	**VH**	• Awareness campaigns to discourage the burial of waste. • Waste daily cover

The SWM activity **"reuse of solid waste from dumpsites as compost by local farmers"** was only identified in village #5. To understand if such a practice is conducted in other villages, further investigations are needed. However, it does not seem very common. High risk was associated with "**spread of contaminants into the soil**" and the related hazard "**inhalation, ingestion and/or dermal contact with contaminants**". The proposed control measures are discussed below.

- **Separation of the organic fraction of waste at the source**. As anticipated with the control measures proposed for disposal of solid waste in dumpsites, in village #5 the composting bins at the household level should be substituted by bins for periodic collection of biowaste. Indeed, in such community, organic waste produced at the household level is already used by farmers. Unfortunately, as aforementioned, there is not waste separation at the source, and farmers take all the waste from dumpsites; then, they separate the organic waste from the rest by themselves. To conceive a separate waste collection at source will allow reusing safer organic waste. Indeed, source separation of organic waste can prevent contact with heavy metal-bearing items and other contaminants, resulting in the production of compost of higher quality (Wei et al., 2017). Source separation of organic waste has been demonstrated effective in developing countries, as it was recently shown by Yeo et al. (2020) in Côte d'Ivoire. The results of two control measures already discussed to reduce the risks related to the disposal of solid waste in dumpsites can be taken as a reference; particularly, the actions **"to reduce the organic fraction of waste disposed of in dumpsites" and "to locate dumpsites further away"**. As a consequence, 1128 bins for the collection of biowaste will be needed (Table 37), i.e., one bin per family. A door-to-door collection with donkey carts will be carried out. The organic waste prod uced in the village will result in about 4.8 ton/week, and five donkey charts will be necessary, assuming a weekly collection. It must be highlighted that such a waste collection frequency can be too low, and waste can generate bad smells. But a higher frequency could be too expensive because it would require double the number of donkey carts. Furthermore, currently, inhabitants do not pay for waste collection from dumpsite and farmers do it because they see waste as a resource, though the high level of contamination of the compost they use. As a consequence, a weekly organic waste collection would represent a positive first step towards a healthy environment in village #5. Such waste collection can be integrated with that previously discussed talking about dumpsites. Indeed, the same donkey carts could collect two different waste flows, i.e. the organic fraction and the others. As previously noted, the transport per donkey cart's capacity would be far below the operative values mentioned by other authors (Shah et al., 2019) and no further donkey carts would needed. In this way, no additional payments will be required for the organic waste collection.

- **Awareness campaigns to encourage organic waste separation at the source**. Correct waste separation at the source will be crucial to obtaining a high-quality compost (Vicente and Reis, 2008). Specific awareness campaigns will be carried out. Chiefs of the communities and other strategical stakeholders will be involved. The awareness campaigns will be characterised by workshops, distribution of leaflets and posters placed around the villages. People will be made aware of the essential role played by an accurate waste separation and of the related environmental and health benefits. As shown in Figure 29, some communication campaigns already started. Still, if the separate waste collection will start, and the organic fraction will be sent to local farmers, such a campaign will have to be more specific, and an agreement with local farmers will be signed.

The control measures related to the **"reuse of solid waste as compost by local farmers"** discussed above are summarised in the last column of Table 43. An estimate of the costs associated with these interventions is presented in section 4.6 (Cost Analysis).

Table 43: Risk matrix with the control measures conceived for the reuse of solid waste as compost by local farmers (in village #5)

Hazardous events	Hazards	Level of Risk	Control measures
Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	**H**	• Separation of the organic fraction of waste at the source • Awareness campaigns to encourage organic waste separation at the source

4.6 Cost analysis

4.6.1 The case study in Serbia

As anticipated, in the first approximation, a cost analysis was carried out to outline the cost of the proposed control measures. Although in Serbia, exchanges of opinion with local stakeholders and on-field missions and further investigations will be needed, defining the order of magnitude of each action's cost is already possible. Such a procedure plays a strategical role, allowing to move from a theoretical to a practical approach.

The first and only hazardous event evaluated in Serbia as with very high risk was the "leaking of leachate in groundwater" associated with the hazard "groundwater contamination (and human consumption)". As previously discussed, to reduce such a risk, a control measure was **"the final top cover of landfill section III"**, and the total surface was 64,000 m^2. Unfortunately, the scientific literature lack of cost analysis related to case studies in Serbia. Therefore, the Italian legislation regarding the final top cover of landfills based on the European directives was taken as a reference (D.Lgs. 36/2003). In line with this choice, an estimate of the cost was conducted based on the values from Pivato et al. (2018), in which the authors made their calculations based on the Italian legislation (D.Lgs. 36/2003). Consequently, the cost of 5,84 €/m^3 was considered. As discussed in section 4.5, the minimum thickness for the final top cover was assumed to be 2.5 m. As a consequence, the total volume resulted in 160,000 m^3 (i.e. 2.5×64,000 m^3). It determined the total cost of 934,400 €. It has to be highlighted that it is a first approximation cost, to give an idea of the possible order of magnitude of the interventions. Such a price in Serbia would probably be lower. However, the final top cover in sanitary landfill usually represents one of the most relevant costs (Pivato et al., 2018).

A further control measure identified consisted in **"water treatment systems at the household level"**. A very dangerous scenario would be represented by confirming contamination of the first aquifer in the whole area of the Klisa suburb (i.e. the closer to the landfill in the direction of the groundwater flow). In such a case, if about 50% of the people of Klisa and Veliki Rit would use groundwater wells that pump water from the first aquifer, the control measure would be costly. However, for what emerged until now, although it seems credible that such water is contaminated, it appears that few people consume the water from the first aquifer. As a consequence, this assumption represents a very precautionary approach. The minimum limit can be assumed with only 10% of the people that consume water from the first aquifer. However, in Novi Sad, there are both buildings and houses. Consequently, people that live in buildings could use a shared well. As anticipated, in the area live about 21,000 people (see Figure 26), i.e. about 9,460 families (taking Table 7 as a reference). Based on the previous assumptions, between 946 and 4,730 households could use water from the first aquifer in the zone. As aforementioned, considering buildings and houses, families that live in the same building could utilise a well in common, reducing the number of water well used. In the absence of detailed data in the area, four families per wells were assumed in the first approximation. Then, the wells on which to intervene were calculated, dividing the number of families by four and rounding up the result. Consequently, between 250 and 1200 wells were counted. In has to be highlighted, on-field investigations will be necessary to evaluate the wells' real number, as discussed in section 4.4. Still, the use of water filters could be extended to other areas of the city if needed. Besides, the cost of a water filter can vary a lot, as shown in Table 44. The performance required will depend on the actual level of water pollution, and it will determine the kind and the cost of a water filter. In the first approximation, it was assumed a water filter costing 400 €, to treat the water of a well. Reimbursement up to the 50% should be guaranteed by the public authority to encourage people buying it, i.e. up to 200 € per water filter. As a consequence, the cost of such control measures would range between 50,000 € and 240,000 €. It as to be considered that the higher value represents a very conservative assumption. To support the local market, also bearing in mind the concept of appropriate technologies (Sorlini et al., 2015), the local authority could sign an agreement with local dealers. Local vendors could grant further discounts to the population. The people of the suburb will be monitored for 12 months, to estimate the percentage of families that bought the filters. Furthermore, the rate of hospitalization and deaths in Novi Sad, before and after the intervention, should be monitored. Indeed, the improvement of water quality will allow reducing the costs related to adverse health outcomes. The activity could represent good administration experience that can be replicated in other contexts.

Table 44: Example of the cost of water filters

Water filter	Technology	Website (source)	Costs
Water filter #1	Reverse Osmosis	https://www.manomano.it/p/acqua-naturale-osmosi-inversa-ro-1500l-giorno-nw-ro400-e2-1811378#/description-anchor	379 €
Water filter #2	Reverse Osmosis	https://it.rs-online.com/web/p/kit-per-filtri-acqua/1952219/?cm_mmc=IT-PLA-DS3A-_-google-_-CSS_IT_IT_Nolabel_ME_Whoop-_-(IT:Whoop%21)+Kit+per+filtri+acqua-_-1952219&matchtype=&pla-329426751756&gclid=Cj0KCQiA6t6ABhDMARIsAONIYyxI8CD9LAclFF8ZS3mCVQchmw4SzAGtMkPGqtJwAsQNZZ6pOk2756AaAsLJEALw_wcB&gclsrc=aw.ds	716 €
Water filter #3	Micro-filtration 1 (50 µm) + micro-filtration 2 (10 µm) + UV disinfection	https://www.acquaxcasa.com/batteri-acqua/purificatore-dacqua-steril-p-736.html?from=kelkoo&gclid=Cj0KCQiA6t6ABhDMARIsAONIYyx6S7bwdVKMCG6HSfOd020KZd0qVTeZA9SOWHsB9J3PENt4i8CssDEaAtQFEALw_wcB&kk=a4c63611775ca4b81d1370f3&utm_campaign=kelkooclick&utm_medium=cpc&utm_source=kelkooit&utm_term=AcquaxcasaPurificatored5C27acquaSteril7	440 €
Water filter #4	Reverse Osmosis	https://www.almamedical.net/prodotti-medicali/tecno-gaz-sistema-di-depurazione-acqua-ad-osmosi-inversa-pura-8886.html	783 €

Always considering "leaking of leachate in groundwater" associated with the hazard "groundwater contamination (and human consumption)", a further control measure aiming at reducing the risk consists in **"awareness campaign and related actions"**. The cost of such an action can vary a lot. The distribution of leaflets among all the Novi Sad people (excluding the other settlements of the municipality shown in Table 7) will be conceived. An exhaustive leaflet per family, with detailed information and recommendations, will be distributed, for a total of 130,000 flyers. To estimate the cost for such distribution was crucial. The average of letters delivered by postmen was assumed as 2,500 units per day, considering 5 hours of work per day, taking Reinert and Lucio (2012) as a reference. Two people will be involved in the activity. Each of them will distribute a total of 65,000 leaflets and about 26 working days will be needed (i.e. 65,000/2,500). As a consequence, a total of 130 hours of work per person will be needed (i.e. 26×5). In Serbia, the minimum wage per hour is 1.79 € (Schulten and Luebker, 2019). A payment of 2 €/hour was assumed. The leaflets distribution cost would be 260 € per workers, i.e. 520 € in total. The price for printing the leaflets can vary a lot, but in the first approximation and considering the use of recycled paper, 0.05 € per brochure can be assumed, resulting in about 6,500 €. Furthermore, an expert from the University of Novi Sad should be involved in the preparation of the leaflet, with the appropriate information, and he can be paid 500 € in total. Summarising, the full cost of the control measure will be:

$$520+6,500+500=7,520\,€$$

Regarding "waste combustion", a control measure proposed for both "injuries (including burning injuries) by formal waste workers" and "inhalation, ingestion and/or dermal contact with contaminants by inhabitants" consisted in the **"implementation of a collection, transport and treatment system of biogas"**. Such a control measure was also conceived for the hazardous event "spread of contaminants in the air (excluding waste combustion)" and the related hazard "inhalation, ingestion and/or dermal contact with contaminants". As a consequence, it is a strategical control measure, that can lead to many benefits. Although further data would be needed, a first estimation of the cost was made possible, thanks to the already available information related to the Novi Sad landfill and literature data. Indeed, as already discussed, a study for landfill gas recovery at the Novi Sad Landfill (Vujic et al., 2012) was available, and it included handy information. Such data were integrated with a cost model proposed by the US EPA (2016a). It is important to note that the model was recently employed by Cudjoe and Han (2021) in African urban areas, significantly different from those in the United States. Consequently, it seems a tool applicable in very diverse contexts, at least to obtain a first estimation of the costs.

The capital cost of installing vertical gas extraction wells was calculated as follows (Cudjoe and Han, 2021; US EPA, 2016a):

$$C_1=EV_1\times Wells\times(D-10)$$

Where:

- C_1 = capital cost of installing vertical gas extraction wells.
- EV_1 = economic coefficient related to the equipment used. It was assumed as 85 USD based on scientific literature (Cudjoe and Han, 2021; US EPA, 2016a), equal to 69.7 €.
- Wells = the number of gas extraction wells, assumed as 172 (as previously discussed and shown in Figure 28).
- D = average waste depth (in feet). It was assumed 15 m (i.e., 49.2 feet) for all three landfill sections (Vujic et al., 2012).

C_1 resulted in 469,945 €.

The capital cost of installing wellheads and pipe gathering was calculated as follows (Cudjoe and Han, 2021; US EPA, 2016a):

$$C_2 = Wells \times EV_2$$

Where:

- C_2 = capital cost of installing the wellheads and pipe gathering.
- EV_2 = economic coefficient related to the equipment used. It was assumed as 17,000 USD based on scientific literature (Cudjoe and Han, 2021; US EPA, 2016a), equal to 13940 €.

C_2 resulted 2,397,680 €.

To calculate the capital cost of the knockout, blower, and flare system, the following equation was used (Cudjoe and Han, 2021; US EPA, 2016a):

$$C_3 = LF^{0.61} \times EV_3$$

Where:

- C_3 = capital cost of the knockout, blower, and flare system.
- LF = the methane flow rate, expressed in ft^3/min. Based on the study of Vujic et al. (2012), the Novi Sad landfill will be capable of producing, at its peak of gas production, 1,358 m^3/h of landfill gas. As a consequence, assuming a gas collection system efficiency of approximately 51% (Vujic et al., 2012), the maximum amount of collected gas will be 693 m^3/h, equal to 407.9 ft^3/min.
- EV_3 = economic coefficient related to the equipment used. It was assumed as 4,600 USD based on scientific literature (Cudjoe and Han, 2021; US EPA, 2016a), equal to 3,772 €.

C_3 resulted 147,570 €.

The total capital costs, i.e. C1 + C2 + C3, resulted 3,015,195 €. All the project components' lifetime was assumed to be 15 years (US EPA, 2016a). During the on-field investigations, it could emerge that some existing gas extraction wells (Figure 14) are in good conditions. It could lead to a reduction in capital costs, although some economy does not appear significant.

The annual operating and maintenance costs were assumed to be 7% of the total capital costs (US EPA, 2008), resulting in 211,063 €.

A further control measure, conceived for the two hazards mentioned above related to “waste combustion” and also for the “spread of contaminants in the air (excluding waste combustion)”, was the **“daily cover of waste”**.It has to be conducted every day in the part of the landfill in which waste is disposed of. Such activity will not be as expensive as the previous one. However, although it will not be as effective as the biogas collection system, it will further reduce the risks. In the first approximation, the daily cover cost was assumed as 0.58 €/m^3, taking Pivato et al. (2018) as a reference. Such unit cost represents a precautionary value because the authors estimated average sanitary landfill costs suitable for Northern Italy. As a consequence, in Serbia, the actual price for the daily cover will probably be lower. Furthermore, the landfill managers could propose using some daily cover less expensive and more available in the area of Novi Sad. After compaction in trucks, the waste density was assumed as 0.45 ton/m^3 (GIZ, 2019). Considering the waste collected every day in the municipality of Novi Sad (GIZ, 2019) and that less than 2% of the total is recovered as recyclable (IMG, 2016), the total amount of waste that is daily disposed of in the landfill is about 365 ton/day. As a consequence, the volume of waste daily disposed of is:

$$\frac{365}{0.45}=811.11\,m^3/\,year$$

Assuming that the daily cover material to use will be the 25% of the volume of waste disposed of in the landfill (Solan et al., 2010), it will be equal to a quarter of 811.11 m^3/day, i.e. 202.78 m^3/day. As a consequence, the annual operating cost related to the daily cover of waste can be calculated as follows:

$$0.58\times202.78\times365=49{,}928\,€/\,year$$

The annual cost for such operation can appear high, but as anticipated, it should be seen as the upper limit that could be reached. On-field visits and exchange of information with the local stakeholders (i.e. who manages the landfill) could significantly decrease such cost.

The **“implementation of safety and training programmes for waste workers”** was the last control measure conceived for the hazard “injuries (including burning injuries) by formal waste workers”. The training courses can be carried out at the landfill, to reduce the cost of such activity and the time required. All the waste workers have to be involved. An estimation of the costs can be made after defining the characteristics of the workshops. A week per year, a five-day seminar will be arranged. Two different teams will be involved in diverse workshops:

- Managers (i.e. the people with the responsibility for the facility's overall management) and supervisors (i.e. the people with the supervisory responsibility for a specific facility site or shift).
- Landfill operators.

For the first team (managers and supervisors), two groups will be set up. The same will be conceived for landfill operators. It will allow maintaining the landfill always operative. As a consequence, four different five-days seminars have to be scheduled. In every workshop, two trainers will be involved, and a total of eight trainers will be needed. In the region in which Novi Sad is placed, an average gross wage equivalent to 550 €/month can be assumed (Kostadinović and Stanković, 2020). However, after consultation with Professor Batinic, a weekly salary of 500 € per trainer was conceived, taking into account the trainers will be independent experts. Consequently, in the first approximation, the annual cost to address such a control measure will be 4,000 €.

A further control measure conceived for “inhalation, ingestion and/or dermal contact with contaminants by inhabitants”, associated with waste combustion, consisted in **“setting up a fast and efficient emergency population warning system”**. Such activity has to be implemented by the local authority through a public alert and warning system (PAWS) plan. It appears difficult to define the costs needed for such action without detailed information about the composition of the technical offices of Novi Sad's municipality. However, experts from the University of Novi Sad or other local institutions should be involved. A grant could be given conceiving an annual salary of 6,600 €, to appoint a full-time researcher in the preparation and follow-up implementation of the PAWS plan. Considering such a plan is done by some institution, and not only by an individual researcher, the action's total cost has been estimated in 10,000 €. However, the payment of such a research grant could be made by the PUC Cistoca or the local authority. Indeed, waste combustion seems mainly happen at the Novi Sad landfill. Based on current knowledge, it seems reasonable to assume that the local authority will implement and keep operative such a plan without looking for further employees. Indeed, the related situation (i.e. high smoke generation during significant waste combustion events at the Novi Sad landfill) happens two times per year. Furthermore, the local authority will be in strict contact with the firefighters. The plan will include communications activities, paying great attention to the most vulnerable groups of people in Novi Sad (e.g. the elderly, children, and respiratory diseases). The total cost for the design and implementation of such activity should only correspond to the research mentioned above (i.e. 10,000 €).

The last control measure discussed for the Serbian case study consisted of **"air filters at the household level"**. It aims to reduce the health risks related to the "spread of contaminants in the air" associated with the hazard "inhalation, ingestion and/or dermal contact with contaminants". As anticipated, to implement it, 9,460 air filters should be distributed at least among people of Klisa and Veliki Rit suburbs (Figure 26). The action could appear excessive, but recent studies highlighted significant health risks associated with air pollution in Novi Sad, in terms of PAHs (Radonić et al., 2017), SO_2 and NO_2 (Jevtić et al., 2014). As a consequence, such an intervention could even be extended to the whole population of Novi Sad, bringing to substantial long-term benefits, both under health and economic point of view. The public authority should conceive some incentives, considering that a 100% reimbursement could be too expensive to manage. In any case, the air pollution is not only due to the Novi Sad landfill, as highlighted by the studies mentioned above (Jevtić et al., 2014; Radonić et al., 2017), and it seems complicated to make the PUC Cistoca pay for such intervention. A solution could consist in an experimental phase, during which a 20% reimbursement only for people of Klisa suburb will be offered for 12 months. The local authority could offer it. The people of the suburb will be monitored for the 12 months, to estimate the percentage of families that bought the air filters. An air filter unit's cost can vary a lot, as shown in Table 45.

Table 45: Example of the cost of air filters

Air filter	Technology	Website (source)	Costs
Air filter #1	Pre-filter + Nano Filter + Activated carbon filter + HEPA filter	https://www.geekbuying.com/item/Proscenic-A8-Smart-Air-Purifier-4-stage-Filtration-System-White-426607.html?Currency=EUR#rdl	118 €
Air filter #2	Carbon fitler + HEPA filter	https://www.klavius.it/catalogo/prodotti/00Q9SMO0ZT	140 €
Air filter #3	HEPA filter	https://greatecno.com/it/salute-e-bellezza/141611-purificatore-d-39-aria-smart-home-xiaomi-3c-bianco-6934177722677.html?SubmitCurrency=1&id_currency=1	107 €

A maximum bonus of 40 € per family will be conceived, equivalent to a 40% reimbursement for a portable air filter of 100 €. Furthermore, bearing in mind the concept of appropriate technologies (Sorlini et al., 2015), the local authority could sign an agreement with local dealers to support the local market. Indeed, local vendors could grant further discounts to the population. The best (but more expensive) scenario would be represented by the purchase of air filters by all the people living in Klisa and Veliki Rit suburbs. It would lead to a maximum cost for the public authority of 378,400 €. However, such a scenario could appear too expensive. As a consequence, a 20% reimbursement could be conceived (i.e. 20 € per family). It would halve the maximum achievable cost, bringing it to 189,200 € (i.e. 20×9,460). However, the benefits above for the local markets have to be highlighted. If successful, the activity could represent good administration experience that can be replicated in other contexts.

The costs associated with all the control measures discussed above are summarised in the last column of Table 46 below.

Table 46: Matrix of health risk including the cost for the control measures

Hazardous events	Hazards	Control measures	Cost
Leaking of leachate in groundwater	Groundwater contamination (and human consumption)	The final top cover of landfill section III	934,400 € (total capital costs)
		Water treatment systems at the household level	Between 50,000 € and 240,000 € (total cost of incentives)
		Awareness campaigns and related actions	7,520 € (total costs)
Waste combustion	Injuries (including burning injuries) by formal waste workers	Implementation of a collection, transport and treatment system of biogas	• 3,015,195 € (total capital costs) • 211,063 €/year (operating and maintenance costs)
		Daily cover of waste	< 49,928 €/year
		Implementation of safety and training programmes for waste workers	4,000 €/year
Waste combustion	Inhalation, ingestion and/or dermal contact with contaminants by inhabitants	Implementation of a collection, transport and treatment system of biogas	See above
		Daily cover of waste	See above
		Setting up a fast and efficient emergency population warning system	10,000 € (total costs)
Spread of contaminants in the air (excluding waste combustion)	Inhalation, ingestion and/or dermal contact with contaminants	Implementation of a collection, transport and treatment system of biogas	See above
		Daily cover of waste	See above
		Air filters at the household level	189,200 € (total cost of incentives)

As can be noted, the highest costs are those related to the "implementation of a collection, transport and treatment system of biogas". Given the importance of such activity, the high level of risk, and considering that such a control measure would be beneficial for at least three out of the four previously discussed hazards, it appears crucial to find the needed funds. Other activities resulted in less expensive, but almost all of them require significant economic efforts. The proposed interventions are in line with the concept of appropriate technologies. As anticipated, before to implement them, field missions will be necessary. The costs summarised in Table 46 are indicative, to have an idea of the order of magnitude, and the actual prices are likely to be lower. Indeed, most of the costs were evaluated following a conservative approach.

4.6.2 The case study in Ghana

A cost analysis was also carried out in Ghana. It regarded the control measures conceived in the nine rural villages characterising the case study. Economic sustainability was crucial to be coherent with the concept of appropriate environmental technologies (Sorlini et al., 2015). As in Serbia's case study, exchanges of opinion with local stakeholders, on-field missions, and further investigations will be needed, but it is already possible defining the order of magnitude of each of the control measure aforementioned. The cost was estimated, considering that specific control measures would only be needed in particular villages. For instance, the actions aimed at reducing the “spread of contaminants into the soil” associated with the “reuse of solid waste as compost by local farmers” have currently been conceived only in village #5. The related international development cooperation project's objectives currently underway in Ghana (CISS, 2020b; Vinti et al., 2020b) were taken into account. Consequently, the choices, including economic ones, were made to make the proposed interventions sustainable in the long term. Therefore, whenever possible, an attempt was made to foresee interventions manageable by the rural communities' members.

Starting with the first **SWM practice**, i.e. **“disposal of solid waste in dumpsites”**, as aforementioned, three different hazardous events were identified with high or very high risk. The only hazardous event that, in some villages, resulted in very high risk was “feed for rodents and other animals” associated with the hazard “infectious and vector-borne diseases”. Four different control measures were conceived to reduce it. The first consisted in **“reducing the organic fraction of waste disposed of in dumpsites”**. Although no dumpsites were found in village #2, such an action will also be necessary for that village. As previously discussed, the best way to implement it consisted of converting waste in the resource as compost through the dissemination and use of composting bins. The only exception will be represented by village #5, in which the local farmers already use the organic fraction as compost. As a consequence, in that village, instead of composting bins, containers for the collection of biowaste will be distributed, as discussed later. Taking Table 37 as a reference, a total of 2,889 composting bins will be necessary (having excluded village #5). Based on the “Sustainable Livelihoods” project (CISS, 2020b), in the first approximation, the maximum cost for each composting bin was assumed 25 €. However, the project planned the distribution of a lower number of composting bins, at least during the first phase. In any case, conceiving the best scenario, all the composting bins would cost no more than 72,225 €. The distribution could not have any cost if some craftsmen dealt with the construction in each community. Such an operation does not appear very challenging given the simplicity that should characterize the composting bins realization (Vinti et al., 2020b; CISS, 2020b), in line with the concept of appropriate technologies (Sorlini et al., 2015).

The second control measure consisted in **“locate dumpsites further away”**. In this case, the costs associated with the waste collection activities were considered. Indeed, as discussed above, dumpsites should be placed at least 1000 m from dwellings, but excessive distances could discourage the population from using them (Coffey and Coad, 2010). Waste collection through donkey carts was conceived to overcome such a risk. Taking Table 39 as a reference, 22 donkey carts and waste collectors will be needed. In the rural areas involved in the project, a market survey conducted remotely, also with the support of the local CISS staff, allowed to estimate the capital and operating costs. The living wage for rural areas of Ghana (Smith et al., 2017) was used to calculate the waste collectors' minimum salary. The living wage is defined as the gross wage required for a basic but decent living standard (Smith et al., 207). It is calculated before considering in-kind benefits that workers receive, which can reduce the need for cash income (Smith et al., 2017). According to Smith et al. (2017), the Volta Region's living wage (i.e. a bit south to the areas of the project) corresponds to 143 € per month. Although the value could appear low, it is much higher than the minimum wage in Ghana. Indeed, the minimum gross salary equates to about 36 € per month (Smith and Sarpong, 2018). Furthermore, in Northern Ghana, waste collection with donkey carts is already conducted (Bellwood-Howard, 2012). As a consequence, waste pickers who already own donkey carts will be hired. If such workers would not be available in some of the nine villages, local farmers who own donkeys should be involved, and some members of their families could be hired for the job. In any case, a cycle of workshops for the waste collectors will be carried out. A total of nine workshops will be conducted. Every workshop will last three days. A local expert will hold the workshops. He will receive a gross salary of 200 € per workshop, i.e. 1,800 € in total. Such seminars should be paid through governmental funds or international development cooperation projects (such as the "Sustainable Livelihoods" project). Regarding the operating costs, keeping in mind the concept of appropriate technologies (Sorlini et al., 2015) and the need for long-term sustainability, it will be necessary that villagers find the way to pay the waste collectors at the community level. The first but more expensive solution would consist of 22 waste collectors' monthly payment at 143 € each one. In such a case, the monthly and annual cost for the waste collectors in every are shown in Table 47.

Table 47: The monthly and annual cost of waste collectors with donkey carts in each village

Village	Donkey carts and waste collectors needed	Monthly cost	Annual cost	Monthly cost per household	Annual cost per household
#1	4	572 €	6,864 €	0.74 €	8.93 €
#2	1	143 €	1,716 €	0.65 €	7.76 €
#3	4	572 €	6,884 €	0.73 €	8.83 €
#4	3	429 €	5,148 €	0.83 €	9.90 €
#5	5	715 €	8,580 €	0.63 €	7.61 €
#6	1	143 €	1,716 €	3.11 €	37.30 €
#7	2	286 €	3,432 €	0.75 €	9.01 €
#8	1	143 €	1,716 €	1.00 €	12.00 €
#9	1	143 €	1,716 €	4.93 €	59.17 €

The total annual cost, considering all the villages, would be:

$$143\,€/month \times 12\,months \times 22\,waste\ collectors = 37{,}752\,€/\,year$$

However, as can be noted in Table 47, in the two smaller villages (i.e. villages #6 and #9) the monthly cost of the service per household is the highest. Indeed, the minimum price related to using a single donkey cart per month should always be 143 €. Considering that it would probably be too expensive in some communities, an alternative solution could consist of payment in kind through subsistence. It would allow dealing with the mentioned costs. The approach could be easier to implement if the waste collectors would be the same community members.

Furthermore, bins for separate waste collection (i.e. excluding organic waste for composting) will be distributed to each household. As a consequence, a total of 4,017 bins will be acquired for all the villages. A single bin's cost can be assumed as lower than that of the composting bins aforementioned, and equal to 15 €, for a total of 60,255 €. Finally, PPE (mask, gloves, boots) will be distributed among waste collectors. After consulting the CISS staff in Ghana, the unit cost was assumed as 25 €, for a total of 550 € (25×22 €).

The third control measure conceived to the deal with "infectious and vector-borne diseases" consisted in **"awareness campaigns to improve hygiene habits related to solid waste"**. As anticipated, some awareness campaigns already started, but they were partially hampered by the pandemic (Covid-19). Through the action, also waste collection will be promoted. For the specific campaign, an expert has to be involved in explaining at the community level good practices, and a cycle of seminars at the local level will be held. Taking into account the current expenses seen in the villages already involved in similar actions (CISS, 2020a), the cost in leaflets and poster printing, and workshops, should be 300 € per village involved. In the expense, the roads' bad quality and the need for a jeep were taken into account. As a consequence, the total cost for such a control measure was estimated in 2,700 €.

The last control measure conceived to reduce the risks of "infectious and vector-borne diseases" related to waste disposal in dumpsites was the **"waste daily cover"**. However, as mentioned, even a waste cover of only three times per week would positively reduce the health risks. For the daily cover, free of charge material should be used - for instance, foundry sands, river silts or ashes (ISWA, 2019). Furthermore, to guarantee the long-term sustainability of such an action, volunteers among the communities will be looked for. The number of volunteers per village should be proportional to donkey carts previously calculated (double, if possible). The estimate of volunteers per village is shown in Table 48, for a total of 44 people. In any case, the volunteers will receive PPE and working tools (i.e. mask, gloves, boots, a shovel, a wheelbarrow), that will represent the only capital cost needed. After consulting the CISS staff in Ghana, the PPE and working tools kit cost was assumed in 50 € per person. It resulted in a total of 2,200 €.

Table 48: Volunteers required in each village for waste coverage

Village	Volunteers for waste coverage
#1	8
#2	2
#3	8
#4	6
#5	10
#6	2
#7	4
#8	2
#9	2

Always for the SWM activity “disposal of solid waste in dumpsites”, considering the hazardous event “free movement of people in the dumpsite” associated with the hazard “inhalation, ingestion and/or dermal contact with contaminants”, four control measures were conceived. However, three out of four actions corresponded to the same of the previous hazardous event (i.e. locate dumpsites further away; awareness campaigns; waste (daily) cover). The additional control measure was the **“build of a fence around each dumpsite”**. Unfortunately, to estimate such a cost was pretty tricky. Indeed, it needs to be anticipated by further field missions that will define the size of the current dumpsites to calculate the total length of each fence in every village. Furthermore, as previously discussed, most of the dumpsites should be moved away; in this case, the abandoned dumpsites should still be fenced off. However, waiting for more details, in case of lack of funds, even the villagers could be involved in building fences to reduce the risk of contact with contaminants.

The hazardous event “spread of contaminants in the air” associated with “inhalation, ingestion and/or dermal contact with contaminants” in dumpsites was evaluated as high risk only in village #1. Furthermore, three of the four control measures already conceived for the hazard “infectious and vector-borne disease” were the same needed for this event. The actions to reduce the health risk were locating dumpsites further away, waste (daily) cover, and reducing the organic fraction of waste disposed of in dumpsites.

The costs associated with all the control measures related to the SWM practice of disposal of waste in dumpsites are summarised in the last column of Table 49.

Table 49: Disposal of solid waste in dumpsites - Matrix of health risk including the cost for the control measures

Hazardous events	**Hazards**	**Control measures**	**Cost**
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	Reducing the organic fraction of waste disposed of in dumpsites	72,225 € (total capital costs)
		Locate dumpsites further away	• 1,800 € (total cost of workshops) • 37,752 €/year (operating cost, that could be reduced by payment in kind) • 60,225 € (capital cost for collection bins) • 550 € (cost of PPEs)
		Awareness campaigns to improve hygiene habits related to solid waste	2,700 € (total costs)
		Waste (daily) cover	2,200 € (total costs)
Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	Locate dumpsites further away	See above
		Awareness campaigns to improve hygiene habits related to solid waste	See above
		Waste (daily) cover	See above

		To build a fence around each dumpsite	If possible, action voluntarily carried out by the villagers
Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	Reducing the organic fraction of waste disposed of in dumpsites	See above
		Locate dumpsites further away	See above
		Waste (daily) cover	See above

The **SWM practice "open burning of waste"** was performed in all the villages, and the hazardous event "spread of contaminants in the air" was always evaluated with very high risk. Open burning of waste is a dangerous activity to discourage strongly. To deter such a practice, reducing waste to dispose of or to burn will play a crucial role. With this in mind, one of the control measures conceived consisted in **"reducing the organic fraction of waste"** through the use of composting bins at the household level. The action is the same proposed for the previous SWM practice (i.e. disposal of solid waste in dumpsites). Consequently, the expenses will be the same as before, and it will be enough to consider them only once.

Another control measure consisted in **"awareness campaign against waste combustion"**. It can be integrated with a similar control measure discussed for "disposal of waste in dumpsites", i.e. "awareness campaigns to improve hygiene habits related to solid waste". The same local experts could examine the threats related to waste combustion during the same workshops. In this way, it would be possible to save money and optimize time.

The last control measure would require meeting with experts, involving local stakeholders such as villagers and their representatives. The action consisted of **"identify specific solutions to discourage the burning of plastic waste"**. As already discussed, the solution would consist of disposing of plastic in dumpsites in the short-term, forbidding waste combustion. Such activity should be carried out by local experts and member of the CISS staff, in contact, remotely, with researchers of the University of Brescia that are already involved in the Sustainable Livelihoods project. The cost for such an action should not be very high, and lower than that required for the awareness campaigns. It was estimated as 150 € per village, for a total of 1,350 €.

The costs for all the control measures related to the SWM practice of open burning of waste are summarised in the last column of Table 50 below.

Table 50: Open burning of waste - Matrix of health risk including the cost for the control measures

Hazardous events	**Hazards**	**Control measures**	**Cost**
Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	Reducing the organic fraction of waste	See above
		Awareness campaigns against waste combustion	2,700 € (total costs, possibly to be combined with the similar ones mentioned before)
		Identify specific solutions to discourage the burning of plastic waste	1,350 € (total costs)

The **SWM practice “uncontrolled burying of solid waste”** was currently identified only in three villages (i.e. #6, #7, and #9). As a consequence, the control measures were conceived for a few villages, influencing the total costs. The hazardous event with very high risk consisted of “feed for rodents and other animals” associated with the hazard “infectious and vector-borne diseases”. Starting with the assumption that the uncontrolled burial of waste has to be deterred, the first control measure identified consisted of **“awareness campaigns to discourage the burial of waste”**. The expenses were evaluated in 300 € per village, for a total cost of 900 €, taking the awareness campaigns aforementioned as a reference.

Considering the **“waste daily cover”**, it will be necessary for those households who are not willing to stop the practice in the short term. However, the waste cover will be free of charge because it should be carried out by the families that own such ditches.

Consequently, the cost for the control measures related to the SWM practice of uncontrolled burying of solid waste would be very. They are summarised in the last column of Table 51 below.

Table 51: Uncontrolled burying of solid waste (in villages #6, #7, #9) - Matrix of health risk including the cost for the control measures

Hazardous events	Hazards	Control measures	Cost
Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	Awareness campaigns to discourage the burial of waste	2,700 € (total costs)
		Waste (daily) cover	Carried out voluntarily

The last **SWM practices** considered was the **“reuse of solid waste from dumpsites as compost by local farmers”**. As already discussed, it was ascertain only in village #5. As anticipated, the related control identified to reduce the health risk duet to “spread of contaminants into the soil” can be integrated with some already conceived for other practices. Indeed, one action should consist in the **“separation of the organic fraction of waste at the source”**, to obtain a good quality compost. In village #5, 1128 bins for the collection of biowaste will be needed. The price of each of them will be the same of the bins discussed for disposal of waste in dumpsites, i.e. 15 € each. The total cost will be 16,920 €. It has to be considered that village #5 is the most populous. However, regarding the cost for waste collection with donkey carts in village #5 was already calculated and it is shown in Table 47. As a consequence, if the control measure previously discussed and named “locate dumpsites further away” will be implemented, additional operating costs for waste collection will not be needed.

Regarding the other control measure conceived, i.e. **“awareness campaign to encourage organic waste separation at the source”**, it can be easily integrated the similar ones discussed for “disposal of solid waste in dumpsites”. As a consequence, additional costs would not be required.

The costs for the control measures related to this last SWM practice are summarised in the last column of Table 52.

Table 52: Reuse of solid waste from dumpsites as compost by local farmers (in village #5) - Matrix of health risk including the cost for the control measures

Hazardous events	Hazards	Control measures	Cost
Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	Awareness campaign to encourage organic waste separation at the source	Can be integrated with those of Table 49
		Separation of the organic fraction of waste at the source	16,920 € (total cost)

All the control measures conceived for the Ghanaian villages have been based on the concept of appropriate technologies. The most expensive was "reducing the organic fraction of waste disposed of in dumpsites" and "locate dumpsites further away". The actions were mainly related to the SWM practice "disposal of solid waste in dumpsites". However, the costs are mostly related to the purchase of bins and the salary of waste collectors. As aforementioned, the compensation could be reduced by payment in kind. Consequently, most of the costs should be affordable for the communities, but further field missions will be necessary. Indeed, many activities need to be agreed with the villagers because long-term sustainability is entrusted to local stakeholders.

The costs for all the control measures related to the case study in Ghana are summarised in Table 53. In the table, all the SWM practices are considered.

Table 53: Matrix of health risk including the cost for the control measures, summarising all the SWM practices conceived in Ghana

SWM practice	Hazardous events	Hazards	Control measures	Cost
Disposal of solid waste in dumpsites	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	Reducing the organic fraction of waste disposed of in dumpsites	72,225 € (total capital costs)
			Locate dumpsites further away	• 1,800 € (total cost of workshops) • 37,752 €/year (operating cost, that could be reduced by payment in kind) • 60,225 € (capital cost for collection bins) • 550 € (cost of PPEs)
			Awareness campaigns to improve hygiene habits related to solid waste	2,700 € (total costs)
			Waste (daily) cover	2,200 € (total

				costs)
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	Locate dumpsites further away	See above
			Awareness campaigns to improve hygiene habits related to solid waste	See above
			Waste (daily) cover	See above
			To build a fence around each dumpsite	If possible, action voluntarily carried out by the villagers (however, further field missions are needed)
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	Reducing the organic fraction of waste disposed of in dumpsites	See above
			Locate dumpsites further away	See above
			Waste (daily) cover	See above
Open burning of waste	Spread of contaminants in the air	Inhalation, ingestion and/or dermal contact with contaminants	Reducing the organic fraction of waste	See above
			Awareness campaigns against waste combustion	2,700 € (total costs, possibly to be combined with the similar ones mentioned before)
			Identify specific solutions to discourage the burning of plastic waste	1,350 € (total costs)
Uncontrolled burying of solid waste	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	Awareness campaigns to discourage the burial of waste	2,700 € (total costs)
			Waste (daily) cover	Carried out voluntarily
Reuse of solid waste from dumpsites as compost by local farmers	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	Awareness campaign to encourage organic waste separation at the source	Can be integrated with those of Table 49
			Separation of the organic fraction of waste at the source	16,920 € (total cost)

5 CONCLUSIONS

This research represents the first step towards a Solid Waste Safety Plan. As discussed, in the last years, Safety Plans have been developed in both Drinking Water (Davison et al., 2005) and Wastewater (WHO, 2015) fields. Given the significance of the topic, they were promoted by WHO. However, even solid waste if not adequately managed can lead to high health risks (WHO, 2016b), and the preparation of a Solid Waste Safety Plan has been the main objective of the PhD thesis. This first attempt of safety plan focused on MSW, taking into account the topic's breadth and novelty.

As discussed, a preliminary sub-objective consisted in carrying out a systematic review of the most recent scientific literature that has analysed MSW practices and adverse health outcomes. The review allowed to have a broader vision on the topic, instrumental for developing the MSWSP. To define the general structure of the MSWSP represented the other sub-objective of the research, alongside the identification of case studies to test it.

The systematic review confirmed the prevalence of detailed studies related to incinerators and sanitary landfills. However, some good investigations on dumpsites were identified. It was crucial to find four cross-sectional studies that have dealt with infectious and vector-borne diseases and dumpsites (Abul, 2010; Babs-Shomoye and Kabir, 2016; Sankoh et al., 2013; Suleman et al., 2015). Indeed, in most cases, in the last 15 years, vector-borne diseases have not been adequately discussed in previous reviews. Unfortunately, it also emerged the paucity of data regarding the open burning of waste and health outcomes. It was in line with what recently highlighted by Cook and Velis (2020). The systematic review allowed to find some evidence of an increased risk of adverse birth and neonatal outcomes for residents near landfills, incinerators, and dumpsites/open burning sites. There was also some evidence of an increased risk of mortality, respiratory diseases, and adverse mental health effects associated with residing near landfills. Additionally, there was some evidence of increased risk of mortality associated with living near incinerators. However, in many cases, the evidence was inadequate to establish a strong relationship between a specific exposure and outcomes. The characteristics of the studies prevented a meta-analysis. Indeed, substantial differences emerged regarding settings, populations, study designs, contexts, MSW management practices, exposure assessment, case definitions, outcome definitions and outcome assessment.

For the structure of the safety plan, both WSP and SSP were taken as a reference. However, an additional section was dedicated to the cost analysis. It represented a novelty that can help define the most appropriate interventions, giving an order of magnitude of their cost. A further crucial point consisted of the health risk assessment matrices. They have been applied in drinking water (WSP) and wastewater (SSP), but not yet exhaustively in the field of solid waste. Only Cook and Velis (2020), recently, made a health risk matrix associating it with waste management practices. However, their work did not focus on a procedure similar to that described in this thesis. Indeed, the matrix they fulfilled played a more general role. Instead, in this thesis, the risk matrices assumed specific importance associated with various hazardous events identified for each case study. The scale of values used, in terms of severity and likelihood, was essential. As already discussed, the values that were assumed can be modified, according to various contexts' needs. It was possible to consider and compare different hazardous events using a common yardstick through the risk matrices. Therefore, the interventions were prioritised based on the risk level.

Two very different case studies were identified. Indeed, the MSWSP was implemented in some small rural villages in Ghana and in Serbia's big urban centre. It highlighted the versatility of the MSWSP.

As a consequence, the main question was answered positively. The development of a solid waste safety plan has proved possible. The benefits that could originate from it are enormous and, like WSP and SSP, the application appears to be extensively possible, both in developing and industrialised countries. Although there is a greater need for such interventions in developing countries, i.e. where the waste management is generally worse (Wilson et al., 2015), the MSW management can often be improved even in industrialised countries.

The MSWSP should be of interest for many stakeholders, such as inhabitants of the communities, local administrations, public or private companies that manage the solid waste sector, NGOs that deal with MSW management in the context of international cooperation.

However, further research will be needed. In particular, the systematic review showed the need for more advanced studies regarding dumpsites, the uncontrolled combustion of waste and health risks. It would be useful to conduct epidemiological studies to fill this gap. The concentration of contaminants in humans and animals should be monitored as well. In this case, the biomonitoring studies of Parera et al. (2013), Scaramozzino et al. (2019) and Xu et al. (2019a; 2019b) can be taken as a reference. Even if they were applied to incineration plants and sanitary landfills, such investigations seem to adapt well to dumpsites and open burning. Furthermore, through the systematic review, the lack of epidemiological studies analysing the health outcomes associated with composting plants, anaerobic digesters, transfer stations and recycling plants emerged. Besides, vector-borne diseases should be better assessed.

Going into the detail of further research and advances that will be necessary concerning the MSWSP, it would be appropriate to open a broader discussion on risk matrices within the scientific community. The matrices represent a crucial element of the safety plan. As already discussed, it is possible to compare dangerous events that are profoundly different from each other, through a standard scale of assigned values. Although it has been highlighted that it will also be up to the MSWSP team members to establish the matrix's specific characteristics, a general structure should be shared. It would allow adapting the matrix to the various case studies analysed. Something similar has already been done in the SSP (WHO, 2015) taken as a reference in this work. Other information on the risk is also available in the WHO (2016a) document concerning microbiological risk in water. The application of the MSWSP to other case studies should allow refining the structure of the risk matrices, which, if necessary, could entail substantial changes. Therefore, it will be essential to seek new case studies to test the safety plan further.

The case studies analysed in the thesis should also undergo further investigations. As previously discussed, the pandemic (Covid-19) has hampered a series of field missions from being carried out. Consequently, when possible, field missions in Serbia and Ghana should be carried out, to conduct many of the investigations suggested previously.

ACKNOWLEDGEMENTS

Many people have been important, directly and indirectly, to the development of my PhD research. I wish to thank my mother, Enza, my father, Piero, and my brother, Daniele. Despite the physical distance, they have always supported me. Besides, many friends have been essential in finding the wellness everyone need. My relatives have also been critical, including those who are no longer in this world. I am grateful to my supervisor, Prof Mentore Vaccari from the University of Brescia, who has contributed to my academic growth. Thanks to him, I took many international contacts, and I gave my research in the right direction. My co-supervisor, Dr Christian Zurbrügg from EAWAG, Switzerland, opened my mind on crucial aspects of solid waste management in developing countries. He also led my activities during my period at Sandec, the Department of Sanitation, Water and Solid Waste for Development at EAWAG. Furthermore, I want to thank Adeline Mertenat, who supervised my activities at Sandec. I am thankful to Prof Sabrina Sorlini, curriculum referent for my PhD programme and Director of CeTAmb LAB, the Research Centre on Appropriate Technologies for environmental management in resource-limited countries at the University of Brescia. If I have expanded my knowledge, it is also because of her. I have to thank Prof Collivignarelli, founder and former Director of CeTAmb LAB. Besides, I cannot forget all my colleagues at the University of Brescia. Prof Bojan Batinić from the University of Novi Sad, Serbia, was essential for developing the case study in Novi Sad. Additional help and clarification came from Prof Maja Petrović, and the PhD Student Isidora Berežni, University of Novi Sad. I have to mention Prof Thomas Clasen from the Emory University, the USA, crucial in developing the systematic review and discussing other ideas. I am grateful to him for the suggestions. Dr Valerie Bauza from the Emory University gave me help in many activities, including developing the health risk assessment matrices. Kate Medlicott, from the World Health Organization, contributed to the improvement of the systematic review. Her observations regarding infectious and vector-borne diseases were fundamental. Dr Terry Tudor, former professor at the University of Northampton, UK, has helped me a lot since I started my research. Finally, the case study in Ghana was carried out in the context of the "Sustainable Livelihoods" project. The project is led by the Italian NGO Cooperazione Internazionale Sud Sud (CISS) in partnership with CeTAmb LAB (University of Brescia) and two Ghanaian NGOs (NECPAD and RUDEYA). It is a project co-funded by the European Union in the CSO RISE programme framework – Civil Society Organisations in Research and Innovation for Sustainable Development. I have to thank all my friends from CISS. In particular, the two more involved in the "Sustainable Livelihoods" project, Margherita Maniscalco and Mauro Bartolomeo.

REFERENCES

Abota, CA, 2012. Recycling of Plastics Waste in Ghana: A Way to Reduce Environmental Problems/Pollutions. Bachelor's Thesis, Arcada University of Applied Sciences, Helsinki, Finland.

Abul, S, 2010. Environmental and health impact of solid waste disposal at Mangwaneni dumpsite in Manzini: Swaziland. Journal of Sustainable Development in Africa, 12, 7

Achudume, AC, Olawale, JT, 2007. Microbial pathogens of public health significance in waste dumps and common sites. Journal of environmental biology 28(1), 151–154.

Adarkwa, K.K., 2005. The reality of decentralisation implementation in Ghana and some emerging concerns. In: Egziabher, T.G., Dijk, M.P. van (Eds.), Issues and Challenges in Regional and Local Development Studies (RLDS). Addis Ababa University, Addis Ababa, Ethiopia.

Agamuthu, P, Khidzir, KM, Hamid, FS, 2009. Drivers of sustainable waste management in Asia. Waste management & research 27 (7), 625–633.

Aguiar, BS, Lorenz, C, Virginio, F, Suesdek, L, Chiaravalloti-Neto, F, (2018). Potential risks of Zika and chikungunya outbreaks in Brazil: A modeling study. International journal of infectious diseases 70, 20–29.

Agyarko, K, Darteh, E, Berlinger, B, 2010. Metal levels in some refuse dump soils and plants in Ghana. Plant, Soil and Environment 56, 244–251.

Albright, WH, Benson, CH, Gee, GW, Roesler, AC, Abichou, T, Apiwantragoon, P, Lyles, BF, Rock, SA, 2004. Field water balance of landfill final covers. Journal of environmental quality 33(6), 2317–2332.

Aljaradin, M, Persson, 2013. Proposed water balance equation for municipal solid waste landfills in Jordan. Waste Management and Research.

ARPA Valle D'Aosta, 2020. Pozzi e Piezometri. ARPA (Agenzia Regionale per la Protezione dell'Ampiente) Valle d'Aosta. Web page. Available online: http://www.arpa.vda.it/it/acque-sotterranee/pozzi-e-piezometri/1027-acque-sotterranee/1452-pozzi-e-piezometri#:~:text=il%20pozzo%20%C3%A8%20dotato%20al,dei%20prelievi%20finalizzati%20al%20monitoraggio (Accessed on 05/12/2020)

APAT, 2005. Criteri Metodologici per l'Applicazione Dell'Analisi Assoluta di Rischio Alle Discariche. Agenzia per la Protezione Dell'Ambiente e per i Servizi Tecnici: Rome, Italy, 2005

APAT, 2008. Criteri metodologici per l'applicazione dell'analisi assoluta di rischio ai siti contaminati. Revisione 2. Agenzia per la Protezione Dell'Ambiente e per i Servizi Tecnici: Rome, Italy, 2008.

APTA (American Public Transportation Association), 2010. Fencing Systems to Control Access to Transit Facilities. NW, Washington, DC, USA.

AS English, 2020. Ghanaian president says airport re-opening hinges on Covid-19 testing capacity. Available online: https://en.as.com/en/2020/08/17/latest_news/1597696779_990691.html#menu (Accessed on 04/11/2020)

Ashworth, DC, Elliott, P, Toledano, MB, 2014. Waste incineration and adverse birth and neonatal outcomes: a systematic review. Environment International 69, 120-32. DOI: 10.1016/j.envint.2014.04.003.

Athanasiou, M, Makrynos, G, Dounias, G, 2010. Respiratory health of municipal solid waste workers. Occup Med 60 (8), 618-623. DOI: 10.1093/occmed/kqq127

Babs-Shomoye, F, Kabir, R. Health Effects of Solid Waste Disposal at a Dumpsite on the Surrounding Human Settlements. Journal of Public Health in Developing Countries 2016, 2 (3), 268-275.

Barroso, PJ, Santos, JL, Martin, J, Aparicio, I, Alonso, E, 2019. Emerging contaminants in the atmosphere: Analysis, occurrence and future challenges. Critical Reviews in Environmental Science and Technology 49 (2), 104-171.

BBC, 2006. Montenegro gets Serb recognition. Available online: http://news.bbc.co.uk/2/hi/europe/5083690.stm (Accessed on 06/11/2020)

BBC, 2014. EU enlargement: The next seven. Available online: https://www.bbc.com/news/world-europe-11283616 (Accessed on 06/11/2020)

Bellwood-Howard, I, 2012. Donkeys and bicycles: capital interactions facilitating timely compost application in Northern Ghana. International Journal of Agricultural Sustainability 10 (4), 315-327

Black, M, Karki, J, Lee, ACK, Makai, P, Baral, YR, Kritsotakis, EI, Bernier, A, Fossier Heckmann, A, 2019. The health risks of informal waste workers in the Kathmandu Valley: a cross-sectional survey. Public Health 166, 10-18. DOI: 10.1016/j.puhe.2018.09.026

Briscoe C, Aboud, F, 2012. Behaviour change communication targeting four health behaviours in developing countries: A review of change techniques. Social Science & Medicine 75 (4), 612-621.

Bru-Adan, V, Wéry, N, Moletta-Denat, M, Boiron, P, Delgènes, JP, Godon, JJ, 2009. Diversity of bacteria and fungi in aerosols during screening in a green waste composting plant. Current microbiology 59(3), 326–335.

Bukari, FIM, Doke, DA, Anokye, NA, 2017. Examination of Household Solid Waste Management in Nadowli Township in Ghana: A Waste Management Hierarchy Approach. Ghana Journal of Development Studies, 14 (2).

Candela, S, Bonvicini, L, Ranzi, A, Baldacchini, F, Broccoli, S, Cordioli, M, Carretta, E, Luberto, F, Angelini, P, Evangelista, A, Marzaroli, P, Giorgi Rossi, P, Forastiere, F, 2015. Exposure to emissions from municipal solid waste incinerators and miscarriages: a multisite study of the MONITER Project. Environment International 78, 51-60. DOI: 10.1016/j.envint.2014.12.008

Candela, S, Ranzi, A, Bonvicini, L, Baldacchini, F, Marzaroli, P, Evangelista, A, Luberto, F, Carretta, E, Angelini, P, Sterrantino, AF, Broccoli, S, Cordioli, M, Ancona, C, Forastiere F, 2013. Air pollution from incinerators and reproductive outcomes: a multisite study. Epidemiology 24(6), 863-870. DOI: 10.1097/EDE.0b013e3182a712f1

Carrière, A., Brouillon, M., Sauvé, S., Bouchard, M. F., Barbeau, B., 2011. Performance of point-of-use devices to remove manganese from drinking water. Journal of environmental science and health. Part A, Toxic/hazardous substances & environmental engineering, 46 (6), 601–607.

CBC News, 2008. Kosovo declares independence. Available online: https://www.cbc.ca/news/world/kosovo-declares-independence-1.733232 (Accessed on 16/11/2020)

Chen, DM, Bodirsky, BL, Krueger, T, Mishra, A, Popp, A, 2020. Environmental Research Letters 15, 074021.

Christensen, TH, Kjeldsen, P, Bjerg, PL, Jensen, DL, Christensen, JB, Baun, A, Albrechtsen, H, Heron, G, 2001. Biogeochemistry of landfill leachate plumes. Applied Geochemistry 16 (7–8), 659-718.

Chung, FF, Herceg, Z, 2020. The Promises and Challenges of Toxico-Epigenomics: Environmental Chemicals and Their Impacts on the Epigenome. Environmental Health Perspectives 128 (1). DOI: 10.1289/EHP6104

CIA (Central Intelligence Agency), 2020b. The world fact book: Serbia. Available online: https://www.cia.gov/library/publications/the-world-factbook/geos/ri.html (Accessed on 23/12/2020)

CISS (Cooperazione Internazionale Sud Sud), 2020a. Accesso all'acqua e salute in Ghana: la campagna di sensibilizzazione WASH di Sustainable Livelihoods. Website. Available online: http://www.cissong.org/accesso-allacqua-e-salute-in-ghana-la-campagna-di-sensibilizzazione-wash-di-sustainable-livelihoods/ (Accessed on 20/12/2020)

CISS (Cooperazione Internazionale Sud Sud), 2020b. Sustainable Livelihoods Project - Call for proposals. Website. Available online: http://www.cissong.org/sustainable-livelihoods-project-call-for-proposals/ (Accessed on 08/12/2020)

Cobbinah, PB, 2014. Towards poverty reduction in developing countries: An analysis of ecotourism implementation in the Kakum Conservation Area, Ghana. Diss. PhD thesis, School of Environmental Sciences, Charles Sturt University, Albury, NSW, Australia.

Cobbinah, P.B., Addaney, M., Agyeman, K.O., 2017. Locating the role of urbanites in solid waste management in Ghana. Environmental Development 24, 9–21.

Coffey M, Coad A, 2010. Collection of municipal solid waste in developing countries. United Nations Human Settlements Programme, UN-HABITAT, Nairobi, Kenya. ISBN 978-92-1-132254-5.

Cointreau, S., 2006. Occupational and environmental health issues of solid waste management: special emphasis on middle and lower-income countries. The World Bank, Urban Solid Waste Management, Washington, DC.

Cook, E, Velis, CA, 2020. Global Review on Safer End of Engineered Life. Engineering X, London, UK.

Cordier, S, Lehébel, A, Amar, E, Anzivino-Viricel, L, Hours, M, Monfort, C, Chevrier, C, Chiron, M, Robert-Gnansia, E, 2010. Maternal residence near municipal waste incinerators and the risk of urinary tract birth defects. Occup Environ Med 67 (7), 493-9. DOI: 10.1136/oem.2009.052456

Cudjoe, D, Han, MS, 2021. Economic feasibility and environmental impact analysis of landfill gas to energy technology in African urban areas. Journal of Cleaner Production 284, 125437.

Das, S, Lee, SH, Kumar, P, Kim, KH, Lee, SS, Bhattacharya, SS, 2019. Solid waste management: scope and the challenge of sustainability. Journal of Cleaner Production 228, 658-678.

Davison, A, Howard, G, Stevens, M, Callan, P, Fewtrell, L, Deere, D, Bartram, J, 2005. Water Safety Plans: Managing Drinking-water Quality from Catchment to Consumer. World Health Organisation, Geneva, Switzerland.

Djogo, M, Radonic, J, Mihajlovic, I, Obrovski, B, Ubavin, D, Turk Sekulic, M, Vojinovic Miloradov, M, 2017. Selection of optimal parameters for future research monitoring programmes on MSW landfill in Novi Sad, Serbia. Fresenius Environmental Bulletin 26 (7), 4867-4875,

D. Lgs. 36/2003. Supplemento ordinario N. 40 alla Gazzetta Ufficiale 12 Marzo 2003 N. 59. Attuazione della della direttiva 1999/31/CE relativa alla discariche di rifiuti. Accessed on 26/12/2020. (Available online: https://www.minambiente.it/sites/default/files/dlgs_13_01_03_36.pdf)

D. Lgs. 152/2006. Decreto Legislativo 3 aprile 2006, n. 152. Norme in materia ambientale. Gazzetta Ufficiale n. 88 del 14 aprile 2006 - Supplemento Ordinario n. 96. Italy.

Domenico, P.A., 1987. An analytical model for multidimensional transport of a decaying contaminant species. J. Hydrol 91, 49–58.

Domingo, JL, Marquès, M, Mari, M, Schuhmacher, M, 2020. Adverse health effects for populations living near waste incinerators with special attention to hazardous waste incinerators. A review of the scientific literature. Environmental research, 187, 109631. https://doi.org/10.1016/j.envres.2020.109631

East Mamprusi District Assembly, 2018. District medium term development plan (2018-2021).

EFSA (European Food Safety Authority), Knutsen, HK, Alexander, J, Barregård, L, Bignami, M,Bruschweiler, B, Ceccatelli, S, Cottrill, B, Dinovi, M, Edler, L, et al. (2018). Risk for animal and human health related to the presence of dioxins and dioxin-like PCBs in food and feed. EFSA J, 16 (11), 05333.

Elliott, P, Richardson, S, Abellan, JJ, Thomson, A, de Hoogh, C, Jarup, L, Briggs, DJ, 2009. Geographic density of landfill sites and risk of congenital anomalies in England. Occup Environ Med 66, 81–89. DOI: 10.1136/oem.2007.038497

Estrellan, C.R., Iino, F., (2010). Toxic emissions from open burning. Chemosphere 80, 193-207.

Faculty of Technical Sciences – Novi Sad, 2012. Regional Waste Management Plan for City of Novi Sad and municipalities of Backa Palanka, Backi Petrovac, Beocin, Zabalj, Srbobran, Temerin and Vrbas (on Serbian), Novi Sad, Serbia.

FAO (Food and Agriculture Organization), WHO (World Health Organization), 2018. Joint FAO/WHO Food Standards Programme. Codex Committee on Contaminants in Foods. 12th Session, Utrecht, 12–16 March 2018. Proposed draft revision of the Code of Practice for the Prevention and Reduction of Dioxins and Dioxin-like PCBs in Food and Feed. Available online: http://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings %252FCX-735-12%252FWD%252Fcf12_08e.pdf (Accessed on 26/03/2020)

Fazzo, L, Minichilli, F, Santoro, M, Ceccarini, A, Della Seta, M, Bianchi, F, Comba, P, Martuzzi, M, 2017. Hazardous waste and health impact: a systematic review of the scientific literature. Environmental health : a global access science source, 16(1), 107. https://doi.org/10.1186/s12940-017-0311-8

Ferronato, N, Torretta, V, 2019. Waste Mismanagement in Developing Countries: A Review of Global Issues. Int. J. Environ. Res. Public Health 16, 1060. DOI: 10.3390/ijerph16061060

Fiani, E, Karl, U, Umlauf, G, De Assunção, JV, Kakareka, S, Fiedler, H, Costner, P, Weber, R, 2013. Toolkit for Identification and Quantification of Releases of Dioxins, Furans and Other Unintentional POPs. United Nations Environment Programme (UNEP), Geneva.

Fjeld, R.A.; Eisenberg, N.A.; Compton, K.L. Quantitative Environmental Risk Analysis for Human Health; John Wiley & Sons: Hoboken, NJ, USA, 2007; ISBN 9780471722434.

Fobil, JN, Hogarh, JN, 2006. The dilemmas of plastic wastes in a developing economy: Proposals for a sustainable management approach for Ghana. West African Journal of applied Ecology 10 (1).

Gaski, JF, 2015. Survey Method versus Longitudinal Surveys and Observation for Data Collection. In The Palgrave Handbook of Research Design in Business and Management. Editor Strang, K. Palgrave Macmillan US.

Geiling, J, Burkle, FM Jr, Amundson, D, Dominguez-Cherit, G, Gomersall, CD, Lim, ML, Luyckx, V, Sarani, B, Uyeki, TM, West, TE, Christian, MD, Devereaux, AV, Dichter, JR, Kissoon, N, 2014. Resource-poor settings: infrastructure and capacity building: care of the critically ill and injured during pandemics and disasters: CHEST consensus statement. Chest 146 (4), E156S-E167S.

Georank, 2020. Coronavirus cases in Serbia by day. Available online: https://georank.org/cov (Accessed on 04/11/2020)

Gerba, CP, Tamimi, AH, Pettigrew, C, Weisbrod, AV, Rajagopalan, V, (2011). Sources of microbial pathogens in municipal solid waste landfills in the United States of America. Waste management & research 29(8), 781–790. https://doi.org/10.1177/0734242X10397968

Ghana Statistical Service, 2013. Population & housing census 2010. Regional analytical report. Northern Region.

Ghana Statistical Service, 2014. Population & housing census 2010. District analytical report. Mampong municipal.

Ghosh, RE, Freni-Sterrantino, A, Douglas, P, Parkes, B, Fecht, D, de Hoogh, K, Fuller, G, Gulliver, J, Font, A, Smith, RB, Blangiardo, M, Elliott, P, Toledano, MB, Hansell, AL, 2019. Fetal growth, stillbirth, infant mortality and other birth outcomes near UK municipal waste incinerators; retrospective population based cohort and case-control study. Environment International 122, 151-158. DOI: 10.1016/j.envint.2018.10.060

GIZ, 2019. Development of Local Plans for Primary Separation and Action Plans for Biodegradable Waste Reduction in Selected Regions in Serbia, DKTI IMPACT-Climate Sensitive Waste Management Project, Belgrade, Serbia.

Gouin, T, Cunliffe, D, De France, J, Fawell, J, Jarvis, P, Koelmans, AA, Marsden, P, Testai, EE, Asami, M, Bevan, R, Carrier, R, Cotruvo, J, Eckhardt, A, Ong, CN, 2020. Clarifying the absence of evidence regarding human health risks to microplastic particles in drinking-water: High quality robust data wanted. Environment International, 106141.

Gouveia, N., do Prado, R.R., 2010. Health risks in areas close to urban solid waste landfill sites. Rev Saude Publica 44 (5), 859-66. DOI: 10.1590/s0034-89102010005000029

Guan, WJ, Zheng, XY, Chung, KF, Zhong, NS 2016. Impact of air pollution on the burden of chronic respiratory diseases in China: time for urgent action. Lancet 388 (10054), 1939-1951.

Gumede, PR, Savage, MJ, 2017. Respiratory health effects associated with indoor particulate matter ($PM_{2.5}$) in children residing near a landfill site in Durban, South Africa. Air Qual Atmos Health 10, 853–860. DOI: 10.1007/s11869-017-0475-y

Heaney, CD, Wing, S, Campbell, RL, Caldwell, D, Hopkins, B, Richardson, D, Yeatts, K, 2011. Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill. Environ Res 111(6), 847-852. DOI: 10.1016/j.envres.2011.05.021

IARC (International Agency for Research on Cancer), 2012. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, No. 100F. 2,3,7,8-TETRACHLORODIBENZO-para-DIOXIN, 2,3,4,7,8-PENTACHLORODIBENZOFURAN, AND 3,3′,4,4′,5-PENTACHLOROBIPHENYL. Available online: https://www.ncbi.nlm.nih.gov/books/NBK304398/ (Accessed on 26/03/2020)

IARC (International Agency for Research on Cancer), 2019.IARC Monographs on the Identification of Carcinogenic Hazards to Humans. Preamble. Lyon, France. Amended January 2019. Available online https://monographs.iarc.fr/wp-content/uploads/2019/01/Preamble-2019.pdf (Accessed on 10/01/2021)

Il Messaggero, 2020. Coronavirus Italia, stop agli arrivi da Serbia, Montenegro e Kosovo. Available online: https://www.ilmessaggero.it/italia/coronavirus_italia_ultime_notizie_paesi_rischio_voli_arrivi_elenco_lista_serbia_montenegro-5349959.html (Accessed on 04/11/2020)

Ilić, M, Nikolić, M, 2016. Waste management benchmarking: A case study of Serbia. Habitat International 53, 453-460.

IMF (International Monetary Fund), 2020a. World Economic and Financial Surveys. World Economic Outlook (WEO). Database - WEO Groups and Aggregates Information. April 2020. Available online: https://www.imf.org/external/pubs/ft/weo/2020/01/weodata/groups.htm (Accessed on 16/11/2020)

IMF (International Monetary Fund), 2020b. Frequently Asked Questions. World Economic Outlook (WEO). Last Updated: October 13, 2020. Available online: https://www.imf.org/external/pubs/ft/weo/faq.htm#q4b (Accessed on 16/11/2020)

IMG (International Management Group), 2015. Concept of waste management system in Novi Sad Region.

IMG (International Management Group), 2016. Partial pre-feasibility study for solid waste management in the Novi Sad Region.

Infodata, 2020. Trenta giorni di lockdown in Italia raccontati in dieci grafici. Il Sole 24 Ore. Available online: https://www.infodata.ilsole24ore.com/2020/04/09/trenta-giorni-di-covid-19-raccontati-in-dieci-grafici/ (Accessed on 04/11/2020)

ISWA (International Solid Waste Association), 2019. Landfill operational guidelines. 3rd Edition. A report from ISWA ‘s working group on landfill 2019.

Jarup, L, Morris, S, Richardson, S, Briggs, D, Cobley, N, de Hoogh, C, Gorog, K, Elliott, P, 2007. Down syndrome in births near landfill sites. Prenat Diagn 27 (13), 1191-1196. DOI: 10.1002/pd.1873

Jevtić, M, Dragić, N, Bijelović, S, Popović, M, 2014. Cardiovascular diseases and air pollution in Novi Sad, Serbia. International Journal of Occupational Medicine and Environmental Health 27 (2), 153 – 164.

Kamariotakis, H, Bogdanov, B, 2016. Desk study - Hydrological and hydrogeological aspects associated with project area (proposed regional landfill in Novi Sad). International Management Group (IMG).

Kamaruddin, M.A.; Yusoff, M.S.; Rui, L.M.; Isa, A.M.; Zawawi, M.H.; Alrozy, R., 2017. An overview of municipal solid waste management and landfill leachate treatment: Malaysia and Asian perspectives. Environ. Sci. Pollut. Res. 24, 26988–27020.

Kampf, G, Todt, G, Pfaender, S, Steinmann, E, 2020. Persistence of coronaviruses on inanimate surfaces and their inactivation with biocidal agents. Journal of Hospital Infection 104 (3), 246-251.

Kaza, S, Yao, LC, Bhada-Tata, P, Van Woerden, F, 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. Urban Development;. Washington, DC: World Bank.

Kelly, FJ, Fuller, GW, Walton, HA, Fussell, JC, 2012. Monitoring air pollution: use of early warning systems for public health. Respirology 17 (1), 7-19.

Khalil, C., Al Hageh, C., Korfali, S., Khnayzer, R.S., (2018). Municipal leachates health risks: Chemical and cytotoxicity assessment from regulated and unregulated municipal dumpsites in Lebanon. Chemosphere 208, 1-13

Khokhar, T, Serajuddin, U, 2015. Should we continue to use the term “developing world”? World Bank Blogs. Available: https://blogs.worldbank.org/opendata/should-we-continue-use-term-developing-world (Accessed on 16/11/2020)

Kloppenborg, SCh,, Brandt, UK, Gulis, G, Ejstrud, B, 2005. Risk of congenital anomalies in the vicinity of waste landfills in Denmark; an epidemiological study using GIS. Cent Eur J Public Health 13(3), 137-143.

Kostadinović, I, Stanković, S, 2020. The analysis of the regional disproportions in the labor market in the Republic of Serbia. Ekonomika 66 (1), 25-35.

Kret, J, Dalidowitz Dame, L, Tutlam, N, DeClue, RW, Schmidt, S, Donaldson, K, Lewis, R, Rigdon, SE, Davis, S, Zelicoff, A, King, C, Wang, Y, Patrick, S, Khan, F, 2018. A respiratory health survey of a subsurface smoldering landfill. Environ Res 166 427-436. DOI: 10.1016/j.envres.2018.05.025

Krystosik, A, Njoroge, G, Odhiambo, L, Forsyth, JE, Mutuku, F, LaBeaud, AD, 2020. Solid Wastes Provide Breeding Sites, Burrows, and Food for Biological Disease Vectors, and Urban Zoonotic Reservoirs: A Call to Action for Solutions-Based Research. Frontiers in public health 7, 405. https://doi.org/10.3389/fpubh.2019.00405

Kvasnicka, J, Stylianou, KS, Nguyen, VK, Huang, L, Chiu, WA, Burton, GA, Jr, Semrau, J, Jolliet, O, 2019. Human Health Benefits from Fish Consumption vs. Risks from Inhalation Exposures Associated with Contaminated Sediment Remediation: Dredging of the Hudson River. Environmental health perspectives, 127(12), 127004. https://doi.org/10.1289/EHP5034

Lato, A, Radulov, I, Berbecea, A, Lato, K, Crista, F, 2012. The transfer factor of metals in soil-plant system. Research Journal of Agricultural Science 44 (3).

Leclert, L, Moser, D, Brogan, J, Mertenat, A., Harrison, J, 2018. Blue Schools - Linking WASH in schools with environmental education and practice, Catalogue of Practical Exercises. 1st Edition. Swiss Water & Sanitation Consortium, Caritas Switzerland, Helvetas, Terre des hommes, Eawag.

Lehmann, U, Dieleman, M, Martineau, T, 2008. Staffing remote rural areas in middle- and low-income countries: A literature review of attraction and retention. BMC Health Services Research 8, 19. https://doi.org/10.1186/1472-6963-8-19

Leslie, HA, Depledge, MH, 2020. Where is the evidence that human exposure to microplastics is safe? Environment International 142, 105807.

Li, RYM, Li, HCY, 2018. Have Housing Prices Gone with the Smelly Wind? Big Data Analysis on Landfill in Hong Kong. Sustainability 10, 341.

Liberati A, Altman DG, Tetzlaff J, Mulrow C, Gøtzsche PC, Ioannidis, J, Clarke, M, Devereaux, PJ, Kleijnen, J, Moher, D, 2009. The PRISMA Statement for Reporting Systematic Reviews and Meta-Analyses of Studies That Evaluate Health Care Interventions: Explanation and Elaboration. PLoS Med 6 (7), e1000100. doi: 10.1371/journal.pmed.1000100

Lin, CM, Li, CY, Mao, IF, 2006. Birth outcomes of infants born in areas with elevated ambient exposure to incinerator generated PCDD/Fs. Environment International 32(5), 624-9. DOI: 10.1016/j.envint.2006.02.003

Lu, JW, Zhang, S, Hai, J, Lei, M, 2017. Status and perspectives of municipal solid waste incineration in China: A comparison with developed regions. Waste management 69, 170–186. https://doi.org/10.1016/j.wasman.2017.04.014

Magnano, E, 2010. Biogas da discarica. Manuale di progettazione, gestione e monitoraggio degli impianti. EPC Libri: Rome, Italy. ISBN: 978-88-6310-230-7

Mann, CJ, 2003. Observational research methods. Research design II: cohort, cross sectional, and case-control studies. Emergency Medicine Journal 20, 54-60,

Mataloni, F., Badaloni, C., Golini, M.N., Bolignano, A., Bucci, S., Sozzi, R., Forastiere, F., Davoli, M., Ancona C., 2016. Morbidity and mortality of people who live close to municipal waste landfills: a multisite cohort study. International Journal of Epidemiology 45(3), 806-815. DOI: 10.1093/ije/dyw052.

Matejczyk M, Płaza GA, Nałęcz-Jawecki G, Ulfig K, Markowska-Szczupak A, 2011. Estimation of the environmental risk posed by landfills using chemical, microbiological and ecotoxicological testing of leachates. Chemosphere 82(7), 1017-1023.

Mattiello, A, Chiodini, P, Bianco, E, Forgione, N, Flammia, I, Gallo, C, Pizzuti, R, Panico, S, 2013. Health effects associated with the disposal of solid waste in landfills and incinerators in populations living in surrounding areas: a systematic review. International Journal of Public Health 58 (5), 725–35. DOI: 10.1007/s00038-013-0496-8.

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., Mensah, M.Y., 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Waste Management 46, 15-27.

Miller, N, 2005. Serbia and Montenegro. In Eastern Europe. An Introduction to the People, Lands, and Culture. Editor: Frucht, R. Santa Barbara, California, USA. Volume 3.

Modern Ghana, 2019. Ghana Now Has 16 Regions. Available online: https://www.modernghana.com/news/916140/ghana-now-has-16-regions.html (Accessed on 09/11/2020)

Moher, D, Liberati, A, Tetzlaff, J, Altman, DG, The PRISMA Group. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. PLoS Medicine 6 (7), e1000097.

Mol, MPG, Caldas, S, 2020. Can the human coronavirus epidemic also spread through solid waste? Waste Management & Research 38, 485-486.

Ncube, F, Ncube, EJ, Voyi, K, 2017. A systematic critical review of epidemiological studies on public health concerns of municipal solid waste handling. Perspect Public Health. 137 (2), 102-108. DOI: 10.1177/1757913916639077

Nzediegwu, C, Chang, SX, 2020. Improper solid waste management increases potential for COVID-19 spread in developing countries. Resources, conservation, and recycling 161, 104947.

Obirih-Opareh, N, Post, J, 2002. Quality assessment of public and private modes of solid waste collection in Accra, Ghana. Habitat International 26 (1), 95-112

Oteng-Ababio, M, Arguello, JEM, Gabbay, O, 2013. Solid waste management in African cities: sorting the facts from the fads in Accra, Ghana. Habitat International 39, 96–104.

Owusu-Sekyere, E, Osumanu, IK, Abdul-Kadri, Y, 2013. An Analysis of the Plastic Waste Collection and Wealth Linkages in Ghana. International Journal of Current Research 5, 205–209.

Paladino, O, Massabò, M, 2017. Health risk assessment as an approach to manage an old landfill and to propose integrated solid waste treatment: A case study in Italy. Waste Management 68, 344–354. DOI: 10.1016/j.wasman.2017.07.021

Palmer, SR, Dunstan, FD, Fielder, H, Fone, DL, Higgs, G, Senior, ML, 2005. Risk of congenital anomalies after the opening of landfill sites. Environ Health Perspect 113 (10), 1362-1365. DOI: 10.1289/ehp.7487

Parera, J, Serra-Prat, M, Palomera, E, Mattioli, L, Abalos, M, Rivera, J, Abad, E, 2013. Biological monitoring of PCDD/Fs and PCBs in the City of Mataró. A population-based cohort study (1995–2012). Science of the Total Environment 461–462, 612–617. DOI: 10.1016/j.scitotenv.2013.04.094

Parkes, B, Hansell, AL, Ghosh, RE, Douglas, P, Fecht, D, Wellesley, D, Kurinczuk, JJ, ì Rankin, J, de Hoogh, K,. Fuller, GW, Elliott, P, Toledano, MB, 2020. Risk of congenital anomalies near municipal waste incinerators in England and Scotland: Retrospective population-based cohort study. Environment International 134, 104845. DOI: 10.1016/j.envint.2019.05.039

Parsaie, A, Haghiabi, AH, 2017. Computational Modeling of Pollution Transmission in Rivers. Applied Water Science 7, 1213–1222. https://doi.org/10.1007/s13201-015-0319-6

Pavlović M., Vulić M., Pavlović A. (2020) Circular Economy in Republic of Serbia and Region. In: Ghosh S. (eds) Circular Economy: Global Perspective. Springer, Singapore. https://doi.org/10.1007/978-981-15-1052-6_18

Pearson, C, Littlewood, E, Douglas, P, Robertson, S, Gant, TW, Hansell, AL, 2015. Exposures and health outcomes in relation to bioaerosol emissions from composting facilities: a systematic review of occupational and community studies. J Toxicol Environ Health B Crit Rev 18 (1), 43-69. DOI: 10.1080/10937404.2015.1009961

Pellizzari, ED, Woodruff, TJ, Boyles, RR, Kannan, K, Beamer, PI, Buckley, JP, Wang, A, Zhu, Y, Bennett, DH, 2019. Identifying and Prioritizing Chemicals with Uncertain Burden of Exposure: Opportunities for Biomonitoring and Health-Related Research. Environmental health perspectives, 127(12), 126001.

Peter-Varbanets, M., Zurbrügg, C., Swartz, C., Pronk, W., 2009. Decentralized systems for potable water and the potential of membrane technology. Water research 43 (2), 245–265.

Petrovic, M, Sremacki, M, Radonic, J, Mihajlovic, I, Obrovski, B, Vojinovic Miloradov, M, 2018. Health risk assessment of PAHs, PCBs and OCPs in atmospheric air of municipal solid waste landfill in Novi Sad, Serbia. Sciene of the Total Environment 644, 1201-1206.

Pietzsch, N, Ribeiro, JDL, Medeiros, JF, 2017. Benefits, challenges and critical factors of success for zero waste: a systematic literature review. Waste Management 67, 324-353. DOI: 10.1016/j.wasman.2017.05.004

Pimpin, L, Retat, L, Fecht, D, de Preux, L, Sassi, F, Gulliver, J, Belloni, A, Ferguson, B, Corbould, E, Jaccard, A, Webber, L, 2018. Estimating the costs of air pollution to the National Health Service and social care: An assessment and forecast up to 2035. PLoS medicine 15(7), e1002602.

Pius C, Koosaletse-Mswela P, Sichilongo K, Dikinya O, 2020. Mapping polychlorinated dibenzo-p-dioxins/dibenzofurans in soils around Pugu municipal dump site in Dar es Salaam, Tanzania: Implications on dermal and soil ingestion exposure for people in the peripheral. Environ Pollut. 258: 113665.

Pivato, A, Masi, S, De Caprio, D, Tommasin, A, 2018. Sanitary landfill costs from design to aftercare: criteria for defining unit cost. Detritus 4, 140-156.

Porta, D, Milani, S, Lazzarino, AI, Perucci, CA, Forastiere, F, (2009). Systematic review of epidemiological studies on health effects associated with management of solid waste. Environ Health 8, 60. DOI: 10.1186/1476-069X-8-60.

Porter RC, 1997. The Economics of Water and Waste in Three African Capitals (Accra, Harare, Gaborone). Ashgate Press: Farnham, UK.

Prüss-Ustün, A, Wolf, J, Corvalán, C, Bos, R, Neira, M, 2016. Preventing disease through healthy environments. A global assessment of the burden of disease from environmental risks. World Health Organization. ISBN 9789241565196

Quartey, ET, Tosefa, H, Danquah, KA, Obrsalova, I, (2015). Theoretical Framework for Plastic Waste Management in Ghana through Extended Producer Responsibility: Case of Sachet Water Waste. International journal of environmental research and public health 12(8), 9907–9919.

Rachiotis, G, Papagiannis, D, Thanasias, E, Dounias, G, Hadjichristodoulou, C, 2012. Hepatitis A Virus Infection and the Waste Handling Industry: A Seroprevalence Study. Int. J. Environ. Res. Public Health 9, 4498-4503

Radonić, J, Jovčić Gavanski, N, Ilić, M, et al., 2017. Emission sources and health risk assessment of polycyclic aromatic hydrocarbons in ambient air during heating and non-heating periods in the city of Novi Sad, Serbia. Stochastic Environmental Research and Risk Assessment 31, 2201–2213.

Ranzi, A, Fano, V, Erspamer, L, Lauriola, P, Perucci, CA, Forastiere, F, 2011. Mortality and morbidity among people living close to incinerators: a cohort study based on dispersion modeling for exposure assessment. Environ Health 10, 22. DOI: 10.1186/1476-069X-10-22

Reinert, F, Lucio, C, 2012. Postmen activity's analysis. Work 41, 5603-5604.

Riveron, JM, Osae, M, Egyir-Yawson, A, Irving, H, Ibrahim, SS, Wondji, CS, 2016. Multiple insecticide resistance in the major malaria vector Anopheles funestus in southern Ghana: implications for malaria control. Parasites Vectors 9, 504.

Robertson, S, Douglas, P, Jarvis, D, Marczylo, E, 2019. Bioaerosol exposure from composting facilities and health outcomes in workers and in the community: A systematic review update. Int J Hyg Environ Health 222 (3), 364-386. DOI: 10.1016/j.ijheh.2019.02.006

Rosenfeld, PE, Feng LGH, 2011. Risks of hazardous wastes. Elsevier, Amsterdam. Hardcover ISBN: 9781437778427.

Sankoh, FP, Yan, X, Tran, Q. Environmental and Health Impact of Solid Waste Disposal in Developing Cities: A Case Study of Granville Brook Dumpsite, Freetown, Sierra Leone. Journal of Environmental Protection 2013, 4, 665-670.

Scaramozzino, P, Battisti, S, Desiato, R, Tamba, M, Fedrizzi, G, Ubaldi, A, Neri, B, Abete, MC, Ru, G, 2019. Application of a risk-based standardized animal biomonitoring approach to contaminated sites. Environ Monit Assess 191, 526. https://doi.org/10.1007/s10661-019-7653-3

Schulten, T, Luebker, M, 2019. WSI minimum wage report 2019. WSI – Institute of Economic and Social Research. Düsseldorf, DE. Report 46, March 2019.

Seltenrich, N, 2020. Beyond the Light under the Lamppost: New Chemical Candidates for Biomonitoring in Young Children. Environmental health perspectives, 128(8), 84005. https://doi.org/10.1289/EHP6902

Serbian Gazette, 2019. "Official Gazette of the RS", No. 50/2012. Available online: https://www.paragraf.rs/propisi/uredba-granicnim-vrednostima-zagadjujucih-materija-vodama.html (Accessed on 02/12/2020)

Serbian Gazette, 2019. “Official Gazette of the FRY", No. 42/98 and 44/99 and "Official Gazette of the RS", No. 28/2019. Available online: https://www.paragraf.rs/propisi/pravilnik-higijenskoj-ispravnosti-vode-pice.html (Accessed on 27/11/2020)

Shah, SZA, Nawaz, Z, Nawaz, S, Carder, G, Ali, M, Soomro, N, Compston, PC, 2019. The Role and Welfare of Cart Donkeys Used in Waste Management in Karachi, Pakistan. Animals 9, 159.

Shroder, JF, Sivanpillai, R, 2015. Biological and Environmental Hazards, Risks, and Disasters. 1st edition. Elsevier: Amsterdam, Netherlands. ISBN: 9780123948472.

Simsek, C, Elci, A, Gunduz, O, Taskin, N, 2014. An improved landfill site screening procedure under NIMBY syndrome constraints. Landscape and Urban Planning 132, 1-15.

Simoneit, BR, Medeiros, PM, Didyk, BM, 2005. Combustion products of plastics as indicators for refuse burning in the atmosphere. Environmental science & technology 39(18), 6961–6970.

Siwila, S, Brink, IC, 2019. Drinking water treatment using indigenous wood filters combined with granular activated carbon. Journal of Water, Sanitation and Hygiene for Development 9 (3), 477–491.

Smith, S, Anker, M, Anker, R, 2017. Living Wage Report, Ghana. Lower Volta Area: Context Provided in the Banana Sector. February 2017. Global living wage coalition. Accessed on: 05/01/2021. Available online: https://www.globallivingwage.org/wp-content/uploads/2018/04/Ghana_Living_Wage_Benchmark_Report.pdf

Smith, S, Sarpong, D, 2018. Living Income Report, Rural Ghana. Cocoa growing areas of Ashanti, Central, Eastern, and Western Regions. September 2018. The Living Income Community of Practice. Accessed on: 05/01/2021. Available online: https://cocoainitiative.org/wp-content/uploads/2018/12/LIVING-INCOME-REPORT-FOR-GHANA.pdf

Solan, PJ, Dodd, VA, Curran, TP, 2010. Evaluation of the odour reduction potential of alternative cover materials at a commercial landfill. Bioresource Technology 101 (4), 1115-1119.

Soltani, A, Hewage, K, Reza, B, Sadiq, R, 2015. Multiple stakeholders in multi-criteria decision-making in the context of Municipal Solid Waste Management: A review. Waste Management 35, 318-328.

Sorlini, S, Rondi, L, Pollmann Gomez, A, Collivignarelli, C, 2015. Appropriate technologies for drinking water treatment in Mediterranean countries. Environmental Engineering and Management Journal 14 (7), 1721-1733.

Srigboh, R. K., Basu, N., Stephens, J., Asampong, E., Perkins, M., Neitzel, R. L., & Fobil, J., 2016. Multiple elemental exposures amongst workers at the Agbogbloshie electronic waste (e-waste) site in Ghana. Chemosphere, 164, 68–74.

Statistical Office of the Republic of Serbia, 2020. Estimated number of population in the Republic of Serbia, 2019. Press release. Available online: https://www.stat.gov.rs/en-us/vesti/20200701-procenjen-broj-stanovnika-2019/?s=1801 (Accessed on 23/12/2020)

Stojanović, M, 2017. Regional landfill in Novi Sad: Growth of pollution and bureaucracy. Center for investigative journalism of Serbia. 7 September 2017. Available online: https://www.cins.rs/en/regional-landfill-in-novi-sad-growth-of-pollution-and-bureaucracy/

Sublett, JL, 2011. Effectiveness of Air Filters and Air Cleaners in Allergic Respiratory Diseases: A Review of the Recent Literature. Current Allergy and Asthma Reports volume 11, 395 (2011). https://doi.org/10.1007/s11882-011-0208-5

Suleman, Y, Darko ET, Agyemang-Duah, W, 2015. Solid Waste Disposal and Community Health Implications in Ghana: Evidence from Sawaba, Asokore Mampong Municipal Assembly. Journal of Civil & Environmental Engineering, 5 (6), 1000202.

The Guardian, 2020. Covid in Europe: how countries are tackling second wave. Available online: https://www.theguardian.com/world/2020/oct/15/covid-in-europe-how-countries-are-tackling-second-wave(Accessed on 04/11/2020)

Themelis, NJ, Ulloa, PA, 2007. Methane generation in landfills. Renewable Energy 32 (7), 1243-1257.

Tilley, E, Ulrich, L, Luthi, C, Reymond, P, Zurbrugg, C, 2014. Compendium of Sanitation Systems and Technologies, 2nd revised ed.; Swiss Federal Institute of Aquatic Science and Technology (Eawag): Dübendorf, Switzerland.

Tilt, CA, 2018. Making Social and Environmental Accounting Research Relevant in Developing Countries: A Matter of Context? Social and Environmental Accountability Journal 38 (2), 145-150.

Tot, B, Živančev, M, Milovanović, D, Vujić, G, 2019. Landfill workers' proffesional education for protection against injury and damage. Recycling and Sustainable Development 12, 25-30.

Tsiboe, IA, Ernest, M, 2004. A Look at Urban Waste Disposal Problems in Accra, Ghana. Master's Thesis, Roskilde University, Roskilde, Denmark.

UNICEF, Ghana Center for Democratic Development, Centre for Social Policy Studies, 2019. 2018/19 District League Table II with new perspectives and modified methodology. Available online: https://www.unicef.org/ghana/media/2131/file/2018-2019-The-District-League-Table-II.pdf (Accessed on 09/11/2020)

United Nations, 2019. World Population Prospects 2019: Data Booklet (ST/ESA/SER.A/424). United Nations, Department of Economic and Social Affairs, Population Division: New York, NY, USA. ISBN 9789211483178.

UNDP (United Nations Development Programme), 2019. Human Development Report 2019. Beyond income, beyond averages, beyond today: Inequalities in human development in the 21st century. United Nations Development Programme: New York, NY, USA.

US EPA (United States Environmental Protection Agency), 2008. Pre-Feasibility Study for Landfill Gas Recovery and Utilization at the Loma de Los Cocos Landfill Cartagena de Indias, Colombia. Available online:

https://www.globalmethane.org/Data/148_LosCocos.Pre-Feasibility.Report.Final.English.pdf (Accessed on 31/12/2020)

US EPA (United States Environmental Protection Agency), 2011. Exposure Factors Handbook: 2011 Edition. National Center for Environmental Assessment, Washington, DC; USA. EPA/600/R-09/052F. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea/efh.

US EPA (United States Environmental Protection Agency), 2016a. Landfill gas energy cost model (LFGcost-Web). U.S. Environmental protection agency landfill methane outreach program (LMOP), version 3.1, user's manual. Available online: https://www.epa.gov/sites/production/files/2016-12/documents/lfgcost-webv3.1manual_113016.pdf (Accessed on 31/12/2020)

US EPA (United States Environmental Protection Agency), 2016b. Toxics Release Inventory (TRI) Program. Dioxin and Dioxin-Like Compounds Toxic Equivalency Information. Available online: https://www.epa.gov/toxics-release-inventory-tri-program/dioxin-and-dioxin-compounds-toxic-equivalency-information (Accessed on 07/04/2020)

US EPA (United States Environmental Protection Agency), 2018. Residential air cleaners. A technical summary. 3rd edition.

Vaccari, M, Tudor, T, Vinti, G, 2019a. Characteristics of leachate from landfills and dumpsites in Asia, Africa and Latin America: an overview. Waste Management 95, 416-431. DOI: 10.1016/j.wasman.2019.06.032

Vaccari, M, Vinti, G, Cesaro, A, Belgiorno, V, Salhofer, S, Dias, MI, Jandric, A, 2019b. WEEE Treatment in Developing Countries: Environmental Pollution and Health Consequences—An Overview. Int. J. Environ. Res. Public Health 2019, 16, 1595.

Vaccari, M, Vinti, G, Tudor, T, 2018. An Analysis of the Risk Posed by Leachate from Dumpsites in Developing Countries. Environments 5, 99.

Vicente, P, Reis, E, 2008. Factors influencing households' participation in recycling. Waste Management and Research 26 (2), 140-146.

Vidanaarachchi, CK, Yuen, ST, Pilapitiya, S, 2006. Municipal solid waste management in the Southern Province of Sri Lanka: problems, issues and challenges. Waste Management 26(8), 920-930.

Viel, JF, Clément, MC, Hägi, M, Grandjean, S, Challier, B, Danzon, A, 2008. Dioxin emissions from a municipal solid waste incinerator and risk of invasive breast cancer: a population-based case-control study with GIS-derived exposure. Int J Health Geogr 7, 4. DOI: 10.1186/1476-072X-7-4.

Viel, JF, Floret, N, Deconinck, E, Focant, JF, De Pauw, E, Cahn, J. Y, 2011. Increased risk of non-Hodgkin lymphoma and serum organochlorine concentrations among neighbors of a municipal solid waste incinerator. Environment international, 37(2), 449–453.

Vijayan, VK, Paramesh, H, Salvi, SS, Dalal, AA, 2015. Enhancing indoor air quality -The air filter advantage. Lung India 32 (5), 473-479.

Vinceti, M, Malagoli, C, Fabbi, S, Teggi, S, Rodolfi, R, Garavelli, L, Astolfi, G, Rivieri, F, 2009. Risk of congenital anomalies around a municipal solid waste incinerator: a GIS-based case-control study. Int J Health Geogr 8, 8. DOI: 10.1186/1476-072X-8-8.

Vinceti, M, Malagoli, C, Teggi, S, Fabbi, S, Goldoni, C, De Girolamo, G, Ferrari, P, Astolfi, G, Rivieri, F, Bergomi, M, 2008. Adverse pregnancy outcomes in a population exposed to the emissions of a municipal waste incinerator. Sci Total Environ 407 (1), 116-121. DOI: 10.1016/j.scitotenv.2008.08.027

Vinti, G, Bauza, V, Clasen, T, Tudor, T, Vaccari, M, Zurbrügg, C, 2020a. Municipal solid waste management and adverse health outcomes of nearby residents: a systematic review. PROSPERO 2020 CRD42020176495 Available online: https://www.crd.york.ac.uk/prospero/display_record.php?ID=CRD42020176495

Vinti, G, Vaccari, M, 2021. Natural resources. Consumption, pollution and health risks. Developed versus developing economies. In *The Routledge Handbook of Waste, Resources and the Circular Economy*, 1st edition; Tudor, T, Dutra, CJC, Eds; Routledge: Abingdon, UK. ISBN 9780367364649

Vinti, G, Vaccari, M, Tudor, T, 2020b. Reducing health risks and environmental issues using solid waste best practice and improved cookstoves among rural communities in Ghana. Brescia, Italy: CeTAmb publications. ISBN: 978-88-97307-17-4. Available online: https://docs.google.com/viewer?a=v&pid=sites&srcid=dW5pYnMuaXR8Y2V0YW1ibGFifGd4OjNjYmZkNTdiODUxZjQzZjI (Accessed on 11/11/2020)

Vujic, G, Ubavin, D, Milovanovic, D, Maodus, N, 2012. Pre-Feasibility Study for Landfill Gas Recovery and Utilization at the Novi Sad Landfill, Serbia. Faculty of Technical Sciences, University of Novi Sad, Serbia.

Wei, Y, Li, j, Shi, D, Liu, G, Zhao, Y, Shimaoka, T, 2017. Environmental challenges impeding the composting of biodegradable municipal solid waste: A critical review. Resources, Conservation and Recycling 122, 51-65.

WHO (World Health Organization), 2006. Guidelines for the safe use of wastewater, excreta and greywater. Wastewater use in agriculture, vol. 2. World Health Organization, Geneva, Switzerland.

WHO (World Health Organization), 2007. Preventing disease through healthy environments. Exposure to mercury: a major public health concern. World Health Organization, Geneva, Switzerland.

WHO (World Health Organization), 2013. WHO methods and data sources for global burden of disease estimates 2000-2011. World Health Organization, Geneva, Switzerland. Available online: https://www.who.int/healthinfo/statistics/GlobalDALYmethods_2000_2011.pdf?ua=1

WHO (World Health Organization), 2015. Sanitation safety planning: manual for safe use and disposal of wastewater, greywater and excreta. World Health Organization, Geneva, Switzerland.

WHO (World Health Organization), 2016a. Quantitative microbial risk assessment: application for water safety management. Updated November 2016. World Health Organization, Geneva, Switzerland.

WHO (World Health Organization), 2016b. Waste and human health: Evidence and needs. WHO Meeting Report.

WHO (World Health Organization), 2017a. Guidelines for drinking-water quality, 4th ed., incorporating the 1st addendum. World Health Organization, Geneva, Switzerland.

WHO (World Health Organization), 2017b. Plague. Fact sheets. Available online: https://www.who.int/news-room/fact-sheets/detail/plague (Accessed on 28/01/2021)

WHO (World Health Organization), 2019a. Preventing disease through healthy environments. Exposure to arsenic: a major public health concern. World Health Organization.

WHO (World Health Organization), 2019b. Preventing disease through healthy environments. Exposure to cadmium: a major public health concern. World Health Organization.

WHO (World Health Organization), 2019c. Preventing disease through healthy environments. Exposure to dioxins and dioxin-like substances: a major public health concern. World Health Organization. Available online: https://apps.who.int/iris/bitstream/handle/10665/329485/WHO-CED-PHE-EPE-19.4.4-eng.pdf?ua=1 (Accessed on 26/03/2020)

WHO (World Health Organization), 2019d. Preventing disease through healthy environments. Exposure to lead: a major public health concern. World Health Organization.

WHO (World Health Organization), 2020a. Coronavirus disease (COVID-19). Latest update 12 October 2020. Available online: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/question-and-answers-hub/q-a-detail/coronavirus-disease-covid-19 ((Accessed on 04/11/2020)

WHO (World Health Organization), 2020b. Timeline of WHO's response to COVID-19. Last updated 9 September 2020. Available online: https://www.who.int/news/item/29-06-2020-covidtimeline (Accessed on 04/11/2020)

WHO (World Health Organization), UNICEF, 2020. Water, sanitation, hygiene, and waste management for SARS-CoV-2, the virus that causes COVID-19. Interim guidance. 29 July 2020. Available online: file:///C:/Users/Acer/Downloads/WHO-2019-nCoV-IPC_WASH-2020.4-eng.pdf

Wilson, DC, Rodic, L, Modak, P, Soos, R, Carpintero Rogero, A, Velis, C, Iyer, M, Simonett, O, (2015). Global Waste Management Outlook. Report. UNEP.

Wittsiepe, J., Feldt, T., Till, H., Burchard, G., Wilhelm, M.,Fobil, J. N., 2017. Pilot study on the internal exposure to heavy metals of informal-level electronic waste workers in Agbogbloshie, Accra, Ghana. Environmental science and pollution research international, 24(3), 3097–3107.

WorldAware, 2020. COVID-19 Alert: Serbia Ends State of Emergency May 6, Easing Preventative Measures From May 8. Available online: https://www.worldaware.com/covid-19-alert-serbia-ends-state-emergency-may-6-easing-preventative-measures-may-8 (Accessed on 04/11/2020)

World Bank, 2017. World Development Indicators: Rural environment and land use. Available online: http://wdi.worldbank.org/table/3.1 (Accessed on 27/05/2020)

World Bank, 2020. World Bank country and leading groups. Country classification. Available online: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups (Accessed on 16/11/2020)

Xu, W, Wang, X, Cai, Z, 2013. Analytical chemistry of the persistent organic pollutants identified in the Stockholm Convention: A review. Analytica chimica acta 790, 1–13. https://doi.org/10.1016/j.aca.2013.04.026

Xu, P, Chen, Z, Wu, L, Chen, Y, Xu, D, Shen, H, Han, J, Wang, X, Lou, X, 2019a. Health risk of childhood exposure to PCDD/Fs emitted from a municipal waste incinerator in Zhejiang, China. Sci Total Environ 689, 937-944. DOI: 10.1016/j.scitotenv.2019.06.425

Xu, P, Wu, L, Chen, Y, Xu, D, Wang, X, Shen, H, Han, J, Fu, Q, Chen, Z, Lou, X, 2019b. High intake of persistent organic pollutants generated by a municipal waste incinerator by breastfed infants. Environ Pollut 250, 662-668. DOI: 10.1016/j.envpol.2019.04.069

Yeo, D, Dongo, K, Mertenat, A, Lüssenhop, P, Körner, I, Zurbrügg, C, 2020. Material Flows and Greenhouse Gas Emissions Reduction Potential of Decentralized Composting in Sub-Saharan Africa: A Case Study in Tiassalé, Côte d'Ivoire. International Journal of Environmental Research and Public Health 17 (19), 7229. https://doi.org/10.3390/ijerph17197229

Yu, B, Huang, Q, Liu, Y, Jiang, G, 2019. Fabrication of composite biofibres based on chitosan and fluorinated graphene for adsorption of heavy metal ions in water. Journal of the Textile Institute 110 (3), 426-434

Yu, Y, Yu, Z, Sun, P, Lin, B, Li, L, Wang, Z, Ma, R, Xiang, M, Li, H, Guo, S, 2018. Effects of ambient air pollution from municipal solid waste landfill on children's non-specific immunity and respiratory health. Environ Pollut. 236, 382-390. DOI: 10.1016/j.envpol.2017.12.094.

Zabzugu District Assembly, 2018. Medium term-development plan (2018-2021). Draft version.

Zhang, M, Buekens, A, Li, X, 2017. Open burning as a source of dioxins. Critical Reviews in Environmental Science and Technology 47 (8), 543-620.

Zhang, T, Fiedler, H, Yu, G, Ochoa, GS, Carroll, WF, Gullett, BK, Marklund, S, Touati, A, 2011. Emissions of unintentional persistent organic pollutants from open burning of municipal solid waste from developing countries. Chemosphere, 84(7), 994–1001.

Ziraba, AK, Haregu, TN, Mberu, B, 2016. A review and framework for understanding the potential impact of poor solid waste management on health in developing countries. Archives of Public Health 74, 55. DOI: 10.1186/s13690-016-0166-4

ANNEXES

Annex 1 - Questions posed to local stakeholders during the field assessment in Ghana (November 2019)

Name of the Community/ GPS Coordinates	
Distance to District Assembly	
Total number of inhabitants	
Most common diseases in the communities	
Is there a dumpsite or a landfill close to the village? If yes, please specify the distance, and if possible, define the coordinates.	• Yes • No
Are there any official solid waste collection systems in the community? (maybe just some informal collectors for some waste as metal, glass…). If yes, please specify.	• Yes • No
Could you explain if and how had poor solid waste management situation in the community led to a high level of pollution and littering in the community?	
What kind of water do people use in each community? (From wells, from the river, from the lake). Is there a useful water source close to the community, or do people have to travel long distances before getting water? (if yes, which distance)?	
Do the majority of the people have latrines? If not, what kind of system do they have to go to the toilet?	
What do people generally do with their garbage? NB: you may select more answers	• People throw around or bury all these wastes • Some of this garbage is thrown around. Some waste is given as food for the animals • People burn or throw around all these wastes • This garbage is collected by people that do this work • Other. Please give the answer if different

	______________________________________
Any particular usage of the biodegradable fraction of the garbage such as vegetable waste, food waste, kitchen waste, garden cuts? If yes, please specify.	• Yes • No
Does in the community exist a collecting system for the garbage? Is there someone that collects garbage in some formal or informal way? NB: you may select more answers	• Yes, all the wastes are collected. (Please give us the frequency ____________) • Yes, some kind of waste (for example plastic, aluminium) is collected by formal or informal workers. The rest is thrown around. • No, we don't have any kind of collecting system. • Other. Please give the answer if different ________________________________
Very few households (or even no households) make use of improved cooking stoves	• Yes • No
Does in the community people use some improved cooking stoves or something rural? (If the situation is "variable" it would be useful to find some general proportion: "the majority use this… someone uses this. etc")	
What do people use as combustible to burn for cooking? (for example coal, wood, plastic, garbage, etc)	
What are the main crop cultivation in the community and its environs by local farmers? Which kind of related "green waste" is produced (which could be used for improved cooks stoves).	
The general condition of the soil, vegetation and ecological zone in the community	• Good • Bad
Water for irrigation availability? If no, what is the source of water for farming?	• Yes • No

Annex 2 - Questions about the municipal landfill of Novi Sad (Serbia) posed to professor Bojan Batinic

1. Does the landfill have a collection and/or leachate treatment system?	
2. Where is the leachate discharged?	
3. Do you have any information about the two ponds where leachate seems to be discharged?	
4. Is there a connection between the drainage system (the channel), the river and the leachate? If I well understood, leachate goes to the drainage system "Vrbak" and then reaches the Danube river. Can you please clarify?	
5. Do you have information about leachate characteristics (chemical analysis, to know the concentration of pollutants, if possible also heavy metals, POPs and so on)?	
6. Is there a continuous presence of leachate in the landfill? Is there information about the hydraulic head of leachate in the landfill? (This would prove there is a constant flow of leachate to the groundwater).	
7. More information about waste characteristics in the landfill. Did the landfill receive other kinds of waste in the past (in addition to MSW)?	
8. Presence of human or animal faeces in the landfill.	
9. Use of the landfill as an open defecation area.	
10. Location of the closest civil wells related to the first aquifer (with the free water table at the depth from 5 to 30-35 m). If possible information taking into account wells located southeast of the landfill (which is the groundwater flow direction). What is the use of these civil	

wells?	
11. Are there wells directly used by inhabitants which pump water from the first aquifer?	
12. In general, wells from the first aquifer (with free water table) are used? If yes, from what?	
13. Location of houses closest to the landfill (legal or illegal).	
14. Groundwater characteristics (in terms of concentration of pollutants), if possible close to the landfill (I have only information related to these chemicals in the groundwater: Sulphates, Chlorides, Nitrates, Nitrites, Ammonium ion, Detergents, BOD, COD, oil and grease).	
15. Danube river characteristics (in terms of concentration of pollutants). If possible before and after the point of discharge of leachate.	
16. How do people use surface water of the Danube river (e.g. for bathing or drinking purposes)?	
17. Is there sometimes waste open burning in the landfill? If yes, how often? Can you take some photographs of the area involved?	
18. If this combustion area exists, where is located? How large is it?	
19. Is there a fire safety system related to the landfill?	
20. Does the landfill have some safety protocols in place? Please specify.	
21. Does the landfill have some safety protocols in place to prevent burn injuries?	
22. Are there farm animals or crop cultivations close to the landfill? If possible, please specify the kind of animals and crops. How far are there	

from the landfill?	
23. About farm animals and crops nearby, can you give the following information? (a) Size of animal breeding sites; (b) Size of crop growing sites; (c) Characteristics of the sites (if there is some protection, and so on).	
24. Presence and frequency of people in the landfill.	
25. Presence and frequency of informal waste workers (such as waste pickers) in the landfill (if any), for instance in relationship with valuable waste.	
26. Do informal waste workers use Personal Protective Equipment (PPE) such as masks, gloves or boots? Which activities do they conduct?	
27. Presence of flammable materials in the landfill. What in particular?	
28. System of monitoring and control of biogas (related to the risk of waste combustion).	
29. Do formal waste workers use PPE in the landfill? Which kind of PPE? Are all fences and barriers in good conditions? Or is it possible for farm animals to enter the landfill?	
30. Are all fences and barriers in good conditions? Or is it possible for farm animals to enter the landfill?	
31. Are there sometimes farm animals in the landfill? Which animals (if possible species and number)? How often (almost every day, or no more than one time per week, or one time per month).	
32. Is there information about	

the rate and the kind of diseases of waste workers?	
33. Is there information about the rate and kind of diseases of the inhabitants close to the landfill?	
34. Is there some information about the rate and kind of diseases in Novi Sad? Some database?	
35. If the kind and rate of diseases are not available, it could be interesting to develop some questionnaires for waste workers.	
36. Frequency and kind of accidents that occurred in the landfill in the past (if any).	
37. Do waste workers attend safety courses? Please give some details about it.	
38. Do waste workers attend refresher courses? Please give some details about it.	
39. Is there sharp waste in the landfill? Are some of these visible (as a consequence they would be in the more superficial layers)? Can you take some photographs?	
40. Are there infectious and vector-borne diseases in the area? Which are the most common?	
41. Are there wild animals in the landfill? Can you specify? (For instance rodents, seagulls, dogs, cats).	
42. Are there many rodents and insects nearby houses of people who live very close to the landfill?	
43. Bad smells felt by people who live nearby the landfill. (If possible ask some people living nearby, taking information about the number of people interviewed and the answer they gave).	

44. How far from the landfill do people smell bad smells? (If possible ask some people living nearby, taking information about the number of people interviewed and the answer they gave).	
45. Is waste coverage conducted in the landfill? Can you please specify type and frequency of waste coverage?	
46. Which Volatile Compounds (VCs) are in the landfill? Do you have some data about it?	
47. Air quality in the area (to also try a comparison Novi Sad areas, more or less close to the landfill). Do you have any information about it?	
48. Are there children in the landfill sometimes?	
49. What is the land uses in the area around the landfill?	
50. Information about the hygiene practices of people in the area. Are they connected to the sewer system?	
51. Information about the hygiene practices of waste workers in the landfill.	
52. Is there information about POPs in the landfill (kind of POPs, concentration in soil, air and water, and so on)? Otherwise, I could forecast their presence in the function of some waste (or waste practices such as open burning).	

Annex 3 – Case study in Ghana. Semi-quantitative health risk assessment matrices (Tables S1-S9)

Table S1. Village #1. Semi-quantitative health risk assessment matrix

Waste management activity	Hazardous event	Hazard	Likelihood (L)	Severity (S)	Risk score (R = L × S)	Risk level (Low, Medium, High, Very High)
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Free movement of people in the dumpsite	Injuries	4	2	8	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	5	8	40	Very High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	2	2	4	Low
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High

	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S2. Village #2. Semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**
Open burning of	Leaking of leachate into	Groundwater contamination	2	2	4	Low

waste	groundwater					
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	16	64	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S3. Village #3. Semi-quantitative health risk assessment matrix

Waste	Hazardous	Hazard	Likelihood	Severity	Risk score	Risk level

management activity	event		(L)	(S)	(R = L × S)	(Low, Medium, High, Very High)
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Free movement of people in the dumpsite	Injuries	4	2	8	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	5	8	40	Very High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	2	2	4	Low
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of	Leaking of leachate into	Groundwater contamination	NA			NA

solid waste	groundwater					
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S4. Village #4. Semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High

	Free movement of people in the dumpsite	Injuries	3	2	6	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	4	8	32	High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of	Inhalation,	NA			NA

	contaminants into the soil	ingestion and/or dermal contact with contaminants				
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S5. Village #5. Semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Free movement of people in the dumpsite	Injuries	4	2	8	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals	Infectious and vector-borne diseases	5	8	40	Very High

	(including insects)					
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	2	2	4	Low
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	2	6	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	8	24	High

Table S6. Village #6. Semi-quantitative health risk assessment matrix

Waste management activity	Hazardous event	Hazard	Likelihood (L)	Severity (S)	Risk score (R = L × S)	Risk level (Low, Medium, High, Very High)

Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Free movement of people in the dumpsite	Injuries	3	2	6	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	4	8	32	High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	2	6	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	2	2	4	Low
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Feed for rodents and other animals	Infectious and vector-borne diseases	5	8	40	Very High

	(including insects)					
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S7. Village #7. Semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Free movement of people in the dumpsite	Injuries	4	2	8	Medium

	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	5	8	40	Very High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	2	2	4	Low
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	5	8	40	Very High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium

Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S8. Village #8. Semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	4	4	16	High
	Free movement of people in the dumpsite	Injuries	3	2	6	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	4	8	32	High
	Spread of contaminants	Inhalation, ingestion	4	2	8	Medium

	in air	and/or dermal contact with contaminants				
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	16	48	Very High
	Proximity to open fires	Injuries (including burning injuries)	3	4	12	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with	NA			NA

		contaminants				
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA

Table S9. Village #9. Semi-quantitative health risk assessment matrix

Waste management activity	**Hazardous event**	**Hazard**	**Likelihood (L)**	**Severity (S)**	**Risk score (R = L × S)**	**Risk level (Low, Medium, High, Very High)**
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
	Free movement of people in the dumpsite	Injuries	3	2	6	Medium
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	4	8	32	High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	3	2	6	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	2	2	4	Low
	Spread of	Inhalation,	3	16	48	Very High

	contaminants in air	ingestion and/or dermal contact with contaminants				
	Proximity to open fires	Injuries (including burning injuries)	2	4	8	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	2	4	8	Medium
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	5	8	40	Very High
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	4	2	8	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	3	4	12	Medium
Reuse of solid waste from dumpsites as compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA			NA
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA			NA
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA			NA