Environmental Research 216 (2023) 114728

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Health risks of solid waste management practices in rural Ghana: A semi-quantitative approach toward a solid waste safety plan

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ARTICLE INFO

Keywords:
Solid waste safety plan
Health risk
Solid waste management
Low- and middle-income countries
Rural Ghana

ABSTRACT

Inadequate solid waste management (SWM) can lead to environmental contamination and human health risks. The health risks from poor SWM can vary based on specific practices and exposure pathways. Thus, it is necessary to adequately understand the local context. This information, however, is rarely available in low-resource settings, particularly in rural areas. A solid waste safety plan could be helpful in these settings for gathering necessary data to assess and minimize health risks. As a step in developing such a tool, a semi-quantitative health risk analysis of SWM practices in nine Ghanaian rural villages was undertaken. Data on SWM in each village were collected through qualitative field observations and semi-structured interviews with local stakeholders. SWM-related health risks were assessed using the collected data, similar case studies in the scientific literature and dialogue among an assembled team of experts. The analysis identified context-specific practices and exposure pathways that may present the most substantial health risks as well as targeted solutions for mitigation risks. A risk assessment matrix was developed to quantify SWM risks as low, medium, high, or very high based on the likelihood and severity of identified hazards. The highest SWM risks were identified from dumpsites and uncontrolled burying of solid waste. More specifically, a very high or high risk of infectious and vector-borne diseases from SWM in the villages was identified, both in the disposal of solid waste in dumpsites and uncontrolled burying of solid waste. Additionally, a very high or high risk of inhalation, ingestion or dermal contact with contaminants was found in the disposal of solid waste in dumpsites, open burning of waste and reuse of waste from dumpsites as compost. The results demonstrate the potential value of a solid waste safety plan and a parsimonious approach to collect key local data to inform its contents.

1. Introduction

Inadequate solid waste management (SWM) can lead to environmental contamination and health risks. Several contaminants that can cause danger to human health are contained in solid waste or generated from solid waste burning. Several factors influence human exposure and it is essential to take into account linkages between potential sources of exposure to different solid waste treatment and disposal practices, possible environmental transport pathways through which the human receptor can absorb contaminants, and possible adverse health outcomes. Typical routes of exposure include direct dermal contact with waste, inhalation of contaminants via air pollution, and direct or indirect ingestion of contaminants via pollution of water, soil, or plants, and accumulation of pollutants in the food chain (EPA, 2011; Naidu et al., 2021; Rotter et al., 2018). Infectious pathogens contained in waste could also be spread by vectors, such as insects (Krystosik et al., 2020). Additionally, if the location of the site is not adequate and the waterproof layer is not appropriately designed, leachate from landfills and dumpsites can reach groundwater posing elevated risks for human health (Vaccari et al., 2018). Practices such as open burning of waste can generate by-products such as dioxins. Long-term exposure to dioxins can result in toxic or carcinogenic effects (WHO, 2019a). In this case, the

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https://doi.org/10.1016/j.envres.2022.114728
Received 22 June 2022; Received in revised form 18 October 2022; Accepted 1 November 2022
Available online 4 November 2022

primary human population exposure to dioxins is through ingestion of contaminated foods of animal origin, because dioxins decompose very slowly and can bioaccumulate through the food chain (WHO, 2019a).

In this scenario, the SWM usually improves moving from low-to high-income countries (Vinti and Vaccari, 2022a; Wilson et al., 2015). Not surprisingly, studies related to solid waste and health risks have mostly been conducted in more industrialised countries, focusing on landfills and incinerators (Mattiello et al., 2013; Vinti et al., 2021). Nevertheless, dumpsites and open burning of waste represent more dangerous practices and are particularly common in low- and middle-income countries (LMICs) (Ferronato and Torretta, 2019; Gómez-Sanabria et al., 2022).

The few studies on solid waste and health risks in rural areas of LMICs have mainly been cross-sectional studies analysing associations between self-reported health outcomes and exposure to an SWM site (Goorah et al., 2009; Reyna-Bensusan et al., 2018; Suleman et al., 2015).

In addition to limited studies measuring health risks for SWM in rural areas of LMICs, there is also a lack of knowledge about the relative contribution of different SWM activities and exposure pathways to health risks. While it would be difficult and expensive to measure and quantify each exposure pathway and risk directly, other fields have developed semi-quantitative intermediate methods to estimate this using a qualitative and quantitative approach. For example, in the areas of drinking water and wastewater, the World Health Organization (WHO) introduced semi-quantitative health risk analysis in the Water Safety Plans (WSP) (Davison et al., 2005) and in the Sanitation Safety Planning (SSP) (WHO, 2015), and a similar approach could be useful for SWM. When detailed exposure data is available, a detailed health risk analysis can be instrumental. For example, the daily assumption by ingestion of contaminants can be calculated, taking as a reference specific exposure factors (EPA, 2011), guidelines (APAT, 2008), or diffusion-dispersion models to evaluate the decrease of contaminants in groundwater (Vaccari et al., 2018). But the lack of data that characterizes rural areas makes such approaches often tricky to apply and it is not possible to follow such a quantitative evaluation for all potential exposure pathways identified. Therefore, a broader semi-quantitative approach has great potentiality.

Ghana is a LMIC where waste management represents a critical issue in terms of health and environmental risks, and therefore can be used as a case study for semi-quantitative risk analysis of SWM practices. In many areas of Ghana, waste open dumping represents the prevalent practice, and open burning is common as well (Bukari et al., 2017; Cobbinah et al., 2017). Organic waste often constitutes more than 50% of solid waste and plastic represents the second most common fraction (Miezah et al., 2015). In rural areas of Ghana, the waste generation rate tends to be lower, and SWM content and practices are less discussed in the scientific literature, but dangerous approaches persist. It is therefore important to find the most appropriate way to describe the risks and exposure pathways associated with these common practices to recommend risk mitigation strategies.

This study was undertaken to identify the health risks associated with SWM practices in rural Ghana with a view toward contributing to the development of a solid waste safety plan for use in low-income settings.

Data from a field assessment carried out in Ghana's rural villages were used to conduct a semi-quantitative risk analysis. A risk assessment matrix was developed to evaluate the SWM practices observed. The semi-quantitative health risk assessment methods within the WSP and the SSP were adapted to SWM to develop the risk matrix.

2. Materials and methods

2.1. Study area

The study involved nine rural villages in the Northern and North East regions of Ghana in the fall of 2019. These villages were in the savannah zone, which is economically the least developed area of Ghana due to reduced rainfall and infertile lands (Miezah et al., 2015). The nine villages involved are indicated in Fig. 1. They were beneficiaries of the Sustainable Livelihoods project (Vinti et al., 2020). One village per district was selected. They were identified by Cooperazione Internazionale Sud Sud (CISS) (the NGO that led the project) and local authorities, who took into consideration: safety factors, easy access to the community, distance from the operational base (Tamale), and the social and environmental fragility of the community.

2.2. Data collection

Data were collected using the semi-quantitative risk matrices methods described in the World Health Organization's Water Safety Plan (WSP) (Davison et al., 2005) and Sanitation Safety Plan (SSP) (WHO, 2015) but adapted to SWM and the specific context of this study. The WSP and SSP are designed to identify specific practices and exposure pathways associated with the most substantial health risks, thereby denoting priority areas for targeted solutions to reduce such risks. Data on SWM in each of the nine villages were collected through qualitative field observations as well as semi-structured interviews with local stakeholders, such as opinion leaders, traditional authorities from the villages and people living near dumpsites. The environmental assessment was part of a broader monitoring effort within the Sustainable Livelihoods project (Vinti et al., 2020). In each assessment, information was collected on solid waste collection, storage and containment practices. In addition, information on commonly reported diseases, sanitation services, and general environmental issues was collected (Table S20, Supplementary Material). Further documentation was provided by local offices (East Mamprusi District Assembly, 2018; Zabzugu

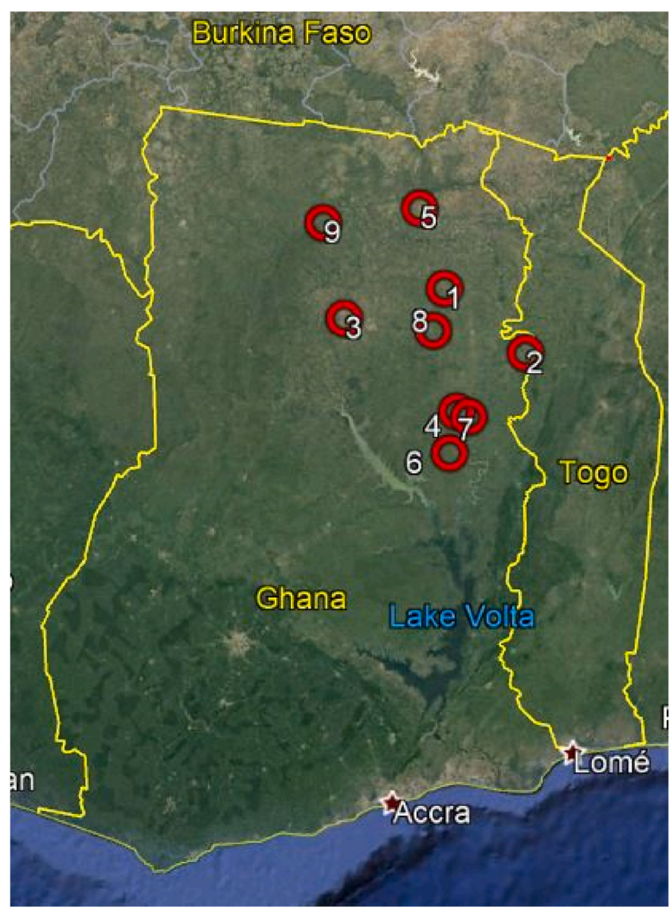

Fig. 1. Physical map of Ghana marking the nine villages visited (using Google Earth software).

District Assembly, 2018). When SWM disposal sites were identified in the village, the sites were visited to understand waste composition, presence of farm animals, distance from homes and presence of children. A portable device (Trotec International, particle measuring device BQ20, measurement interval 0–2000 μg/m^3, resolution 1 μg/m^3, detector type: scattered light measurement) was employed to measure the concentration of $PM_{2.5}$ and PM_{10} in the air at different points of each village. In village #1, 10 air measurements were conducted in correspondence with waste burning activities.

2.3. Data analysis

The data from the field assessment were used to conduct a semi-quantitative risk analysis. Risk assessment matrices were developed; they were specific to the SWM practices observed based on literature review and internal consultation among the authors. In the work, the WSP and the SSP were taken as a reference. The general structure of the risk matrix used for this study is shown in Table 1. The matrix and the related hazardous events are discussed in detail in the Results and Discussion sections. For the construction of this matrix, the definitions adopted by Davison et al. (2005) in the WSP were used, with a hazard defined as any chemical, biological or physical agent having the potential to cause harm, a hazardous event described as a situation that can lead to the presence of a hazard, and a risk defined as the likelihood that identified hazards can cause harm of a certain magnitude in exposed populations.

The parameters used in the SSP (WHO, 2015) for the severity, likelihood, and risk level measurement scales were then employed, as summarised in Table 2. However, as exposure pathways and risks related to SWM can be different from wastewater and drinking water, the definitions from the SSP were adapted to develop distinct meanings for the SWM semi-quantitative risk assessment parameters, which are summarised in Table 3.

A risk assessment was conducted for each specific SWM activity in each village. Following an internal consultation among some of the

Table 2
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.

Table 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				
	Free movement of farm animals in the dumpsite	Ingestion of contaminants by inhabitants (through the food chain)				
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants				
	Free movement of people in the dumpsite	Injuries				
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases				
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants				
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants				
Waste open burning	Leaking of leachate into groundwater	Groundwater contamination				
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants				
	Proximity to open fires	Injuries (including burning injuries)				
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination				
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases				
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants				
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants				
Reuse of solid waste from dumpsites as a compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination				
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases				
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants				
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants				

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.

authors, specific hazardous events were identified for each SWM activity and then a severity and likelihood of each event were assigned. Many of the scores could be derived from the observations and data collected during field assessments. As quantitative data regarding the concentration of contaminants in the environment require specialized technological devices which are expensive and difficult to obtain in rural settlements of developing countries, data from scientific publications from similar contexts were used when available. In some instances, when there was insufficient collected or published data, scores for likelihood and severity were derived from the technical knowledge and expertise of the team members, as recommended by Davison et al. (2005). When possible, based on the data available, the assumption rate of contaminants by humans through environmental compartments was evaluated. As we sought to identify the highest exposure risks to human health, when possible, we focused on children exposure because they usually represent the most vulnerable population segment (Miller et al., 2002). Equation (1) was used to estimate the daily ingestion of contaminated soil by children per kilogram of body weight (APAT, 2008):

$$EM = \frac{IR \times FI \times EF \times ED}{BW \times AT \times 365} \quad (1)$$

where

- EM = the daily amount of contaminated matrix to which the receptor is exposed per kg of bodyweight [mg/(kg × day)]
- IR = ingestion rate = 200 mg/day
- FI = soil fraction ingested = 1 [without dimensions]
- EF = exposure frequency = 350 d/year
- ED = exposure duration = 6 year for children
- AT = averaging time = ED for non-carcinogenic compounds; an average value between childhood and adult age for carcinogenic compounds
- BW = bodyweight = 15 kg

Equation (1) and the values reported above were taken from the Italian guidelines of the National Environmental Agency for the estimation of contaminated lands (APAT, 2008). However, it is important to consider that the ingestion rate of 200 mg/day represents a conservative assumption taken from the US Environmental Protection Agency (EPA, 2011).

The children's daily estimated ingestion of contaminated soil was multiplied for the concentration of pollutants in the soil, taking the values reported in the study of Agyarko et al. (2010) as a reference. Then, to evaluate the Severity, the resulting values, in terms of μg/(kg x time interval), were compared with the tolerable daily (or weekly, or monthly) intake given by WHO (2007, 2019b, 2019c). Furthermore, when a specific activity (e.g., burying of waste) was not performed in a 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).

More details about scoring given to Likelihood, Severity and Risk related to each Hazardous Event in each village are available in Supplementary Material (Tables S1–S9). Likewise, the methodology followed in weighing each hazardous event in terms of Likelihood and Severity is available in Table S10 (Supplementary Material). In following the procedure, Tables 1–3 were crucial. Furthermore, the information collected and summarised in Section 3 were used, alongside those gathered in Annex 5 (Characteristics of the nine rural villages – Report based on the field assessments) of Supplementary Material.

3. Results

3.1. Summary of local information

In villages most people were farmers that bred animals (i.e., goats, poultries, and in some cases, cows and pigs) and cultivated crops. Villages varied in size and distance from nearest urban centres, but all of them had less than 10,000 inhabitants. Two villages (#6 and #9) had a population size of less than 500 people. Most villages had dirt roads, with only three out of the nine rural villages connected to the nearest urban centre through paved roads, influencing the time needed to reach the communities. Malaria, respiratory infections and diarrhoea were the three most common diseases in all villages. A summary of village characteristics and the SWM activities observed in each village is available in Table 4. A report with more detailed information, analysis and consideration, is available as Annex 5 (Supplementary Material). Furthermore, the concentration of $PM_{2.5}$ and PM_{10} in the air was measured in all the villages, and the values are available in the Supplementary Material (Table S21). As expected, the worst air quality was found during the open burning of waste, that was measured in village #1. Thus, during waste burning, PM concentration was higher than at other times, even by more than an order of magnitude. In general, the PM concentration in villages was not alarming in the absence of open fires, even close to dumpsites. Thus, considering that, however, respiratory infections are one of the most common diseases, we also evaluated other sources of air contamination. For example, previous research (Mataloni et al., 2016) found associations between the vicinity of landfills and respiratory infections in young people considering H_2S. However, PM pollution from open burning cannot be underestimated. Indeed, as noted in another research study (Vinti and Vaccari, 2022b), both open burning of waste and unsafe cooking systems can periodically increase the PM concentration in the rural communities involved in the research, threatening health (e.g. respiratory infections). It was also noted by Reyna-Bensusan et al. (2018) in Mexican rural communities.

In almost all villages, the presence of groundwater was verified. Groundwater from wells was used as drinking water. The wells were usually open, and water was often collected by a bucket, but in some cases, manual pumps were noted.

As shown in Table 4, rainfall in the villages was generally low, and

Table 4
Characteristics of the nine villages and their solid waste management practices.

Village, district and region	Number of inhabitants	Distance from nearest urban centre [a]	Road connections quality [b]	Main crops	Dumpsites [c] within the village	Groundwater and wells	Scattered waste within the village	Open burning of solid waste	Burial of waste	Rainfall in the area [d]
#1. Gushegu district, Northern Region	5919	35 km	dirt roads	corn, yam, bean, millet	Yes	Yes	Yes	Yes	NA	C
#2. Zabzugu district, Northern Region	1700	11 km	dirt roads	yam, manioc, corn, rice, bean	No	Yes	Yes	Yes	NA	C
#3. Tolon-Kumbungu district, Northern Region	6000	<1 km	paved roads	corn, millet, bean, yam	Yes	Yes	Yes	Yes	NA	C
#4. Nanumba South district, Northern region	4000	13 km	dirt roads	yam, manioc, rice, cashew, corn	Yes	NA	Yes	Yes	NA	C
#5. East Mamprusi district, Northeast Region	8681	20 km	paved roads	corn, millet, bean, nut	Yes	Yes	Yes	Yes	No	D
#6. Kpandai district, Northern region	350	9 km	dirt roads	yam, manioc, corn, wheat	Yes	Yes	Yes	Yes	Yes	C
#7. Nanumba North district, Northern region	2932	15 km	dirt roads	corn, yam	Yes	Yes	Yes	Yes	Yes	C
#8. Mion district, Northern Region	1100	5 km	paved roads	corn, manioc, bean	Yes	NA	Yes	Yes	NA	C
#9. Mamprugu Moagduri district, Northeast region	222	>15 km	dirt roads	bean, corn, rice	Yes	Yes	Yes	Yes	Yes	D

NA: Not Available.
[a] Nearest urban centre refers to urbanized cities and/or district capitals.
[b] Considering connections with inhabited centres nearby.
[c] Also considering small dumpsites.
[d] Taking as a reference www.worldweatheronline.com. The following values were assigned, on the basis of the average annual rainfall from 2015 to 2019 (if available): (D) $x < 500$ mm/year; (C) $500 = x \leq 1000$ mm/year; (B) $1000 < x \leq 1500$ mm/year; (A) $x > 1500$ mm/year. More information available in Supplementary Material (Tables S11–S19).

the annual rainfall as an average from 2015 to 2019, was lower than 1000 mm/year. In two cases (village #5 and village #9), it was lower than 500 mm/year. More detailed information about rainfall values in these villages and their implications on leachate generation is available in Supplementary Material, Tables S11–S19 and Annex 1.

During the field assessments, four unique SWM activities were observed and assessed: (1) Disposal of solid waste in dumpsites, (2) Open burning of waste, (3) Uncontrolled burying of solid waste, and (4) Reuse of solid waste from dumpsites as compost by local farmers. They are summarised, along with the related hazardous events and hazards, in Fig. 2.

For the activity “uncontrolled burying of solid waste”, it refers to the entire period during which a hole is gradually filled with waste, as shown in Fig. 3. This practice is usually related to the construction of new houses. Indeed, mainly in peri-urban and rural Ghana, when people build their houses, they can also use the soil as a building material, digging a ditch (Ansah et al., 2020; Hagan, 1997). Thus, the hole they obtain is used as a waste disposal site (Vinti, 2021). However, the field assessment confirmed that in some cases people bury a pit just to have a private waste disposal site.

The SWM emerged as a common issue that characterized all the villages. Scattered waste was always observed, and waste burning was practised in all the villages. Uncontrolled burying of solid waste was confirmed in three villages. Disposal of solid waste in dumpsites of different size was noted in all the villages, except for village #2. The reuse of solid waste from dumpsites as compost by local farmers was ascertained in village #5.

In villages with dumpsites, the dumpsites typically had a horizontal surface between 20 m^2 and 200 m^2. However, village #1 had a larger dumpsite in the core of the village (horizontal surface greater than 400 m^2), and villages #6 and #9 had very small dumpsites (<20 m^2). Most dumpsites were located in central parts of villages, in some cases close to local markets to facilitate waste disposal or periodical collection. None of the dumpsites had fences or other protections, making them easily accessible by adults, children and animals. Farm animals were frequently observed at dumpsites during the field assessments. In some cases, mainly in small villages, some households had their personal small dumpsite to use, a few meters from the house. People disposed of

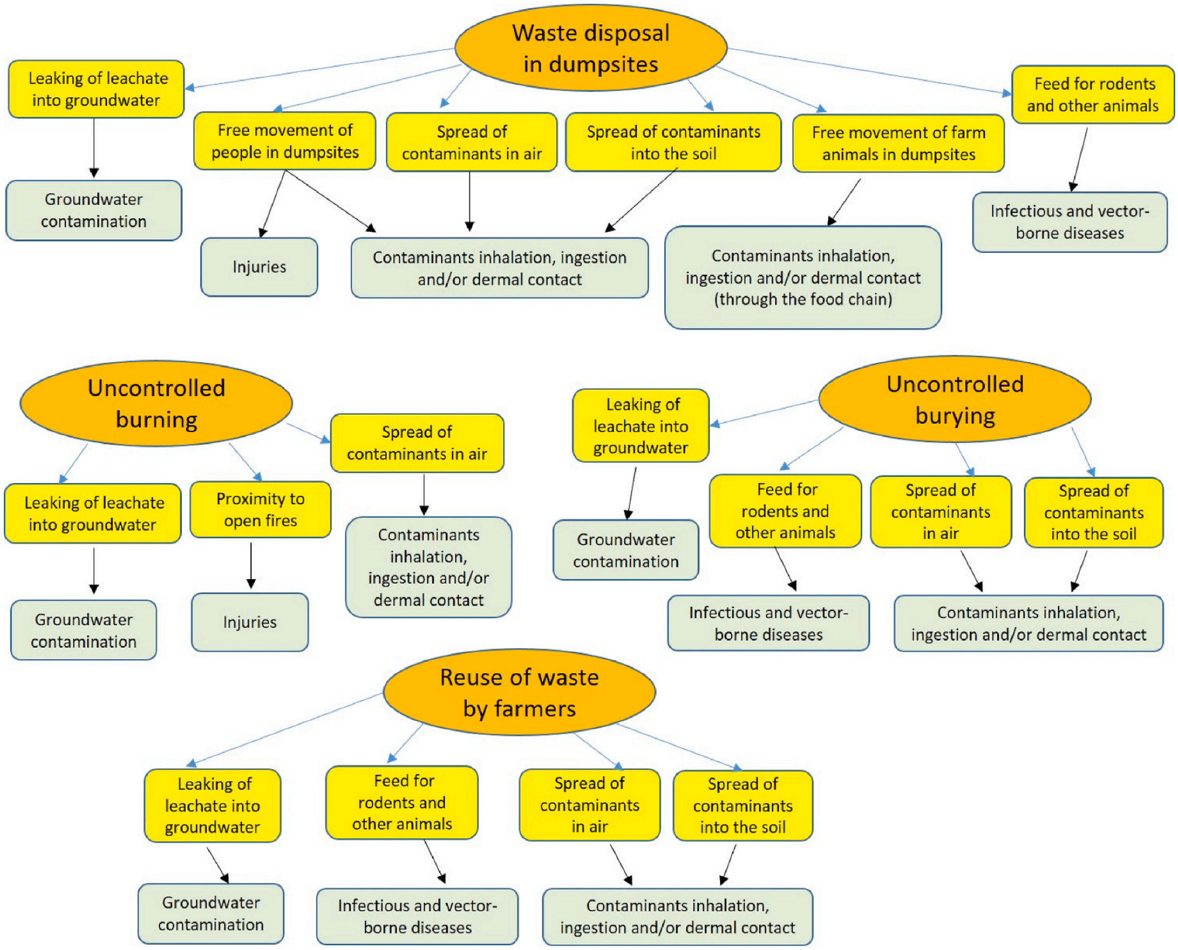

Fig. 2. Schematic representation of the hazardous events (in yellow) and hazards (in light blue) associated with the four SWM practices identified in the rural villages.

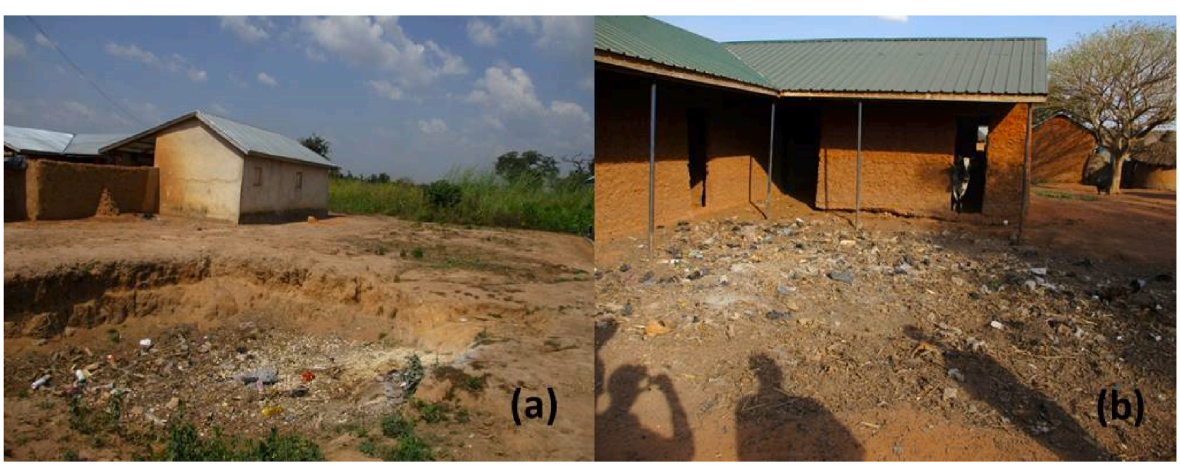

Fig. 3. Uncontrolled burying of solid waste: (a) pit filling phase and (b) pit full of waste (photographs taken during the field assessments).

household waste in dumpsites, primarily consisting of organic waste, but the plastic waste was common as well. Metals and glass were also observed, although in low quantity, probably because those materials have more value for villagers. Electronic waste and other assorted waste were rare, and it was easier to find it in the larger villages of the survey, as previously noted by Agyarko et al. (2010) in other parts of Ghana. Additionally, human faeces were sometimes observed in dumpsites. In some cases, children were also seen using dumpsites as an open defecation area during the field assessment.

Waste burning represented a common practice used by the population to reduce waste volume. In some cases, it was periodically conducted in dumpsites or where people buried their waste. In any case, open burning of waste was practised inside the villages. Farm animals were often seen eating in areas in which waste burning was practised. The waste that people preferred to burn was plastic because, unlike the organic fraction, it does not degrade and the volume of plastic increases when it is accumulated. However, the organic fraction was also burned.

Uncontrolled burying of solid waste represented a practice mainly related to houses building. It was ascertained in three villages, but may also be conducted in the other villages that we visited. As it can be seen in Table 4, the information was Not Available (NA) in most other communities. Fig. 3 shows (a) pit filling phase and (b) pit full of waste. Mainly during the pit filling phase, the hole can provide breeding and feeding sites for animals and insects, as it was witnessed during the field assessment in village #6, in which a pit close to a new house was used by poultries. As can be noted in Fig. 3, the size of the hole is usually not huge, because it depends on the soil needed for the house.

The reuse of solid waste from dumpsites as compost by local farmers was confirmed only in village #5 (Fig. 4). In the other villages, it was not possible to find this information and further surveys would be needed. In village #5 farmers periodically took waste from dumpsites located close to the local market, about two times per month. Waste disposed of in these dumpsites included household waste and waste produced in the market. As a consequence, there was a high 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 the presence of periodic fires, mostly generated accidently, due to, for example, hot ashes. In this village, considering the value that farmers gave to waste as compost, even from dumpsites, waste burning was discouraged. During the field assessment, farm animals, such as pigs and goats, were observed eating in dumpsites. Furthermore, dumpsites were used for open defecation. It is essential to highlight that farmers periodically collected all this waste from dumpsites, then they sorted the organic fraction from the rest by themselves (i.e., there is not a separation of waste at source). As a consequence, the organic fraction will likely be contaminated with many other substances. Furthermore, farmers burned the remaining waste (i.e. the residues, mainly plastics) by themselves in areas close to their lands.

3.2. The health risk assessment matrix and the highest risks

A semi-quantitative health risk assessment matrix was created for each village, summarising the risk level associated with each hazardous event for all SWM activities in each village (Table 5).

The exposure pathways with the highest risk varied by type of SWM activity, but each SWM activity had specific hazardous events that were scored as creating either a high or very high health risk. For disposal of solid waste in dumpsites, high or very high risk was found in the following hazardous events: feed for rodents and other animals, free movement of people in the dumpsite, and spread of contaminants in the air. In the case of waste burning, high or very high risk resulted in the spread of contaminants in the air. For uncontrolled burying of solid waste, very high risk resulted for feed for rodents and other animals. Reuse of solid waste from dumpsites as compost by local farmers was ascertained only for village #5, and high risk resulted for the spread of contaminants into the soil.

Targeted recommendations can be made based on this assessment to reduce health risk in these and similar communities.

Furthermore, more detailed information for all the risks (low, medium, high, and very high) is available in Annexes 1-4 from Supplementary Material. In addition, Annex 5 provides further details on the characteristics of the nine rural villages based on the field assessment.

4. Discussion

4.1. Disposal of solid waste in dumpsites

There was a high or very high risk of infectious and vector-borne diseases resulting from dumpsites in villages, due to waste creating feed or breeding sites for rodents and other animals, including insects like mosquitoes that spread malaria. This finding is supported by results from past cross-sectional studies conducted in Africa which found higher incidence of malaria close to dumpsites (Abul, 2010; Sankoh et al., 2013; Suleman et al., 2015). Additionally, Ghana is one of the countries with the highest incidence of malaria in the world (Riveron et al., 2016), and it was one the three most common diseases in the districts involved in this field assessment, which contributed to a severity of major and a likelihood of likely or almost certain being assigned to this risk across villages.

The free movement of people in the dumpsites also resulted in a high health risk in most villages due to the hazard related to inhalation, ingestion and/or dermal contact with contaminants. In particular, the severity was assumed as moderate (i.e., acute illness such as diarrhoea or upper respiratory illness) in all the villages. It is important to note that during the surveys children were usually observed in such dumpsites.

Fig. 4. Dumpsite in village #5, whose waste is periodically collected by farmers (photograph taken during the field assessments).

Table 5
Semi-quantitative health risk assessment matrix – summary of the results for each village.

Waste management activity	Hazardous event	Hazard	Risk level (Low, Medium, High, Very High) in each village								
			#1	#2	#3	#4	#5	#6	#7	#8	#9
Disposal of solid waste in dumpsites	Leaking of leachate into groundwater	Groundwater contamination	Medium	–	Medium	NA	Medium	Medium	Medium	NA	Medium
	Free movement of people in the dumpsite	Inhalation, ingestion and/or dermal contact with contaminants	**High**	–	**High**	**High**	**High**	**High**	**High**	**High**	Medium
	Free movement of people in the dumpsite	Injuries	Medium	–	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	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	**Very High**	–	**Very High**	**High**	**Very High**	**High**	**Very High**	**High**	**High**
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	**High**	–	Medium	Medium	Medium	Medium	Medium	Medium	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	Medium	–	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Open burning of waste	Leaking of leachate into groundwater	Groundwater contamination	Low	Low	Low	NA	Low	Low	Low	NA	Low
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	**Very High**	**Very High**	**Very High**	**Very High**	**Very High**	**Very High**	**Very High**	**Very High**	**Very High**
	Proximity to open fires	Injuries (including burning injuries)	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
Uncontrolled burying of solid waste	Leaking of leachate into groundwater	Groundwater contamination	NA	NA	NA	NA	–	Medium	Medium	NA	Medium
	Feed for rodents and other animals (including insects)	Infectious and vector-borne diseases	NA	NA	NA	NA	–	**Very High**	**Very High**	NA	**Very High**
	Spread of contaminants in air	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	–	Medium	Medium	NA	Medium
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	–	Medium	Medium	NA	Medium
Reuse of solid waste from dumpsites as a compost by local farmers	Leaking of leachate into groundwater	Groundwater contamination	NA	NA	NA	NA	Medium	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 air	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	Medium	NA	NA	NA	NA
	Spread of contaminants into the soil	Inhalation, ingestion and/or dermal contact with contaminants	NA	NA	NA	NA	**High**	NA	NA	NA	NA

Indeed, there were no fences, and children could go in without restrictions. Children played and sometimes used the sites as open defecation areas. Therefore, as faeces were disposed of in dumpsites, and the survey confirmed that diarrhoea was among the most common diseases in the villages, there was an assumed risk of diarrhoea transmission from contact with dumpsites. However, the adverse health outcomes related to ingestion of soil with metals and metalloids were not considered further due to the low ingestion rates of metals calculated using Equation (1) for soil ingestion rates (APAT, 2008) and the assumed metal contamination of soil based on Agyarko et al. (2010) which analysed a dumpsite from another Ghanaian rural village. Three metals and metalloids pollutants (i.e., Cd, Hg, As) were chosen for analysis among those that Agyarko et al. (2010) found at higher levels at dumpsites. The resulting values from this analysis, in terms of μg/(kg x time interval) for all the three compounds were found to be more than an order of magnitude below the tolerable daily (or monthly) intake given by WHO (2007, 2019b, 2019c) and were therefore considered negligible risk. More details are available in Supplementary Material (Table S22).

Furthermore, in one village (village #1) the spread of contaminants in air from dumpsites was found to result in a high risk, following a precautionary approach. In particular, a moderate severity was assigned. In assigning this score in village #1, the epidemiological study of Hoffmeyer et al. (2014) was taken into account, in which the authors found a higher incidence of chronic bronchitis in former compost workers. Although the Hoffmeyer study evaluated health risks associated with 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 obtaining a high level of risk.

These risks associated with dumpsites could be reduced by locating dumpsites at the edge of villages or further away from homes, building a fence around each dumpsite, and by reducing the organic fraction of waste disposed of in dumpsites. In rural communities of LMICs, the organic fraction usually represents more than half of MSW produced at the household level (Han et al., 2018), which was also observed in these study sites. Reducing the amount of this organic waste disposed of at dumpsites could be achieved through the introduction of composting bins at the household level.

Other hazardous events, including leaking of leachate into groundwater, exposure from spread of contaminants into the soil, and injuries from free movement of people were considered medium risk for all villages in which a value could be assigned. For leaking of leachate into groundwater, this risk level was primarily driven by the low annual rainfall likely to leave the system through evapotranspiration (Aljaradin and Persson, 2013), small dumpsite size, and relatively low levels of leaching contaminants measured from a dumpsite in a different Ghanaian rural village (Agyarko et al., 2010). For exposure from the spread of contaminants into soil this risk level was primary driven by the lack of a geomembrane to prevent waste contact with soil, and assumed daily soil contamination ingestion rates discussed above. For the injuries risk level, this was primarily driven by the composition of waste (mostly organic and plastic, with few glass and aluminium components) and the absence of fences.

The final hazard of ingestion of contaminants by inhabitants through the food chain from the free movement of farm animals in the dumpsite could not be assigned any level of risk. While many farm animals were observed in dumpsites, and it is plausible bioaccumulation of POPs in their body could cause adverse health outcomes to people eating these animals and their derivatives, the related field of research is still novel with results that are partially discordant. Therefore, the uncertainty around this risk led us to consider the risk NA (see Annex 1 in Supplementary Material for further details).

4.2. *Reuse of solid waste from dumpsites as compost by local farmers*

In the only village in which it was possible to ascertain reuse of solid waste from dumpsites as compost by local farmers (village #5), a high risk was associated with spread of contaminants into the soil. Indeed, an immature compost, as seems that used in village #5, presents high risks of toxicity and can harm the soil (Mahapatra et al., 2022). In terms of likelihood, this event was assumed as possible, and in terms of severity, it was considered major. As there was not a waste separation at the source, and farmers separated the organic fraction from the rest of the waste by themselves. As shown in Fig. 4, the quality of the mixed waste taken from the dumpsites was very low. As a consequence, even after separation, biowaste would likely contain pollutants. Furthermore, the survey confirmed that sometimes there are unintentional fires in dumpsites from village #5 that can generate POPs such as dioxins. When studying MSW open burning, Fiani et al. (2013) identified the emission factor in terms of release of PCDD/PCDF in the ashes as 5–10% of the emission factor in air. This highlights that when farmers use such a waste as compost for their crops, it can also lead to dioxins that bioaccumulate in the environment.

To reduce such risk, the separation of the organic fraction of waste at the source and awareness campaigns to encourage organic waste separation at the source are recommended. Indeed, to conceive a separate waste collection at source will allow reusing safer organic waste. It is crucial to consider that 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). In addition, an appropriate composting process is recommended. For example, composting bins at the household level can allow to obtain a mature compost (Mahapatra et al., 2022).

4.3. *Open burning of waste*

There were very high health risks found for the spread of contaminants in air from waste open burning in all villages. In terms of likelihood, the event was assumed as possible or likely, based on information collected during the surveys. This assessment also considered literature values from studies of the concentration of pollutants generated during open burning of MSW, which highlighting the elevated concentration of POPs (such as dioxins) and other toxic and carcinogenic compounds (Estrellan and Iino, 2010; Zhang et al., 2011). Furthermore, many epidemiological cohort studies (Candela et al., 2013, 2015; Ghosh et al., 2019; Parkes et al., 2020), as well as human biomonitoring studies (Xu et al., 2019b, 2019a), have been conducted 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 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 the case of MSW from rural settlements (Zhang et al., 2011).
- POPs, such as dioxins and furans, can bioaccumulate through food chains (WHO, 2019a).
- 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 air pollutants.

To reduce risks associated with open burning of waste, awareness campaigns against waste combustion and efforts to reduce the organic fraction of waste are recommended. Reducing the organic waste fraction should reduce the need to burn waste to reduce its volume.

4.4. *Uncontrolled burying of solid waste*

There was a very high risk of infectious and vector-borne diseases resulting from sites with uncontrolled burying of solid waste, due to waste creating feed or breeding sites for rodents and other animals, including insects like mosquitoes. As already discussed in the case of dumpsites, the severity was assumed as major because, in Ghana, malaria is endemic. It is one of the countries with the highest incidence of malaria in the world (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 of waste. 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 survey in some pits and the holes were usually a few meters from houses. As a consequence, the likelihood was assumed as “almost certain”.

Other risks associated with this uncontrolled burying on solid waste were assessed as medium, with generally similar rationale to those for dumpsites. Awareness campaigns to discourage the burial of waste are recommended to reduce these health risks.

More details concerning all risks for all types of SWM practices are available in Supplementary Material (Tables S1–S9 and Annexes A1-A4).

4.5. Progress towards a solid waste safety plan

This research represents the first step in the way of the Solid Waste Safety Plan (SWSP). Indeed, the health risk assessment matrix approach represents a core element in structuring and developing a safety plan, as WSP and SSP proved. With this in mind, we developed risk assessment matrices specific to the SWM practices observed. We adopted a similar approach used in the WSP and the SSP. The scale of values used was essential in terms of severity and likelihood. Therefore, it was possible to consider and compare different hazardous events using a common yardstick through the risk matrices. Therefore, the interventions should be prioritised based on the risk level. Thus, the method developed could also be used as a low-cost way to assess relative health risks associated with different exposure pathways in other communities and the first step towards developing an SWSP.

Previous studies have highlighted the economic and health benefits of reducing environmental risk factors (Landrigan et al., 2018). Thus, considering that each person produces solid waste as a potential source of pollution, the advantages associated with an SWSP can be enormous, bridging an existing literature gap.

Previously, Cook and Velis (2020) and Velis and Cook (2021) have made a health risk matrix associated with waste management practices. However, their work did not focus on a procedure similar to that described in this manuscript. Indeed, the matrix they fulfilled played a more general role. Instead, in this manuscript, the risk matrix assumed a relevance associated with the specific hazardous events that were identified. The scale of values used for severity and likelihood was essential. However, the values can be modified according to the particular local context. Indeed, although it will also be up to the team members to establish the matrix’s specific characteristics, a general structure should be agreed upon globally. It will allow adapting the matrix to the various case studies analysed. It has already been done in the SSP (WHO, 2015). The results from the present research demonstrate the potential value of an SWSP and a parsimonious approach to collecting essential local data to inform its contents.

4.6. Limitations

This study has several limitations. First, data related to surface water were not collected and analysed. Indeed, areas involved were in the Savannah zone, and people mostly used water from wells. However, there were some rivers within a few kilometres from some villages. As a consequence, further research should include the assessment of these water bodies. Additionally, soil quality was not assessed through specific measurement devices. Air quality was assessed in each village in terms of PM2.5 and PM10, but air quality during solid waste open burning was measured in only village #1. More accurate air quality assessments would also be beneficial; for example, different contaminants can be contained in PM, posing various health risk levels (Lei et al., 2020). In addition, other air pollutants, such as H_2S, can be monitored (Mataloni et al., 2016). Furthermore, the use of maps could be beneficial to make the local context clearer and better highlight the differences and similarities among the villages. Unfortunately, existing maps were not available. Thus, it is advisable for future case studies to find such maps or accurately draw them, also indicating the position of all the waste sites discussed previously. Such maps could also be associated with software like GIS to gather information in different layers.

The limitations mentioned above may have impacted the results obtained. Indeed, for example, some people could use water from rivers, even if it appeared that most of them used water from wells. As a consequence, it is a risk that could be taken into account in the future. At the same time, the lack of quantitative data in the environmental analysis reduced the accuracy of the results. However, as anticipated, we overtook these limitations, common in such contexts, through the methodology we chose and a conservative approach. Future, more accurate field assessments could allow comparison and evaluate the accuracy achieved with the discussed procedure. Indeed, NA events could pose some risks, and practices for which high and very high risks were estimated should receive more detailed and specific monitoring.

5. Conclusions

This manuscript introduced a first version of the health risk assessment matrix associated with SWM practices in specific contexts. The matrix represents a crucial step in developing an SWSP.

The benefits that could originate from an SWSP are enormous, and, like WSP and SSP, the application appears to be extensively possible, both in developing and industrialised countries.

In the nine rural villages involved in the research, the paucity of quantitative information represented one of the main challenges. It was an issue that often characterizes such areas. To tackle it, data collected during a field assessment were used alongside the search for similar case studies in the scientific literature and the consultation among the team of experts that was set up. Events resulting in high and very high risks should be prioritised in terms of control measures to mitigate them. Such control measures were introduced in this manuscript. However, they will be discussed in detail, alongside the general structure of an SWSP, in a further manuscript.

Additionally, the matrix proposed in this manuscript could likely be improved through implementation in further contexts and case studies. A broader discussion on risk matrices and the structure of the SWSP within the scientific community should be opened.

Credit author statement

Giovanni Vinti: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Valerie Bauza**: Conceptualization, Methodology, Validation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Thomas Clasen**: Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing, Visualization, Supervision. **Terry Tudor**: Conceptualization, Methodology, Validation, Writing – original draft, Visualization, Supervision. **Christian Zurbrügg**: Conceptualization, Methodology, Validation, Supervision. **Mentore Vaccari**: Conceptualization, Methodology, Validation, Supervision.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The case study in Ghana was analysed in the context of the “Sustainable Livelihoods” project, led by Cooperazione Internazionale Sud

Sud (CISS) NGO in partnership with CeTAmb (University of Brescia) and two Ghanaian NGOs (NECPAD and RUDEYA). The project is co-funded by the European Union in the framework of the CSO RISE programme - Civil Society Organizations in Research and Innovation for Sustainable Development.

Giovanni Vinti was funded by a grant to the University of Brescia from the European Union (in the context of the "Sustainable livelihoods" project).

The collection of many field data was possible thanks to the contribution of Mauro Bartolomeo (CISS NGO).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envres.2022.114728.

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