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ORIGINAL ARTICLE

Assessing potential health impacts of waste recovery and reuse business models in Hanoi, Vietnam

Mirko S. Winkler · Samuel Fuhrimann · Phuc Pham-Duc · Guéladio Cissé · Jürg Utzinger · Hung Nguyen-Viet

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Abstract

Objectives In resource-constrained settings, the recovery of nutrients and the production of energy from liquid and solid waste are important. We determined the range and magnitude of potential community health impacts of six solid and liquid waste recovery and reuse business models in Hanoi, Vietnam.

Methods We employed a health impact assessment (HIA) approach using secondary data obtained from various sources supplemented with primary data collection. For determining the direction (positive or negative) and magnitude of potential health impacts in the population, a semiquantitative impact assessment was pursued.

Results From a public health perspective, wastewater reuse for inland fish farming, coupled with on-site water treatment has considerable potential for individual and community-level health benefits. One of the business models investigated (i.e. dry fuel manufacturing with agro-waste) resulted in net negative health impacts.

Conclusions In Hanoi, the reuse of liquid and solid waste—as a mean to recover water and nutrients and to produce energy—has considerable potential for health benefits if appropriately managed and tailored to local contexts. Our HIA methodology provides an evidence-based decision-support tool for identification and promotion of business models for implementation in Hanoi.

Keywords Business models · Health impact assessment · Resource recovery and reuse · Sanitation safety planning · Vietnam

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M. S. Winkler (✉) · S. Fuhrimann · G. Cissé · J. Utzinger
Swiss Tropical and Public Health Institute, P.O. Box, CH-4002, Basel, Switzerland
e-mail: mirko.winkler@unibas.ch

M. S. Winkler · S. Fuhrimann · G. Cissé · J. Utzinger
University of Basel, Basel, Switzerland

P. Pham-Duc · H. Nguyen-Viet
Center for Public Health and Ecosystem Research, Hanoi School of Public Health, Hanoi, Vietnam

H. Nguyen-Viet
International Livestock Research Institute, Hanoi, Vietnam

Introduction

Unprecedented population growth, increasing per capita consumption and rapid urbanisation have resulted in densely populated and fundamentally transformed cities in low- and middle-income countries (LMICs), particularly in Africa and Asia (Utzinger and Keiser 2006). In this context, sanitation infrastructures and waste collection systems struggle to keep pace with increasing volumes of wastewater, faecal sludge, animal manure, organic waste and municipal solid waste (Fuhrimann et al. 2014; Rydin et al. 2012). Meanwhile, the recovery of water and nutrients, as well as the production of energy from liquid and solid waste, is gaining importance (Lehmann 2011; Spangberg et al. 2014). Indeed, resources recovered from solid and liquid waste that are used in agriculture and aquaculture and for energy production have the potential to increase crop yields, decrease the use of inorganic fertilizers, reduce emission of atmospheric greenhouse gases and ultimately result in cost recovery in the sanitation sector (Drechsel et al. 2015). Moreover, recovery and use of waste provides livelihood opportunities for marginalised communities and promotes food security (Pleissner 2016). However, inappropriate waste management systems, coupled with increasing wastewater and faecal sludge reuse practices in agriculture and aquaculture in LMICs, exacerbate the transmission of infectious diseases caused by bacteria, viruses, intestinal protozoa and parasitic worms (Bartram and Cairncross 2010; Fuhrimann et al. 2014, 2016c; Pham-Duc et al. 2013). Additionally, non-communicable diseases are of concern due to potential chemical contamination of wastewater-fed agriculture and aquaculture (Ackah et al. 2014; Fuhrimann et al. 2015). Against this background, the promotion of safe recovery and reuse of liquid and solid waste is an important strategy for working towards the United Nation's Sustainable Development Goals (SDGs). Specifically, the safe recovery and reuse of liquid and solid waste will be essential for working towards SDG#3, that is to ensure healthy lives and promote well-being for all at all ages, and for acting on SDG#6 (clean water and sanitation) and SDG#8 (employment and economic growth).

The resource recovery and reuse project had the primary objective to test business models (BMs) for their potential to scale-up smallholder farming operations based on the safe use of wastewater, greywater and excreta (IWMI 2016). This scaling up aims at large-scale, economically viable and safe use of solid and liquid waste streams. With financial support from the Swiss Agency for Development and Cooperation, a consortium was created, led by the International Water Management Institute (IWMI) and the World Health Organization (WHO), bringing in other Swiss partners to address public health, safety and business issues. In the first phase of the project, more than 150 business cases (i.e. existing resource recovery and reuse businesses) were identified worldwide and systematically described. On the basis of these case studies, 21 promising BMs were developed by a team of economists. Table 1 gives and overview of a selection of promising BMs (IWMI 2016). To assess whether the implementation of the proposed BMs in a large-scale scenario holds potential to scale-up the productive use of waste resources, whilst providing for improved human and environmental health, was then determined in feasibility studies carried out in four large cities (i.e. Bangalore in India; Hanoi in Vietnam; Kampala in Uganda; and Lima in Peru). Two central aspects of the feasibility studies were: (1) the identification of control measures to be incorporated in the proposed BMs to safeguard occupational and public health; and (2) a prospective assessment of potential health impacts under a scenario where the BMs are implemented at a large scale (e.g. through broad promotion and replication of a proposed safe recovery and reuse business activity in peri-urban areas of Hanoi). The latter was investigated by employing a health impact assessment (HIA) methodology. HIA is defined as "a combination of procedures, methods and tools that systematically judges the potential, and sometimes unintended, effects of a policy, plan, programme or project on the health of a population and the distribution of those effects within the population" (Quigley et al. 2006). The objective of HIA is to raise awareness among decision-makers on how the proposed action might impact the health of affected population groups so that health effects are considered in subsequent deliberations (Winkler et al. 2013).

Here, we present our methodology and findings from a case study pertaining to solid and liquid waste recovery and reuse BMs potentially to be implemented in Hanoi. The purpose of the HIA was to assess the magnitude of potential health impacts in different population groups affected by the proposed BMs. Our assumption was that control measures would be implemented following WHO guidelines for the safe use of wastewater, excreta and grey water, resulting in reduced exposure to pathogens and toxic chemicals. Hence, the assessment focused primarily on potential health benefits (e.g. reduction in adverse health outcomes in farmers reusing wastewater), yet potential adverse health impacts (e.g. increased exposure to toxic emission due to promotion of biomass briquettes) were also considered.

Methods

The HIA comprised two main phases. In the first phase, secondary data were obtained from the peer-reviewed literature and reports pertaining to health outcomes that are associated with the recovery and reuse of solid and liquid waste (i.e. soil-, water- and waste-related diseases, vector-related diseases, respiratory diseases and non-communicable diseases) and underlying determinants (i.e. wastewater quality, access to sanitation and personal protective equipment used by farmers). The information was supplemented with primary data collected through a cross-sectional environmental, epidemiological and questionnaire survey (Fuhrimann et al. 2016a, b). In the second phase, a semiquantitative impact assessment was applied for combining the evidence-base of the HIA with the detailed description provided for each of the BMs to be tested in Hanoi (IWMI 2016).

Data collection

A methodological triangulation was employed for collection of data within the HIA (Winkler et al. 2011). At the city level, this entailed the collection of secondary data (i.e. disease cases reported through the routine health information system and the peer-reviewed literature) to define the

Table 1 Description of the business models (BMs) and their respective scenario of scale in the context of Hanoi, Vietnam, 2015

Business model (BM) description	Scenario of scale and population affected	Impact definition
BM#1—Agro-waste to electricity Animal manure in combination with agro-waste are transformed into electricity using an anaerobic digestion process	The business will be implemented in 50 rural and peri-urban villages with an average size of 1000 people per village 30% of the people in the villages are exposed to untreated animal manure in their living and working environments ($50 \times 1000 \times 0.3 = 15{,}000$ community members)	The use of animal manure for producing electricity has the potential to reduce exposure of community members to pathogens commonly found in animal manure that is disposed in the environment
BM#2—On-site energy generation by sanitation service providers In communities that lack access to toilet facilities, this model aims at transforming black and brown water into electricity by means of an anaerobic digestion process. The sludge from the anaerobic digestion process will be treated to be sold as soil conditioner	The business will be implemented in 30 rural and peri-urban villages that lack access to toilet facilities, with an average size of 1000 people per village 10% of the people in the villages are exposed to pathogens deriving from faecal matter in their living and working environment ($30 \times 1000 \times 0.1 = 3000$ community members)	The provision of sanitation services to underserved communities has the potential to reduce exposure of community members to pathogens deriving from faecal matter being disposed in the environment
BM#3—Dry fuel manufacturing Crop residues such as wheat stalk, rice husk, maize stalk, groundnut shells, coffee husks and saw dust will be processed for converting them into briquettes to be sold for use in cooking stoves. The processing of crop residues will assure that the briquettes will be free of inorganic contaminants, sharp objects and pathogens	2% of the population in Hanoi will use briquettes from the BM as cooking fuel Briquettes as cooking fuel will be of interest to 2% of the 6.7 million people living in Hanoi; 80% of the urban population is using kerosene, gas or electricity; and only 10% of those would actually switch to briquettes (6.7 million $\times$ 0.02 $\times$ 0.8 $\times$ 0.1 = 10,720 briquette users)	Burning briquettes at household level induces prolonged exposure to carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), hydrocarbons and particulate matter. This results in an increased incidence of chronic respiratory diseases and other non-communicable diseases, including stroke, ischaemic heart disease and lung cancer
BM#4—Wastewater-duckweed-fish rearing system By means of constructed wetlands, partially treated wastewater will be produced for use in aquaculture and agriculture. Of note, in locations where the concentration of toxic chemicals such as heavy metals in wastewater and receiving soils exceed national and international threshold values, source reduction and/or physico-chemical removal processes are a pre-requisite for the implementation of this BM	Three constructed wetland will be implemented serving 500 farmers in peri-urban area of Hanoi Treated wastewater used for irrigation in agriculture (e.g. vegetables and salads) and aquaculture to grow fish will be produced by the 1500 farmers (3×500). This results in crop and fish that will be consumed by 150,000 ($3 \times 50{,}000$) and 30,000 ($3 \times 10{,}000$) consumers, respectively	Through the treatment of wastewater, the BM has the potential to reduce exposure to microbial and chemical hazards commonly found in untreated wastewater. In addition, the use of treated wastewater for fish breeding results in a reduction of food-borne trematodiasis transmission
BM#5—Large-scale composting for revenue generation The organic fraction of municipal solid waste is collected and separated from inorganic components for subsequent co-composting with dried faecal sludge for producing organic fertilizer	Two centralised co-composting plants are installed in urban Hanoi, serving 2000 households each Reduced load of faecal sludge being disposed in the environment will benefit farmers (500) using untreated wastewater and 50,000 crop consumers	In Hanoi, collecting and processing faecal sludge reduces loads of pathogens in the city's wastewater and thus reduce exposure to pathogens in urban farmer using untreated wastewater and consumers of their produce
BM#6—Compost production for sanitation service delivery Human excreta will be separated into liquid and solid portions at the source (urine-diversion dry toilets). In addition, organic waste will be collected at household level. Co-composting of dried faecal sludge with organic waste will be applied for the production of soil conditioner. The treated urine will be diluted with fresh water for subsequent use as organic fertilizer	This BM will be implemented in 30 rural and peri-urban villages with an average size of 1000 people per village 10% of the population in the villages is exposed to pathogens deriving from faecal matter ($30 \times 1000 \times 0.1 = 3000$ community members) in their living and working environment	The provision of sanitation services to underserved communities has the potential to reduce exposure of community members to pathogens deriving from faecal matter

epidemiological profile of the citizens of Hanoi. At a more fine-grained scale (i.e. in areas where solid and liquid waste is recovered and used in agriculture and aquaculture), primary data were collected to obtain a precise understanding of the epidemiology and agricultural practices in the given context. Therefore, a cross-sectional epidemiological survey was carried out from April to June 2014 in communities living in the southern part of Hanoi along the To Lich River and the Red River in which most of Hanoi's wastewater is being discharged (Fuhrimann et al. 2016a). Data on self-reported health problems and the use of personal protective equipment among wastewater treatment plant workers, farmers and community members were obtained through administration of a questionnaire. In an environmental assessment, samples of wastewater designated for the use in agriculture and aquaculture were collected and analysed for microbial and chemical pollutants. In a cross-sectional epidemiological survey, targeting people aged $\geq$18 years that were at risk of wastewater exposure, the prevalence of intestinal parasite infections was determined. While the data from these primary data collection efforts are pivotal for the evidence-base of the HIA reported here, the key findings from the cross-sectional surveys have been presented elsewhere (Fuhrimann et al. 2016a, b).

Semiquantitative impact assessment

As preparatory step for the semiquantitative impact assessment, a scenario of scale and impact definition was developed for each BM (Table 1). The scenario of scale was informed by the data collected in the frame of the HIA, as well as other feasibility studies of the overall resource recovery and reuse (i.e. waste supply and availability analysis, technology assessment and health risk assessment), and defined the scale of each BM to be implemented and the estimated number of people affected, stratified by specific population groups (e.g. farmers, community members and consumers).

The impact definition consisted of a description of the main exposure pathways through which the BM will affect the health status of exposed population groups. Against the background of the impact definition, the most important potential health impacts were defined based on the information obtained through the primary and secondary data collection. Due to the lack of accurate data for all of the diseases of concern in the context of the recovery and reuse of liquid and solid waste, a set of disease groups were defined for the impact assessment (i.e. diarrhoeal diseases, helminth infections, food-borne trematodiasis, acute respiratory diseases, chronic respiratory diseases and non-communicable diseases) instead of applying specific health outcomes. Subsequently, the relevant data were extracted from the secondary and primary data sources and summarised for each BM, which was then used as evidence base for the semiquantitative impact assessment to characterise the direction (positive or negative) and magnitude (minor to major) of potential health impacts.

The methodology of the semiquantitative impact assessment was developed according to recommendations on the design and use of risk matrices (Duijm 2015). Additionally, it was inspired by the health risk assessment framework proposed in the sanitation safety planning (SSP) manual that was recently published by WHO for translating the 2006 guidelines for the safe use of wastewater, excreta and greywater into a simple, step-by-step, approach (Jackson et al. 2015). Furthermore, a modified Delphi approach was applied that took into consideration that the rankings for the semiquantitative impact assessment were done by trained assessors who received additional specific instructions. Results were discussed until consensus was reached on the final scores.

In a first step of the semiquantitative impact assessment, the likelihood (L) and impact level (IL) (ranging from major negative impact to major positive impact) were determined for each potential health impact by applying the definitions provided in Table 2. Depending on whether or not the affected population group included children, different scores were assigned. For example, diarrhoeal disease were ranked as minor in farmers [IL-score $\pm$0.1 on a scale from 0 (no effect) to 1 (detrimental effect)] and moderate in community members (IL-score $\pm$0.5), as the latter includes children, who are particularly vulnerable to diarrhoeal diseases.

In a second step, the estimated number of people in all population groups affected was multiplied with the scores obtained under the respective categories (IL-score and L-score) for each of the potential health impacts. The obtained magnitude, which does not have a specific unit, provides a semiquantitative description of the potential of a BM to have a positive (i.e. reduction in adverse health outcomes compared to baseline) or negative overall impact on the health of specific populations groups.

Finally, the overall impact rating of the potential health impact of each BM was derived from the sum of the magnitudes and ranked according to the following categories: (1) major positive impact (magnitude $\geq$3500); (2) moderate positive impact (magnitude 50–3499); (3) minor positive impact (magnitude 0.05–49.9); (4) insignificant (magnitude 0); (5) minor negative impact (magnitude -0.05 to -49.9); (6) moderate negative impact (magnitude -50 to -3499); and (7) major negative impact (magnitude ≤ -3500). The magnitude ranges applied were obtained when multiplying the size of the population group affected with the respective values of the IL and L, as shown in the risk matrix put forth in Fig. 1.

Table 2 Definitions and scores of the impact level (IL) and likelihood (L) applied in the semiquantitative impact assessment of solid and liquid waste recovery and reuse business models in Hanoi, Vietnam, 2015

Category	IL-Score	Description
Impact level (IL)		
Major positive impact	1	Impact reduces incidence of disease or injury with severe health effects (e.g. HIV/AIDS, cancer, bone fracture) that may be chronic or result in loss of life
Moderate positive impact	0.5	Impact reduces incidence of disease or injury with moderate health effects that may require hospitalisation (e.g. malaria, acute intoxication)
Minor positive impact	0.1	Impact reduces incidence of disease or injury with minor health effects (e.g. acute diarrhoea, headache, skin cuts)
Insignificant	0	Impact not resulting in any perceivable or measurable health effect
Minor negative impact	−0.1	Impact increases incidence of disease or injury with minor health effects (e.g. acute diarrhoea, headache, skin cuts)
Moderate negative impact	−0.5	Impact increases incidence of disease or injury with moderate health effects that may require hospitalisation (e.g. malaria, acute intoxication)
Major negative impact	−1	Impact increases incidence of disease or injury with severe health effects (e.g. HIV/AIDS, cancer, bone fracture) that may be chronic or result in loss of life
Category	**L-Score**	**Description**
Likelihood (L)		
Very unlikely	0.05	It is very unlikely that the proposed action will trigger the impact in the next 12 months for infectious diseases and accidents, or next 10 years for non-communicable diseases (odds <5%)
Unlikely	0.3	It is unlikely that the proposed action will trigger the impact in the next 12 months for infectious diseases and accidents, or next 10 years for non-communicable diseases (odds 5–40%)
Possible	0.5	It is possible that the proposed action will trigger the impact in the next 12 months for infectious diseases and accidents, or next 10 years for non-communicable diseases (odds 41–60%)
Likely	0.7	It is likely that the proposed action will trigger the impact in the next 12 months for infectious diseases and accidents, or next 10 years for non-communicable diseases (odds 61–95%)
Almost certain	0.95	It is almost certain that the proposed action will trigger the impact in the next 12 months for infectious diseases and accidents, or next 10 years for non-communicable diseases (odds >95%)

Fig. 1 Impact assessment matrix that combines the scores of the impact level (IL) and likelihood (L) with the size of the population group affected to calculate the magnitude of impact in Hanoi, Vietnam, 2015

		Population group affected				
		Individual cases	Specific population	Medium population	Large population	Major population
		10	100	1000	10,000	100,000
Impact level (IL): Major positive impact	1	0.50	30	500	7000	95,000
Moderate positive impact	0.5	0.25	15	250	3500	47,500
Minor positive impact	0.1	0.05	3	50	700	9500
Insignificant	0	0.00	0.00	0.00	0.00	0.00
Minor negative impact	-0.1	-0.05	-3	-50	-700	-9500
Moderate negative impact	-0.5	-0.25	-15	-250	-3500	-47,500
Major negative impact	-1	-0.50	-30	-500	-7000	-95,000
		0.05	0.3	0.5	0.7	0.95
		Very unlikely	Unlikely	Possible	Likely	Almost certain
		Likelihood (L)				

Ethical considerations

Ethical approval for the HIA was obtained from the Hanoi School of Public Health (Hanoi, Vietnam; reference no. 010/2014/YTCC-HD3) and the ethics committee of the cantons of Basel-Stadt and Basel-Landschaft (EKBB; reference no. 137/13). For the primary data collection, all participants were informed about the purpose, procedures, and potential risk and benefits of the study and they were invited to sign a written informed consent.

Results

Evidence-base of the HIA

In the primary data collection for our HIA, the prevalence of self-reported 14-day diarrhoea in adults from the general population, farmers and sanitation workers along the To Lich River and Red River in the southern part of Hanoi was 8–12% (Fuhrimann et al. 2016b). In the same communities, prevalence rates of intestinal parasite infections were highest in peri-urban farmers (30%) and moderate in the other study groups (7–22%). Hookworm and *Trichuris trichiura* were the predominant helminth species (overall infecting 25 and 5%, respectively). The overall prevalence of intestinal protozoa was low (1.2%). In Vietnam, food-borne trematodes that infect the liver and the intestines are common (Fürst et al. 2012). In 2005, *Clonorchis sinensis* was recovered from 51.5% of individuals that participated in a cross-sectional survey southeast of the capital of Hanoi (Dung et al. 2007). Of note, *C. sinensis* and other food-borne trematodes may result in hepatobiliary complications, such as biliary obstruction, and are strongly associated with cholangiocarcinoma (Qian et al. 2016).

Various vector-related diseases are endemic in Vietnam (e.g. malaria, dengue and Japanese encephalitis). However, the geographical distribution shows considerable heterogeneity. Due to climatic and environmental factors, Hanoi is considered at low risk of malaria transmission; indeed, only few cases are reported by Hanoi's health system (Cui et al. 2012). The reported annual number of cases with a dengue fever in Hanoi ranged from 500 to 16,000 in 2009–2011, with a declining tendency (Cuong et al. 2011).

Acute respiratory tract infections are the second leading cause of consultations at health facilities in Hanoi, and thus represent a major public health issue. This was confirmed by our primary data collected in the peri-urban and urban communities living along rivers and channels receiving wastewater; self-reported prevalence of acute coughing ranged between 25 and 30% among study participants (Fuhrimann et al. 2016b). The burden of chronic respiratory diseases, cardiovascular diseases and cancers is high in Vietnam, accounting for 7, 33 and 18% of the overall mortality, respectively (all ages, both sexes) (WHO 2014).

In urban and peri-urban Hanoi, water deriving from the wastewater channels being used in agriculture and aquaculture is heavily contaminated with thermotolerant coliforms (TTC), *Escherichia coli* and *Salmonella* spp. (Fuhrimann et al. 2016a). Levels of microbial contamination were up to 110-fold above Vietnamese discharge limits for restricted agriculture and up to 260-fold above WHO's tolerable safety limits for unrestricted agriculture. Helminth egg concentrations in wastewater were less of an issue with levels below WHO thresholds of <1 egg/l. In addition to microbial contamination, chemical pollution primarily deriving from untreated industrial wastewater is of concern in Hanoi's river and channel systems. Various studies have found high concentrations of heavy metals in wastewater and sediments of Hanoi's rivers (Ingvertsen et al. 2013; Marcussen et al. 2008). Concentration of heavy metals in soil samples and vegetables are elevated in agricultural areas of Hanoi with cadmium (Cd), copper (Cu) and lead (Pb) exceeding permissible levels of the Vietnamese standards (Nguyen et al. 2010). Little is known on pollution with chemical substances other than heavy metals.

In 2009, about one in ten households in Hanoi was using non-improved toilet facilities, with the large majority relying on flush toilets that are connected to septic tanks (General Statistics Office of Vietnam 2010). Similar data emerged by our cross-sectional survey: 93% of peri-urban community members and 98% of urban community members reported to use flush toilets (Fuhrimann et al. 2016b). However, effluents of the septic tanks are often informally discarded into storm- and wastewater channels, adding to the burden of microbial and inorganic contamination of the environment (Anh 2011). Urban and peri-urban farmers in Hanoi, usually show a high acceptability of using personal protective equipment. In our survey conducted among 279 farmers, more than three quarters were in possession of gloves, boots, long sleeves and face masks (Fuhrimann et al. 2016b).

Semiquantitative impact assessment

A summary of the nature and magnitude of predicted health impacts for each of the proposed BMs in Hanoi is presented in Table 3. Five out of the six BMs investigated show potential for a reduction in adverse health outcomes if implemented at large scale in Hanoi. For example, wastewater treatment by means of a constructed wetland for subsequent supply of treated wastewater to agriculture and aquaculture (BM#4), showed the largest potential for positive health impacts (major positive impact, magnitude 16,583). This was followed by large-scale composting for revenue generation (BM#5; moderate positive impact, magnitude 1505), agro-waste to electricity (BM#1; moderate positive impact, magnitude 450), on-site energy generation by sanitation service providers (BM#2; moderate positive impact, magnitude 90) and compost production for sanitation service delivery (BM#6; moderate positive impact, magnitude 90). The only BM that was associated with predicted negative health impacts

Table 3 Parameters and findings of the semiquantitative impact assessment of business models (BMs) for potential implementation in Hanoi, Vietnam, 2015

Health impacts	Affected population group	People affected (PA)	Scores		Magnitude	Impact rating
			Impact level (IL)	Likelihood (L)		
BM#1—Agro-waste to electricity						
Impact 1.1: reduction in diarrhoeal diseases	Community members	15,000	0.5	0.05	375.0	Moderate positive impact (450)
Impact 1.2: reduction in helminth infections	Community members	15,000	0.1	0.05	75.0	
BM#2—On-site energy generation by sanitation service providers						
Impact 2.1: reduction in diarrhoeal diseases	Community members	3000	0.5	0.05	75.0	Moderate positive impact (90)
Impact 2.2: reduction in helminth infections	Community members	3000	0.1	0.05	15.0	
BM#3—Dry fuel manufacturing						
Impact 3.1: increase in acute respiratory diseases	Briquette users	10,720	−0.1	0.5	−536.0	Major negative impact (−3752)
Impact 3.2: increase in chronic respiratory diseases	Briquette users	10,720	−0.5	0.5	−2680.0	
Impact 3.3: increase in other non-communicable diseases	Briquette users	10,720	−1.0	0.05	−536.0	
BM#4—Wastewater-duckweed-fish rearing system						
Impact 4.1: reduction in diarrhoeal diseases	Farmers	1500	0.1	0.5	75.0	Major positive impact (16,583)
	Crop consumers	150,000	0.5	0.05	3750.0	
	Fish consumers	30,000	0.5	0.05	750.0	
Impact 4.2: reduction in helminth infections	Farmers	1500	0.1	0.05	7.5	
Impact 4.3: reduction in food-borne trematode infections	Fish consumers	30,000	0.5	0.3	4500.0	
Impact 4.4: reduction in cancer	Crop consumers	150,000	1.0	0.05	7500.0	
BM#5—Large-scale composting for revenue generation						
Impact 5.1: reduction in diarrhoeal diseases	Farmers	500	0.1	0.05	2.5	Moderate positive impact (1505)
	Crop consumers	50,000	0.5	0.05	1250.0	
Impact 5.2: reduction in helminth infections	Farmers	500	0.1	0.05	12.5	
	Crop consumers	50,000	0.1	0.05	250.0	
BM#6—Compost production for sanitation service delivery						
Impact 6.1: reduction in diarrhoeal diseases	Community members	3000	0.5	0.05	75.0	Moderate positive impact (90)
Impact 6.2: reduction in helminth infections	Community members	3000	0.1	0.05	15.0	

was transforming crop residues into biomass briquettes to be used as cooking fuel (BM#3) with a magnitude of −3752. This is due to the risk that less harmful cooking fuels such as liquefied petroleum gas (LPG), kerosene and electricity are replaced by biomass briquettes. Thus, fugitive emissions from burning briquettes for indoor cooking will result in an increased incidence of chronic obstructive pulmonary disease and other non-communicable diseases, including stroke, ischaemic heart disease and lung cancer.

Discussion

We present a novel, prospective, semiquantitative HIA approach and found that BMs targeting safe reuse of solid and liquid waste have the potential to positively impact on the health of affected community members, farmers and consumers if implemented at a large scale in the context of Hanoi. In particular, wastewater reuse for inland fish farming (BM#4), coupled with on-site water treatment, has substantial potential for health benefits in crop and fish consumers if implemented along with a multi-barrier approach for risk mitigation (WHO 2006). Interestingly, the proposed BM mimics the well-known Vietnamese farming practices 'VAC' (Vuon (garden or crop), Ao (fishpond), Chuong (livestock)), which combines gardening with fishponds and livestock breeding for optimising nutrient recycling (Nguyen-Viet et al. 2015). Similarly, compost production for sanitation service delivery (BM#6 with a moderate positive impact) is already widely applied in urban agriculture in and around Hanoi with wastewater readily used for crop irrigation and fish production, and human excreta and animal manure composted for the use as soil conditioner (Nga et al. 2011). However, the current practices represent environmental and health risks for farmers and community members due to insufficient treatment of the waste (Pham-Duc et al. 2013, 2014).

Since the majority of the population in Hanoi is relying on LPG as cooking fuel, the promotion of biomass briquettes as proposed by BM#3 has the potential to result in adverse health impacts such as chronic obstructive pulmonary disease and lung cancer (Fullerton et al. 2008). Hence, BM#3 should not be implemented in Hanoi, unless the biomass briquettes target other customer segments than households (e.g. industrial cement plants). It is interesting to note that the use of biomass for cooking was quite popular in Hanoi in the 1990s and 2000s. However, in recent years, this practice lost in prominence, mainly because of the growing awareness of the population about the negative health impacts of this practice, coupled with sustained economic growth (Hanh et al. 2012). Therefore, it is not advisable to promote BM#3 in Hanoi, unless the biomass briquettes are promoted together with safe cooking stoves in communities that are primarily using solid fuels for cooking (Hartinger et al. 2013).

Since our HIA was based on the assumptions that the proposed BMs incorporate appropriate technology and control measures that assure compliance with national and international safety threshold values of processes and emissions, our findings relate to an optimistic scenario and the magnitude of potential positive health impacts may be overstated. In a preparatory step of the overall HIA that governed the development of detailed mitigation plans for each of the BMs, we found a reasonable set of control measures for the proposed business activities, with the exception of chemical hazards. It must be noted, however that elimination of heavy metals and other chemical compounds in wastewater is technology-intensive, and thus feasibility depends on resource considerations (Shaheen et al. 2013). Nontechnical mitigation measures to chemical hazards in wastewater, such as harvesting fish in aquaculture at young age or applying crop restrictions in wastewater irrigation systems, as well as efforts to reduce industrial pollution at source are also important short- and long-term control strategies to be considered (WHO 2006).

Risk assessment matrices are a widely accepted, semiquantitative tool for assessing risks and setting priorities in risk management and mitigation (Cox 2008). While this method has many limitations, and can even be misleading in specific cases (Vatanpour et al. 2015), it is a useful tool if the assessment has to deal with a diverse set of hazards across a broad portfolio of possible impact pathways, as is the case in the present HIA (Duijm 2015; Winkler et al. 2010). While a simple risk ranking is often sufficient to set priorities in impact mitigation for potential environmental hazards, HIA is often confronted with the assessment of impacts on different population groups of varying sizes (Quigley et al. 2006). To address the constraint of a simple risk ranking of not accounting for population size, we have multiplied the risk level with the number of people in the potentially affected population group. This novel feature proved useful in the present HIA and was appreciated by the different assessors who carried out the semiquantitative impact assessment. Nevertheless, the magnitudes presented in the HIA need to be treated with healthy scepticism, acknowledging their purpose of providing an evidence-based rating of the overall potential of the studied BMs to result in health benefits or adverse outcomes, but not representing or replacing a quantitative impact assessment (Perez and Künzli 2009; Verma et al. 2012). Moreover, the estimates obtained are influenced by many assumptions such as the scale of the BM and the number of people potentially affected, which might considerably influence the outcome of the impact assessment. On the other hand, the robustness of the HIA was strengthened by primary data obtained from communities and environments that are representative for many of the applied scenarios, and thus an accurate recent evidence-base was at the core of the semiquantitative impact assessment (Fuhrimann et al. 2016a, b). Finally, the transparency of the HIA does fully disclose the parameters applied, which also allows for accommodating changes in the scenario of interest, if need be.

To our knowledge, we present the first application of a HIA approach to BMs. In conjunction with other research components (i.e. health risk assessment, waste supply and availability analysis, market analysis, technical assessment, environmental risk assessment, socioeconomic assessment and institutional analysis) the HIA made a valuable contribution to the integrated assessment of the feasibility of proposed BMs in Hanoi and might be applicable in other cities in Asia, Africa and Latin America. Especially in the given context of solid and liquid waste reuse, health considerations played a key role in supporting which businesses should be promoted and ultimately implemented in the next phases of the current resource recovery and reuse project.

Conclusions

The recycling of liquid and solid waste does not only hold promise to close water, nutrient and energy cycles, and thus make an important contribution to the current era of the SDGs in resource-constraint settings, but also holds considerable potential for health benefits if appropriate control and mitigation measures are put in place. Our semiquantitative HIA approach provides an evidence-based decision-support tool for the selection of the most promising BMs for implementation in Hanoi. Application of prospective HIA, in combination with occupational health risk assessment and sanitation safety planning, is an expedient approach for developing strategies that are tailored for specific and acceptable risk mitigation of resource recovery and reuse businesses.

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Compliance with ethical standards

Conflict of interest Mirko S. Winkler declares that he has no conflict of interest. Samuel Fuhrimann declares that he has no conflict of interest. Phuc Pham-Duc declares that he has no conflict of interest. Guéladio Cissé declares that he has no conflict of interest. Jürg Utzinger declares that he has no conflict of interest. Hung Nguyen-Viet declares that he has no conflict of interest.

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Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Ethical approval for the research was obtained from the Hanoi School of Public Health (Hanoi, Vietnam; reference no. 010/2014/YTCC-HD3) and the ethics committee of the cantons of Basel-Stadt and Basel-Landschaft (EKBB; reference no. 137/13). Informed consent was obtained from all individual participants included in the study.

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