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Review article

Dynamic assessment of economic and environmental performance index and generation, composition, environmental and human health risks of hospital solid waste in developing countries; A state of the art of review

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ABSTRACT

Many studies have been conducted on hospital solid waste management (HSWM) throughout the world, especially developing countries. This interdisciplinary study aims to summarize the available knowledge on the health and environmental risks of hospital solid waste (HSW) and also, develop a dynamic associational assessment among hospital solid waste generation rate (HSWGR), hospital solid waste composition (HSWC), gross domestic product (GDP) per capita, and environmental performance index (EPI) in some developing countries for the first time. The results of this study showed that researchers from India, China, Pakistan, Brazil, and Iran had found more evidence about the health, economic, and environmental issues in HSW than the other developing countries. The literature showed that the highest and lowest reported HSWGR (in national average level) belonged to Ethiopia (6.03) and India (0.24) kg bed $^{-1}$ day^{-1}, respectively. It has also been shown that all studied countries except Serbia, have higher levels of hazardous waste in their HSWC, based on the WHO's standard. Furthermore, the quantity and quality of HSW in developing countries depend on the service provided by the hospital, type of hospital, HSWM system, and the level of regional economic and culture. The association analysis showed that the EPI and GDP per capita of developing countries were significantly (p-value < 0.05) associated with HSWGR, non-hazardous HSW, and hazardous HSW by the Spearman coefficients equal to 0.389, 0.118, −0.118, and 0.122, 0.216, and −0.346, respectively. However, it can be concluded that GDP per capita and EPI have a weak correlation with hazardous HSW and non-hazardous HSW. Moreover, HSW has many hazardous health and environmental risks such as dioxin and furan, that must be controlled and managed through implementing programs and policies based on sustainable development. As a final point, we believed that the present study can be considered to be a guide for future studies on HSWM in developing countries.

1. Introduction

The changing trends of human lifestyle, consumption habits, use of harmful compounds, and urban activities have affected the quantitative and qualitative characteristics of municipal solid waste (MSW) (Özeler et al., 2006). In recent decades, MSW has threatened the public health and the environment as well as all the natural resources through extensive production and toxic compound emissions from landfills and incinerators (Liu et al., 2016). Previous studies on municipal solid waste management (MSWM) suggest that, the consideration of hazardous and complex wastes in MSW such as materials generated in hospitals is the major approach to controlling the harmful effects of MSW on public health and the environment (Cleary, 2009; Sharholy et al., 2008; Zhang et al., 2010). Recently, concerns over the negative

Abbreviations: MSW, municipal solid waste; MSWM, municipal solid waste management; MSWG, municipal solid waste generation; MSWI, municipal solid waste incinerators; HSW, hospital solid waste; HSWM, hospital solid waste management; HSWGR, hospital solid waste generation rate; HSWI, hospital solid waste incinerator; HCW, health care waste; HCFs, health care facilities; HDI, Human Development Index; GDP, gross domestic product; EPI, environmental performance index

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impacts of solid waste produced in hospitals have grown worldwide, especially in developing countries (Windfeld and Brooks, 2015). While, previous studies have reported the great potential of hospital solid waste (HSW) to spread pathogens and hazardous compounds such as toxic chemicals as well as nuclear and radioactive materials into the environment (Ghasemi et al., 2018). However, a few case studies have been conducted on the generation rate and composition of HSW in developing countries. In these case studies, a wide range of variation of generation rate and percent composition are reported. Therefore, the generation rate and composition should be estimated separately, considering environmental and economic status (Tesfahun et al., 2016). In addition, in 1989, the Basel Convention announced that the HSW is the second most dangerous waste after nuclear and radioactive wastes (Annex et al., 1989). The HSW has been categorized by the World Health Organization (WHO) into two main classes: hazardous HSW and non-hazardous HSW (WHO, 2014). Hazardous HSW includes various components that have harmful potential effects on human health and the environment such as infectious, chemical, toxic, pharmaceutical, sharp, radioactive, and other similar wastes. In contrast, non-hazardous HSW refers to the components of HSW that are usually non-dangerous for human health and the environment (WHO, 2014). The public health and environmental risks of hazardous HSW have been explored in several studies. For public health risks, several acute diseases have been reported, such as, hepatitis, anthrax, and cholera human immunodeficiency virus infection and acquired immune deficiency syndrome (HIV/AIDS) (Gupta and Boojh, 2006), Hepatitis (Ali et al., 2017a), Anthrax (Ali et al., 2017a), and cholera (Raila and Anderson, 2017). Moreover, WHO estimates that unsafe usage of sharps and other inoculating equipment poses an annual global 20 million infections such as HIV, hepatitis B and C (Gupta et al., 2013). On the other hand, the environmental pollutions related to hazardous HSW have been explored in extensive studies. For example, Zhang et al. showed that unsafe transportation and disposal of hazardous HSW such as solvents and reagents can release toxic chemicals into the environment and interrupt the ecological balance (Zhang et al., 2015). Additionally, the HSW is known as the fourth largest emitter of mercury to the environment (Bourtsalas and Themelis, 2019). Furthermore, the emission from hospital solid waste incinerators (HSWIs) may contain toxic compounds such as dioxins and furans that must be immobilized to avoid the spread of hazardous compounds (Ashworth et al., 2014; Schuhmacher et al., 2014; Yasir, 2017). Zimmer and McKinley reported that minimization and control of these risks not only improves the quality of hospital solid waste management (HSWM) but also affects environmental performance (Zimmer and McKinley, 2008). Accordingly, Eckelman and Sherman concluded that, due to the emission of much of the pollution in the U.S. into the air, water, and soils through hospitals, it is expected that the environmental performance of the country's healthcare sector be associated with the quality of HSWM (Eckelman and Sherman, 2016). In addition, it is indicated that life cycle assessment (LCA) is a proper tool to evaluate the environmental performance of MSWM in a specified area. However, it seems to be inefficient for comparing several countries (Cleary, 2009). Recently, the environmental performance index (EPI) has been used to evaluate the environmental performance of countries as a global method published by the Yale Center for Environmental Law and Policy (YCELP) (Yale Center for Environmental Law & Policy, 2018). This metric provides a gauge at a national scale for how close countries are to the established environmental policy goals (Ravichandran, 2017). Therefore, in the present study, for the first time, the association among hospital solid waste generation rate (HSWGR), hospital solid waste composition (HSWC), and the EPI in developing countries were analyzed. Besides, gross domestic product (GDP) was considered as a socioeconomic factor to evaluate the association between MSW generation and economic factors (Chen, 2018; Fu et al., 2015; Khandelwal et al., 2019). From among types of GDP, GDP per capita is the best way to compare GDP across countries (James et al., 2012). GDP per capita, as the central indicator of a country's economic performance, is a measure of a country's economic output that accounts for its number of people. It divides the country's gross domestic product by its total population. That makes it the best measurement of a country's standard of living. GDP per capita allows comparing the economic status of countries with different population sizes (Nolan et al., 2018). However, so far, no study has assessed the association among GDP per capita, HSWGR, and HSWC. Thus, the present review study was conducted to summarize the information and knowledge available on the existing health and environmental risks of HSW and provide a dynamic associational assessment among HSWGR, HSWC, GDP per capita, and EPI in selected developing countries.

2. Methodology

2.1. Study area

A developing country (or a low and middle-income country (LMIC), less developed country, less economically developed country (LEDC), or underdeveloped country) is a country with a less developed industrial base and a low Human Development Index (HDI) relative to other countries. HDI has been used to identify the developing countries in solid waste management studies (Ali et al., 2017c; Caniato et al., 2015; Minoglou et al., 2017). The HDI was developed by the United Nations Development Programme (UNDP) to emphasize that people and their capabilities should be the crucial criteria to assess the development of a country along with economic growth. Based on HDI, a developing country is recognized with the value of HDI (< 0.8) (Sagar and Najam, 1998). The HDI of the countries was shown in Supplementary. In the present study, the developing countries have been considered according to the human development reports of UNDP (UNDP, 2018).

2.2. Study search

At present study, the computerized databases and publication indexes such as Web of Knowledge (ISI), PubMed, Embase, and Scopus during the period of 2004 to 2019 were searched by the following words and MeSH headings were used individually or in combination in title, abstract and keywords of the scientific articles: “hospital waste”, “medical waste”, “health care waste”, “clinical waste”, “infectious waste”, “developing countries”, and any developing country's name.

2.3. Study selection

The main inclusion criterion was articles that have focused on the HSWM in each developing country. The exclusion criteria were non-English language publication, book chapters, expert opinion, correspondence, commentaries publications, and any publication that reported non-managerial issues or articles that only focused on evaluating limited categories of hospital solid waste such as dental waste.

2.4. Study data extraction

The data related to the generation, composition, health, and environmental risks of HSW in developing countries were extracted from the literature by the desk study of open literature survey method. Besides, the data related to the GDP per capita of selected countries were obtained from World Bank national accounts data. Finally, the 2018 EPI data was obtained from the Yale Center for Environmental Law and Policy, Yale University. All data were adjusted based on the year of the study.

2.5. Study statistical analyses

The value of HSWGR for each country was calculated in the form of the average of all of reported HSWGR in the previous studies for each

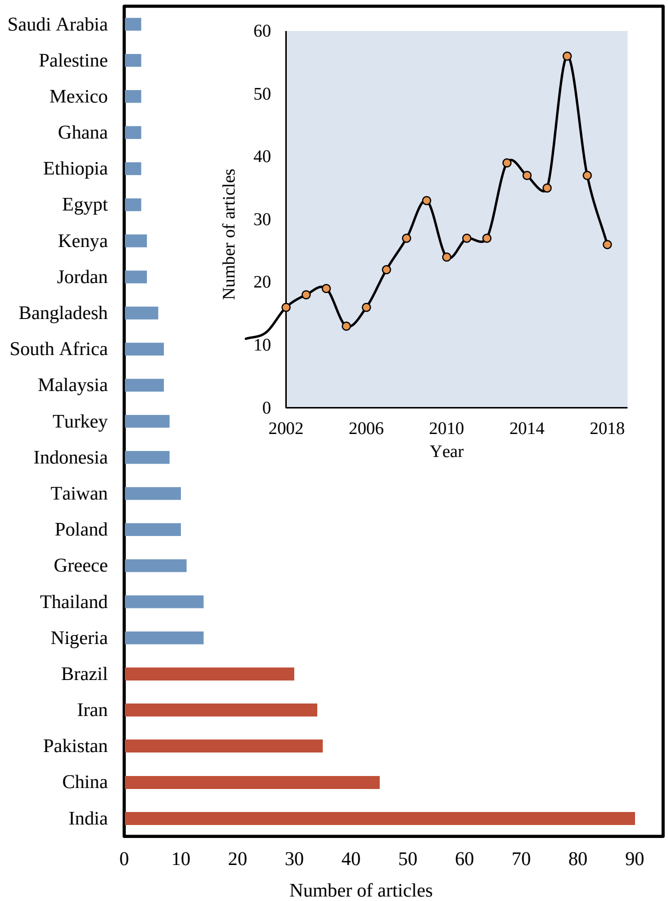

Fig. 1. Literature analysis in HSWM studies in developing countries.

country. Further, the value of GDP and EPI for each country was also calculated as the average of years in which the HSWGR was reported in those years. The Spearman correlation coefficients were also calculated for all pairwise comparisons to include GDP, EPI, HSWGR, and HSW composition in selected countries.

3. Results and discussion

3.1. Literature analyzing

Fig. 1 presents the published articles related to the HSWM in selected developing countries during 2000–2019. As shown in Fig. 1, the consideration on the HSWM has been rapidly increased among developing countries since 2000. In addition, most of these studies belong to India, China, Pakistan, Brazil, and Iran. Therefore, these results indicate that researchers from India, China, Pakistan, Brazil, and Iran have found more evidence supporting the health, economic, and environmental issues in HSW among developing countries.

3.2. HSW quantity and quality

The quantitative and qualitative characteristics of HSW in the studied developing countries are presented in Table 1. As shown in Table 1, the unit of HSWGR has been measured and reported as a kilogram of HSW per bed per day (kg bed^{-1} day^{-1}) which is considered as the most common unit to report HSWGR (Amfo-Out and Doo, 2015; Mmereki et al., 2017). Furthermore, previous studies have reported the HSWGR with different units such as kg day^{-1} (Gitipour et al., 2017; Rajan et al., 2018), kg patient^{-1} day^{-1} (Ali et al., 2017b), and ton time^{-1} (Rolewicz-Kalińska, 2016; Stoch et al., 2018) that did not have the ability to report in Table 1. Regarding the suitable unit of HSWG, Windfeld and Brooks found that providing a comprehensive unit to report current status of HSWGR lead to better judgment on the effectiveness of HSWM's costs (Windfeld and Brooks, 2015). In addition, reporting the HSWGR as kg patient^{-1} day^{-1} can lead to this fault that the waste generated by outpatients and visitors not be considered in HSWGR (Farzadkia et al., 2018). As presented in Table 1, Addis Ababa in Ethiopia 6.03 (Tadesse and Kumie, 2014) and Lagos in Nigeria 0.37 kg bed^{-1} day^{-1} (Awodele et al., 2016) had the maximum and minimum of HSWGR among the studied developing countries, respectively. Tadesse and Kumie reported that the production of this large amount of waste (6.03 kg bed^{-1} day^{-1}) may be due to the higher visitors' number of hospitals in the study time and high resource allocation to the hospitals (Tadesse and Kumie, 2014). In contrast, Awodele et al. showed that the production of this HSWGR (0.37 kg bed^{-1} day^{-1}) was due to the high level of hospital solid waste workers (HSWWs) awareness. Moreover, they indicated that in most the hospitals the Lagos Waste Management Authority (LAWMA) as a training based program is implemented (Awodele et al., 2016). Therefore, from Awodele et al.'s study it can be concluded that the implementation of a proper awareness training for HSWWs has a great influence in the calculated HSWGR. In Table 1, several differences were observed among HSWGR in a country. For example, In Ethiopia; Tadesse and Kumie reported that the HSWGR was 6.03 kg bed^{-1} day^{-1} while Tesfahun et al. reported about 2.45 kg bed^{-1} day^{-1}. In Nigeria, further analysis indicated that the amount of HSWGR was different between public hospitals (0.56 kg bed^{-1} day^{-1}) (Longe, 2012) and private hospitals (0.181 kg bed^{-1} day^{-1}) (Awodele et al., 2016). By comparing the above studies, it can be concluded that the differences in the type of hospitals between governmental and private hospital were the reason for the difference in HSWGR. Similarly, previous studies have indicated that the level of HSWGR was significantly differed between governmental hospitals and private hospitals so that, the HSWGR level was higher in government than private hospitals (Ali et al., 2016; Farzadkia et al., 2015; Oli et al., 2016). In addition, significant differences in HSWGR (as kg bed^{-1} day^{-1}) among Iranian hospitals were detected such as, Urmia (3.92) (Tapouk et al., 2016), Paveh (1.59) (Pirsaheb et al., 2016), Karaj (5.8) (Farzadkia et al., 2015), Sistan and Baluchestan (2.76) (Bazrafshan and Kord Mostafapoor, 2011). The reason for this is that, as Karaj's contribution to total national GDP per capita (3.8%) is higher than Urmia (1.9%), Paveh (1%), and Sistan and Baluchestan (1%), more quantities of one-use plastic materials are introduced into the HSW stream (Farzadkia et al., 2015). These results match those observed by Al-Khatib et al., that local socio-economic status affects the HSWGR (Al-Khatib et al., 2009). Therefore, HSWGR depend on factors such as the number of actives wards, type of hospitals, economic and cultural condition, level of HSWW's skill, and HSWM system. Fig. 2 presents the spatial distribution and the average of HSWGR of selected countries. As can be seen from Fig. 2, the HSWGR in Brazilian hospitals (4.375 and 3.24 kg bed^{-1} day^{-1}) was more than Egypt (0.87), Turkey (0.63), Serbia (1.9), Jordan (1.88–3.49), Pakistan (0.66). This may be due to that Brazil is in the head of the E7 (a group of emerging countries) and strongly being influenced by concepts developed in high-income countries (Fuss et al., 2018). In Pakistan, Mahmood et al. investigated that the spatial trend of MSW generation is varied; city center has a high rate of generation and towards periphery generation lowers. Based on the current population growth and MSW generation rate in the most populous cities of Pakistan, it is expected to generate 2.8 times more waste by the year 2050 (Mahmood et al., 2018). Therefore, they found a need to develop a proper solid waste management plan to reduce the potential risk of environmental degradation of MSW and protect human health (Mahmood et al., 2018). Moreover, WHO showed that the average of HSWGR in North America, South America, Western Europe, Eastern Europe, Asian high and low-income countries were about 7–10, 3, 3–6, 1.4–2, 2.5, and 1.8–2 kg bed^{-1} day^{-1}, respectively (WHO, 2014). In the other study, Chauhan

Table 1
Quantitative and qualitative characteristics of HSW in developing countries.

Country	City/region	Type of hospital	Year	Generation rate (kg bed^{-1} day^{-1})	Non-hazardous (%)	Hazardous (%)	References
Brazil	Bauru	G	2018	4.375	48	52	(Delmonico et al., 2018)
India	Uttarakhand	P	2017	0.24	36.33	63.67	(Thakur and Anbanandam, 2017)
Botswana	Botswana	P	2017	NM	48.84	52.52	(Mmereki et al., 2017)
Iran	Hormozgan	G	2017	1.83	53	47	(Dehghani and Vafadar, 2017)
Pakistan	Gujranwala	P	2016	0.667	73.8	26.67	(Ali et al., 2016)
Iran	Gorgan	G	2016	2.63	59.73	40.27	(Zazouli et al., 2016)
Ethiopia	Amhara	P	2016	2.45	46.32	53.68	(Tesfahun et al., 2016)
Iran	Urmia	G	2016	3.92	59	41	(Tapouk et al., 2016)
Iran	Paveh	G	2016	1.59	74.28	25.72	(Pirsaheb et al., 2016)
Colombia	Bogotá	P	2016	NM	45	55	(Rodríguez-Miranda et al., 2016)
Palestine	Gaza Strip	P	2016	1.3	80	20	(Caniato et al., 2016)
Nigeria	Lagos	P	2016	0.181	69.5	30.5	(Awodele et al., 2016)
Iran	Isfahan	G	2015	3.94	60	40	(Sartaj and Arabgol, 2015)
Iran	NA	G	2015	3.16	56	44	(Jaafari et al., 2015)
Iran	Karaj	G	2015	5.8	60.4	39.6	(Farzadkia et al., 2015)
Ghana	Akuapem	P	2015	0.58	86.1	13.9	(Amfo-Out and Doo, 2015)
Ethiopia	Addis Ababa	G	2015	6.03	62	38	(Tadesse and Kumie, 2014)
Kenya	Nairobi	P	2014	1.03	35	65	(Nkonge et al., 2014)
El Salvador	San Salvador	G	2013	0.37	61.4	38.6	(Johnson et al., 2013)
Brazil	Sao Paulo	P	2013	NM	56.5	43.5	(Moreira and Günther, 2013)
Bangladesh	Dhaka	G	2012	1.8	78.8	21.2	(Syed et al., 2012)
Nigeria	Lagos	G	2006	0.57	50–66	50–34	(Longe, 2012)
Cameroon	Southwest	G	2011	NM	49	51	(Manga et al., 2011)
Iran	Sistan	G	2011	2.76	47.2	52.8	(Bazrafshan and Kord Mostafapoor, 2011)
Egypt	El Beheira	P	2010	0.87	61.1	38.9	(Abd El-Salam, 2010)
Turkey	Istanbul	P	2009	0.63	59	41	(Birpinar et al., 2009)
Iran	Tehran	P	2009	2.75	87.5	12.5	(Farzadkia et al., 2009)
Serbia	Nisava/Tropica	P	2008	1.9	98.7	1.3	(Stankovic et al., 2008)
Jordan	North	G	2007	1.88–3.49	74	26	(Bdour et al., 2007)
Brazil	Rio Grande	G	2005	3.24	83	17	(Da Silva et al., 2005)
Iran	Fars	G	2004	4.45	71.4	28.6	(Askarian et al., 2004)

G: governmental; P: private; NA: not available.

and Singh showed that the production and composition of HSWs are influenced by staff attitudes and hospital budget (Chauhan and Singh, 2016). Compared to developed countries, HSW waste production in the developing world is rising quickly due to upgraded access to hospitals services, which allow always more numbers of people to receive new health care. The growing trend away from multi-use health care equipment towards safer, single use health care equipment is further adding to the generation of HSW in developing nations. These combined trends are causing a rapid increase in the amount of medical waste that requires safe disposal in developing nations (Mbongwe et al., 2008). In the developed countries, a promptly aging population is the main parameter of increasing hospitals usage, and this rising usage is generating a corresponding increase in HSWGR (Brownlee et al., 2017). Therefore, it can be concluded that HSWGR depends on the level of regional economics and culture. Recent studies have shown that the total quantity of HSW has been increasing in the developing countries over the recent two-decade because of some of the reasons such as an increase in population, the number of hospitals and the use of disposable medical products (Kalogiannidou et al., 2018; Minoglou and Komilis, 2018; Sharma and Gupta, 2017). The qualitative and spatial distribution of HSW in studied countries is shown in Fig. 3. As shown in Fig. 3, Serbia had the maximum proportion of non-hazardous waste (98.7%) and Kenya had the maximum proportion of hazardous waste (65%) among developing countries. According to WHO, approximately 85% of HSWs are non-hazardous wastes while about 15% of HSWs are considered as hazardous wastes. With regard to the standard ratio, it is concluded that all studied countries did not comply with the standard except Serbia. The researchers have explained various reasons for increasing the proportion of hazardous waste to non-hazardous waste in HSWM. In Kenya, the lack of segregation of HSW in HCFs had been mentioned as a major reason for the high proportion of hazardous waste to non-hazardous waste (Nkonge et al., 2014). In the other study, Oroei et al. indicated that the quantitative and qualitative characteristics of HSW were dependent on various factors such as the service provided by hospital and HWSM elements (such as definition, classification, storage, and segregation) (Oroei et al., 2014). In addition, the composition of HSW is also dependent on the type of hospital. Oli et al. demonstrated that hazardous HSW in governmental hospitals were significantly higher than in private hospitals (Oli et al., 2016). Similarly, Longe indicated that governmental hospitals generated more infectious, sharps, and pathological waste than private hospitals (Longe, 2012). However, Delmonico et al. mentioned that the proportion of hazardous-HSW per bed was approximately similar at both public and private hospitals (Delmonico et al., 2018).

3.3. GDP and HSW quantity and quality

As mentioned in the literature, the municipal solid waste generation (MSWG) is significantly associated with economic factors such as GDP per capita. Zaman found a positive correlation ($r = 0.539$, p-value < 0.05) between GDP per capita and MSWG (kg $capita^{-1}$ $year^{-1}$) in 172 countries and also, observed a similar significant correlation ($r = 0.653$, p-value < 0.05) between GDP per capita and per capita MSW recovery (kg $year^{-1}$) (Zaman, 2016). Accordingly, Shekdar indicated that countries with a high GDP per capita produce a larger amount of MSW with a higher proportion of paper and packaging waste than countries with a low GDP per capita. In contrast, countries with a low GDP per capita produce lower amounts of MSW with a higher proportion of biodegradable waste than other countries (Shekdar, 2009). Further, a multiple-regression model showed that MSWG significantly correlated ($R^2 = 0.905$, p-value < 0.0005) by GDP per capita (Chhay et al., 2018). In the other study, the MSWG was significantly correlated with GDP per capita ($R^2 = 0.94$, p-value < 0.0005) based on the multivariable adjustment (Chu et al., 2016). Since, in many countries, HSW is considered as part of MSW, it is excepted that changes in GDP per capita should affect the average of HSWGR. For example,

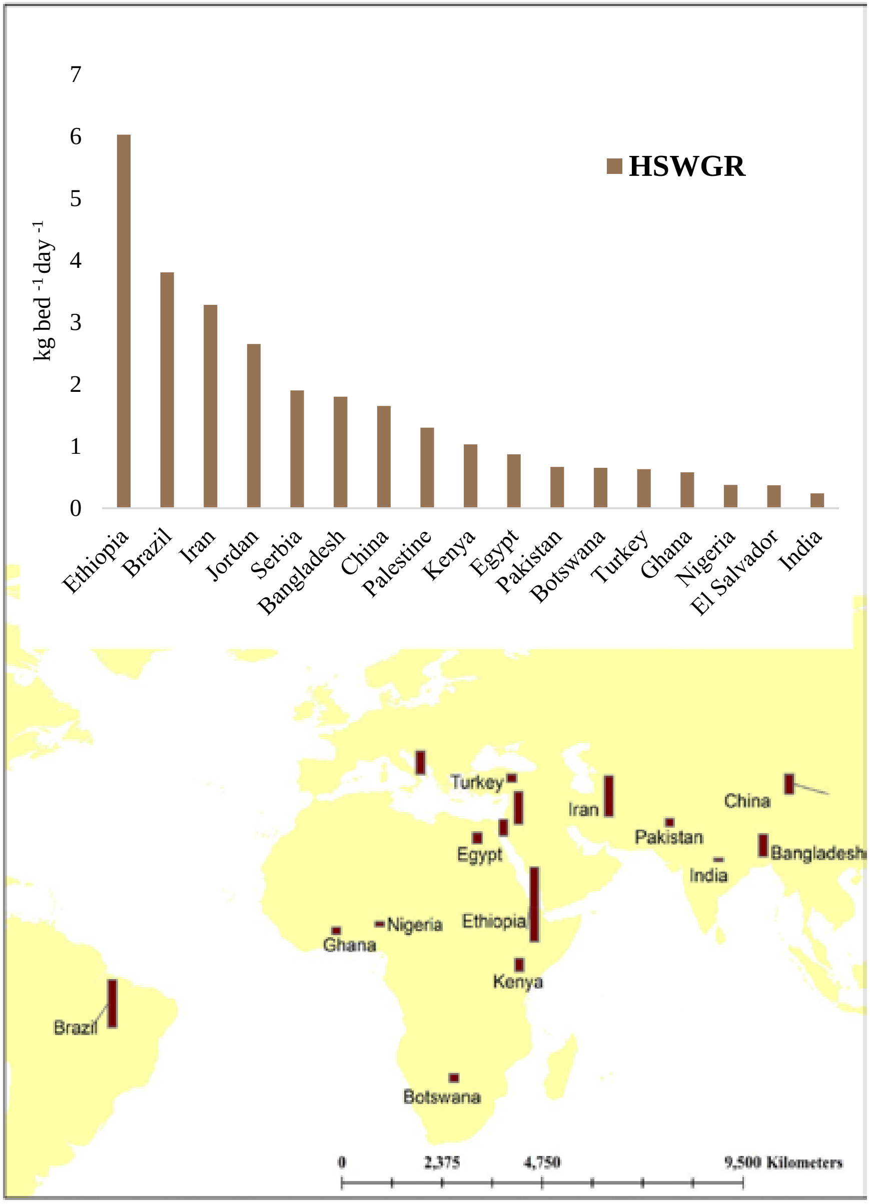

Fig. 2. HSWGR in studied developing countries (kg bed^{-1} day^{-1}).

Minoglou et al. examined the dependence of HSWGR on GDP in 42 countries (developing and developed) with the use of the 2015 GDP only. They found that HSWGR was positively correlated with GDP (R^2 = 0.35, p-value < 0.0005). It is worth noting that in Minoglou et al.'s study, the year of reported HCW generation rate has not been adjusted to take into account the year of GDP. This can hinder the understanding of the relationships between HSWGR and GDP (Minoglou et al., 2017). Therefore, in the present study, the GDP per capita was adjusted with regard to the year of HSWGR. Table 2 shows the association among EPI, GDP per capita, HSWGR, and HSW composition in the selected countries. As can be found from Table 2, GDP per capita was significantly associated with EPI, HSWGR, hazardous HSW, and non-hazardous HSW by the Spearman coefficient equal to 0.47, 0.122, 0.216, and −0.346, respectively. Given these values, it should be expected that with the increase of GDP per capita in developing countries, EPI, HSWGR and the percentage of nan-hazardous waste will increase but also, the share of hazardous waste from the total HSW is reduced. Moreover, the results of this study confirm the results of Minoglou et al. (2017), Zaman (2016), Shekdar (Zaman, 2016), Chhay et al. (Zaman, 2016), and Chu et al. (2016) which showed that the amount of hospital waste is dependent on the GDP and other economic indicators. The spatial distribution of GDP per capita and HSWGR of selected countries are presented in Fig. 4. As observed in Fig. 4, countries with high GDP per capita seem to have high HSWGR as well. For example, in Brazil, Iran, and China as high GDP per capita countries, there were high HSWGR, while the HWSGR was clearly much lower in China, Palestine, and Nigeria. This observation confirms the association between GDP per capita and HSWGR. Besides, Windfeld and Su-Ling Brooks demonstrated the trend of increasing HSW generation with increasing global GDP per capita (Windfeld and Brooks, 2015). Furthermore, Fig. 5 shows the spatial distribution of GDP per capita and qualitative characteristics of HSW of selected countries. As illustrated in Fig. 5, both Kenya and Botswana have a high composition of hazardous-HSW (> 50% of total HSW) among selected countries. However, Kenya has a GDP per capita equal to $1508, and Botswana has equal to $7596 (6 more times). Additionally, both Ghana and Serbia have a low composition of hazardous-HSW (lower than 8% of total HSW) among studied countries. However, GDP per capita in Ghana (1642) was 3.5 times lower than Serbia (5900). Turkey has the highest value of GDP per capita among selected countries. However, 41% of all Turkish HSW was

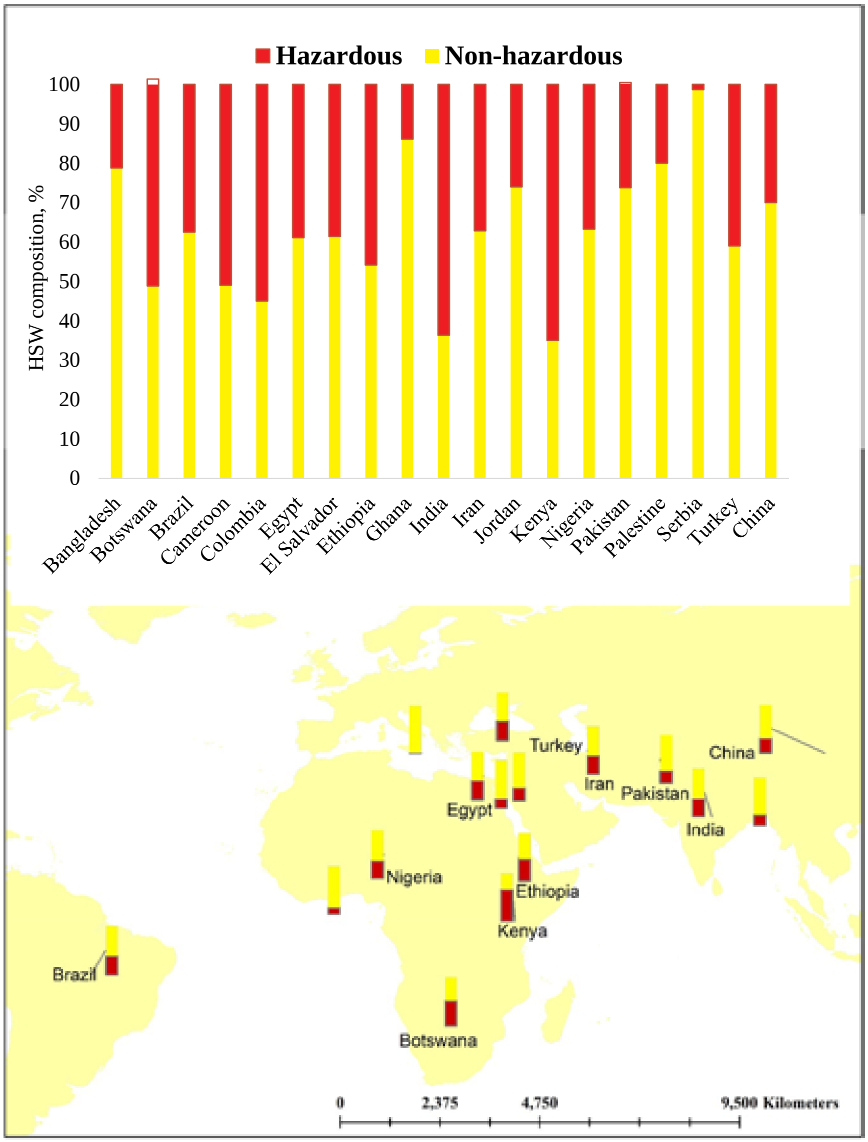

Fig. 3. HSW composition in studied developing countries (%).

Table 2
Association analysis between GDP, EPI, HSWGR, and HSW composition.

		GDP per capita (US$)	HSWGR (kg bed^{-1} day^{-1})	Non-hazardous HSW (%)	Hazardous HSW (%)
GDP	Spearman coefficient	1	0.122	0.216	−0.346
	P value		0.005	0.005	0.008
EPI	Spearman coefficient	0.47	0.389	0.118	−0.118
	P value	0.001	0.003	0.002	0.001

hazardous-HSW that was two times higher than the WHO's standard (15–20% of total HSW is hazardous-HSW). It is concluded from Fig. 5 and Table 2 that GDP per capita has a week correlation with hazardous HSW (r = 0.216) and non-hazardous HSW (r = −0.346). These findings further support the mutual reaction between economic growth and the quality of the environment. Based on the Environmental Kuznets curve, it is predicted that, by increasing the income of a country on the path of sustainable development, environmental pollution will first increase and then begins to decrease with an increase in per capita income (Stern, 2004). Consequently, with the economic growth of developing countries and increasing their GDP per capita, it is expected that HSW production and the proportion of hazardous waste in HSWC should decrease.

3.4. EPI and HSW quantity and quality

With regard to the United Nation's Sustainable Development Goals, governments are forced to explain their performance on their pollution control programs and environmental impact of technologies or activities with reference to quantitative metrics (Griggs et al., 2013). The EPI is one of the most known environmental performance metrics that has been used in several studies and frequently receives innovations and improvements for measurement of environmental trends and progress (Adeel-Farooq et al., 2018; Dragos and Dragos, 2013; Liu et al., 2015). The EPI ranks 180 countries on 24 performance indicators across ten issue categories covering environmental health and ecosystem vitality. The EPI covers health impacts, air quality, water and sanitation, water

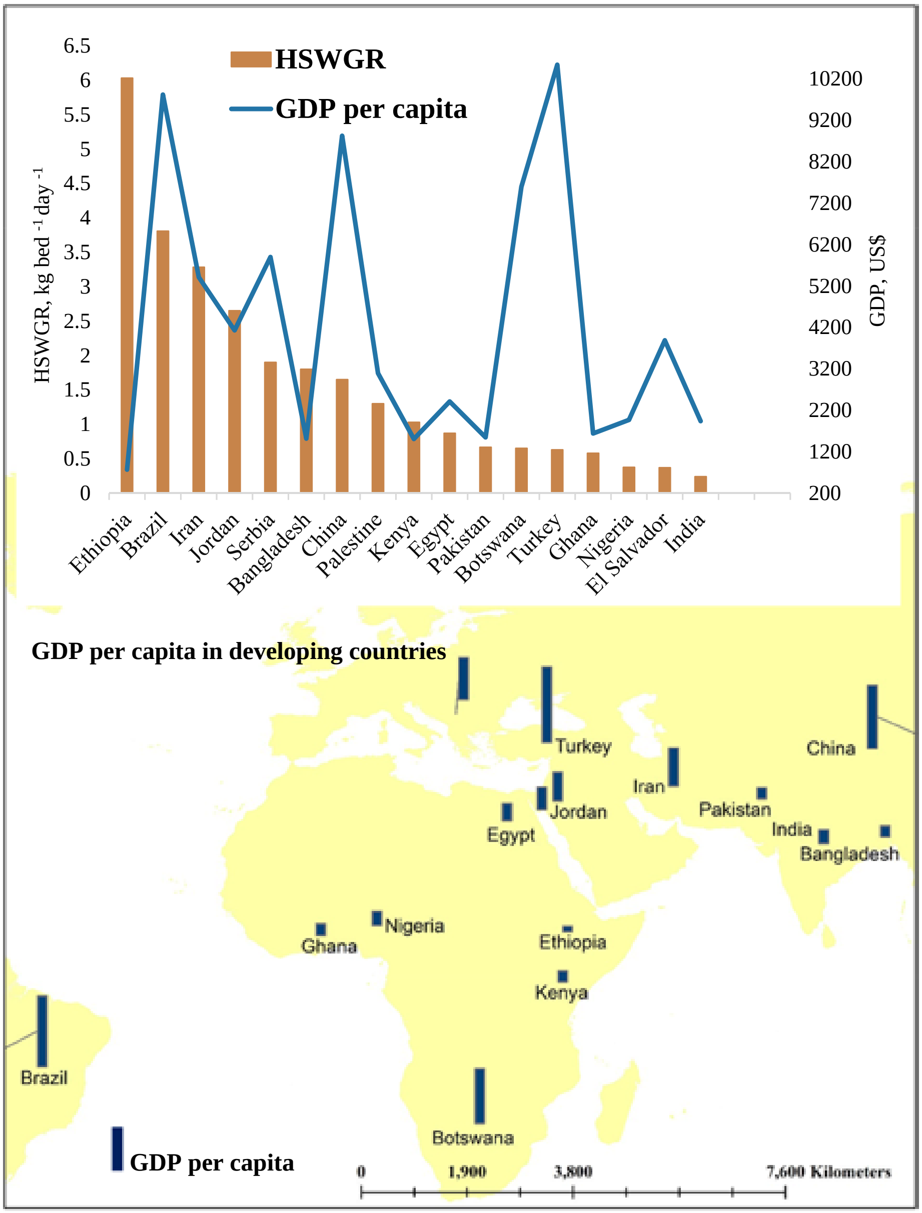

Fig. 4. GDP per capita and HSWGR of studied developing countries (kg bed^{-1} day^{-1}).

resources, agriculture, forests, fisheries, biodiversity and habitat, and climate and energy (Wendling Emerson et al., 2018). Among the ten criteria for the EPI calculation, several criteria are directly related to HSWM such as health impacts, air quality, energy, and water resources, due to the potential risks in HSW. Therefore, it seems reasonable to compare this index with the quality and quantity of HSW. In the present study, the association analysis among GDP per capita, EPI, HSWGR, and HSWC is shown in Table 2. As can be found, EPI significantly was associated with GDP per capita, HSWGR, non-hazardous HSW, and hazardous HSW by the Spearman coefficient equal to 0.47, 0.389, 0.118, and −0.118, respectively. It is apparent from Table 2 that there is a significant relationship between the environmental performance of developing countries with the per capita rate and composition of hospital waste production. Moreover, it should be expected that with the increase of EPI in developing countries, HSWGR and the percentage of nan-hazardous waste will increase but also, the share of hazardous waste from the total HSW is reduced. For the first time, this study assessed the country's EPI interacting with the rate of production and composition of HSW. Therefore, due to the lack of previous studies, no evidence for better comparison is available. The EPI index and the HSWGR of selected countries are shown in Fig. 6. As presented in Fig. 6, Palestine (75.01) and Bangladesh (29.56) had the maximum and minimum of EPI among studied developing countries, respectively, whereas Ethiopia (6.03) and India (0.23) had the maximum and minimum of HSWGR (kg bed $^{-1}$ day^{-1}) among other selected countries, respectively. Furthermore, Fig. 7 illustrates the EPI and qualitative characteristics of HSW in selected countries. As illustrated in Fig. 7, the maximum proportion of hazardous-HSW belonged to Kenya (65%). However, Kenya has more EPI's score (47.25) than Bangladesh (29.56), Pakistan (37.5), and India (30.57). With comparing two neighboring countries, Iran and Pakistan, it can be observed that despite the higher level of hazardous-HSW in Iran (37.149) rather than Pakistan (26.67), the level of environmental performance in Iran (58.16) was more than Pakistan (37.5).

3.5. HSW health risks

All persons exposed to HSW are potentially at health risk of being

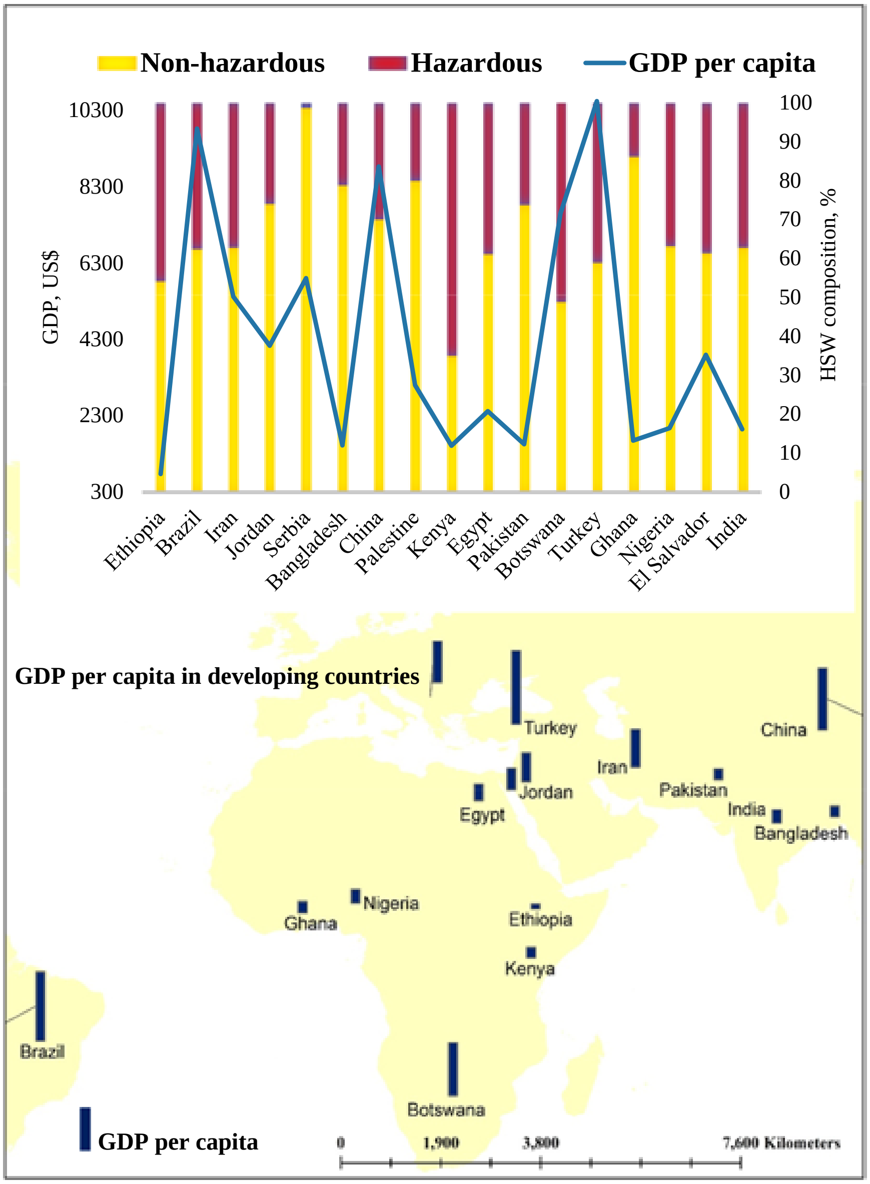

Fig. 5. GDP (per capita) and HSW composition (%).

injured or infected. They include medical staff, patients, hospital solid waste workers (HSWWs), and the general public. HSW health risks have been transmitted to the above persons through contact with hazardous HSW in the various elements of HSWM. Collection and separation are considered as the first elements of HSWM in which HWS can threats human health. Therefore, WHO has proposed a color-coded bins or bags system, based on the nature of the waste, for proper collection and separation of HSW. This system suggested that non-hazardous waste and a small quantity of anatomical waste should be collected in black bins. Furthermore, anatomical, contaminated sharps, infectious, and radioactive waste should be collected in yellow bins, and also, pharmaceutical, chemicals, and heavy metal wastes should be collected in brown bins (WHO, 2014). However, in developing countries, some differences were found in the used color-coded systems. For example, in India, based on the Biomedical Waste Management and Handling Rules (2016), HSW were collected and separated according to the following order; yellow bins for all those wastes that are to be burned, red bins for recyclable wastes, blue bins for glass disposed in cardboard boxes, and white bins for sharps wastes (Sharma and Gupta, 2017). In the other region of India, it is reported that the generated HSW was divided into four major bins: red, yellow, blue, and black (Thakur and Anbanandam, 2017). In Botswana, it is shown that there was five color-based collections and separation system that have been used to collect different types of hospital solid waste (Mmereki et al., 2017). In South African, based on the South African National Standards (SANS), all infectious waste must be separated according to their potential risks. For example, infectious waste must be stored in red plastics while sharps must be collected in yellow puncture and leak-proof containers labeled as "danger" (Hangulu and Akintola, 2017). In Nigeria, the color-coding system for sharp waste was varied from brown to white containers in some Nigerian hospitals (Macaulay and Odiase, 2016). As noted above, local look to a color-coding system and non-compliance with WHO's color-coding standard have been seen dramatically among the developing countries. It is indicated that the lack of the integrated color-coding system can result in difficult storing of HSW for HSWWs and incorrect detection of hazardous HSW from non-hazardous. Therefore, it causes unwanted mixing of non-hazardous wastes with hazardous wastes, and consequently, the health risk of exposure to hazardous HSW increases. However, the literature has reported that the mainstream generated HSWs do not have hazardous characteristics in their primary

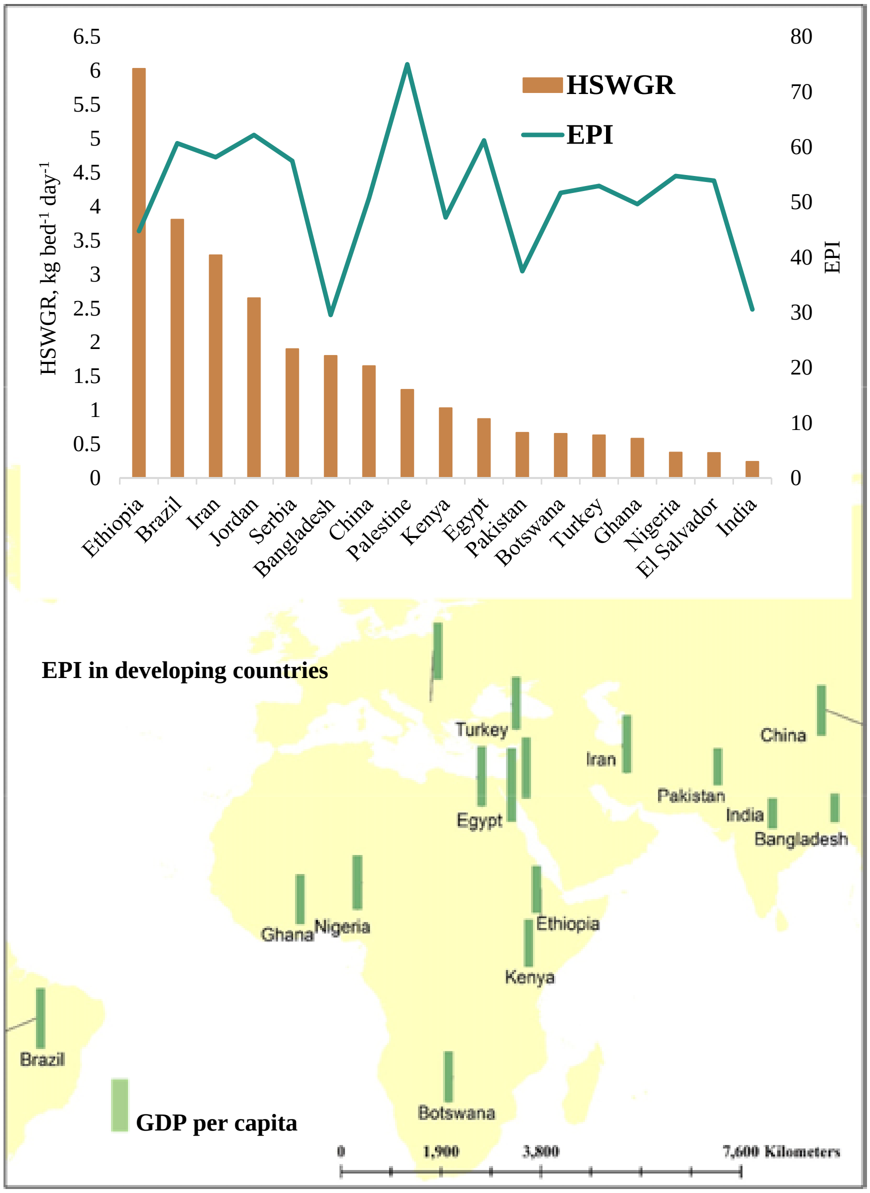

Fig. 6. EPI and HSWGR (kg bed^{-1} day^{-1}).

form and can be simply disposed of by MSW landfills or processed in MSW recycling programs. So far, several studies have been done to estimate the risks of diseases that are transmitted through the MSW. The vast majority of these studies have been conducted to show the level of health risks between workers who exposed to hazardous solid waste compared with those who not exposed to hazardous waste. Table 3 demonstrates the prevalence of viral hepatitis infections among municipal solid waste workers (MSWWs) and HSWWs in developing countries. As illustrated in Table 3, Ansari-Moghaddam et al. estimated that the prevalence of Hepatitis B virus (HBV) among Iranian municipal solid waste workers (MSWWs) exposed to hazardous waste was 6.20% (95% CI: 2.70–9.70) (more than nine times) compared with those who not exposed to hazardous waste. in a systematic review and meta-analysis of observational studies by Corrao et al. (2013), the prevalence of HBV among MSWWs was calculated 11% (Corrao et al., 2013). Therefore, based on Corrao et al.'s study, the HBV prevalence of MSWWs in Iran was lower than the global rates. Similarly, Dounias et al. by reporting the prevalence of HBV among MSWWs 7% indicated that the health risk of MSW between Greece was similar to that of Iran (Dounias et al., 2005). Furthermore, El-Wahab et al. estimated the occurrence of the human immunodeficiency virus (HIV) (0.0%), HBV (6.1%) and Hepatitis C (HCV) (8.4%) among Egyptian MSWWs and also, they reported that about 50% of the MSWWs were at risk of HBV infection in which male workers with low educational and economic levels had predominance. In addition, El-Wahab et al. by using Pearson correlation demonstrated that the prevalence of HBV positively and significantly correlated with several factors include the body weight ($r = 0.1$, p-value = 0.04), presence of chronic disease ($r = 0.1$, p-value = 0.03), HCV/HBV co-infection ($r = 0.11$, p-value = 0.02), and substance abuse ($r = 0.1$, p-value = 0.05). Moreover, they reported that HCV infection was primarily associated with past history of parenteral anti-schistosomal therapy, intravenous infusion and direct exposure to the solid waste (El-Wahab et al., 2015). In the other study, the results of infectious and inflammatory markers among Brazilian MSWWs showed that total leukocyte, neutrophils and monocytes counts in waste transportation drivers compare to the controls and the sweepers were in high value. Furthermore, the presence of parasites such as Entamoeba hystolítica, *Giardia lamblia*, *Strongyloides stercoralis*, Blastocystis, Hominis, Hymenolepis nana was evident among MSWWs (Graudenz, 2009). In the other similar studies the health risks related to

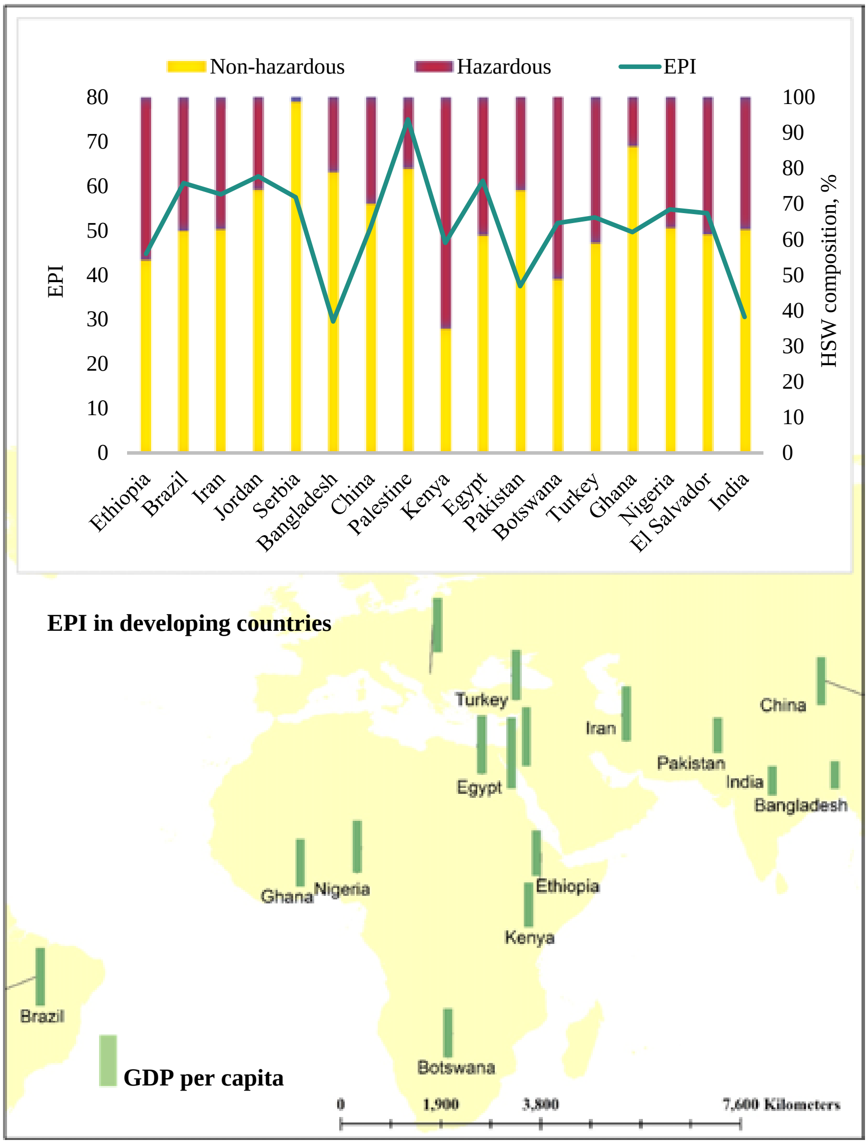

Fig. 7. EPI and HSW composition (%).

Table 3
Prevalence of hepatitis infectious among the exposed and unexposed groups of solid waste workers.

Year	Location	Type of waste	Focus groups (Person)		Health endpoint	Results		References
			Exposed	Unexposed		OR (95% CI)	Prevalence in the exposed group (%)	
2016	Ethiopia	HSW	152	82	HBV	3.17 (1.64, 6.13)	39.4	(Amsalu and Worku, 2016)
2016	Ethiopia	HSW	152	82	HCV	0.54 (0.03, 8.69)	0.7	(Amsalu and Worku, 2016)
2016	Iran	MSW	178	476	HBV	1.63 (0.65, 3.43)	6.2	(Ansari-Moghaddam et al., 2016)
2016	Brazil	HSW	61	461	HCV	5.42 (0.86, 33.97)	3.3	(Mol et al., 2016)
2016	Brazil	HSW	61	461	HBV	1.77 (0.60, 5.27)	9.8	(Mol et al., 2016)
2015	Egypt	MSW	186	160	HBV	0.03 (−1.14, −1.19)	0.03	(El-Wahab et al., 2015)
2014	Greece	MSW	83	50	HBV	5.9 (1.58, 73.3)	15	(Tsovili et al., 2014)

HSW: hospital solid waste; MSW: municipal solid waste; OR: odds ratio; CI: confidence interval; HBV: Hepatitis B virus; HCV: Hepatitis C Virus.

prevalence hepatitis infectious among HSWWs and MSWWs were investigated in other developing countries in Thailand (Luksamijarulkul et al., 2008; Rachiotis et al., 2012), Ethiopia (Anagaw et al., 2012; Shiferaw et al., 2011), and Libya (Franka et al., 2009). Based on the results of previous studies, it can be concluded that HSW and MSW strongly associated with viral infectious diseases. In addition, HSWWs or MSWWs have a four times greater probability of contracting viral infection compared to the general public, and the risk of this viral infection in an unvaccinated HSWW after a single exposure is 6 to 30% (Zeeshan et al., 2007). Therefore, many studies have strongly suggested that to decrease the health risks of HSW, several critical acts should be done such as life skills education, good personal hygiene habits, use of safe and adequate equipment during work, vaccination programs against viral infectious diseases, more boost for immunization against viral infectious diseases, and improvement of the occupational safety conditions.

Table 4
Status of HSW disposal method in developing countries.

Country	HSW disposal method	References
Botswana	Incineration, open dump, landfilling	(Mmereki et al., 2017)
Nigeria	Hydroclaving, incineration	(Awodele et al., 2016)
Palestine	Incineration, landfilling	(Al-Khatib et al., 2016)
Pakistan	Landfilling, incineration, open dumping	(Ali et al., 2016)
Ethiopia	Incineration	(Tadesse and Kumie, 2014)
Brazil	Incinerator, autoclave, microwave, sanitary landfilling, skeptical ditches, open-air dumps	(Moreira and Günther, 2013)
Jordan	Autoclave, chemical disinfection, Incineration, landfilling	(Moreira and Günther, 2013)
China	Incineration, burning on-site	(Zhang et al., 2013)
Turkey	Landfilling, incineration, autoclaving	(Ciplak and Barton, 2012)
India	Autoclaving, hydroclaving, microwave, incineration, landfilling, pit burial, vermiculture pyrolysis/gasification	(Sheikh, 2012)
Bangladesh	Autoclaves, open places	(Sheikh, 2012)
Algeria	Incineration and chemical disinfection, on-site burial	(Bendjoudi et al., 2009)
South Africa	Incineration, autoclaving, open dump and landfilling	(Bendjoudi et al., 2009)

Vermiculture is the process of garden composting using worms.
Pyrolysis is a process that thermally decomposes biomass by heating it at elevated temperatures under controlled inert conditions.
Chemical disinfection refers to kill or inactivate the pathogens; this treatment usually results in disinfection rather than sterilization. Chemical disinfection is most suitable for treating liquid waste such as blood, urine, stools, or hospital sewage.

3.6. HSW environmental risks

The review of previous studies has indicated that inappropriate hospital waste disposal has caused many developing countries facing environmental risks. Several methods have been applied for the disposal of hospital wastes such as incineration, landfill, microwave, steam sterilization technologies, and chemical disinfection in developing countries (Table 4) that have been reviewed as below.

Compared to developed countries, disposal of HSW is of particular concern as developing countries frequently burn HSW in uncontrolled conditions and without any flue gas treatment systems, leading to high levels of dioxin emissions from these waste disposal facilities (Ananth et al., 2010). Therefore, populations living near HSW burning facilities in developing countries are frequently exposed to very high dioxin levels (Windfeld and Brooks, 2015).

3.6.1. Incineration

Incineration is the broadest method used for the elimination of HSW in developing countries. In the literature, three critical types of hospital solid waste incinerators (HSWIs) were identified in the studied developing countries; controlled air, excess air, and a rotary kiln. Among these three types, the controlled air incinerator was the most used disposal method for HSW. Generally, the incineration method has a unique advantage in reducing the volume of waste and can decrease HSW up to 90% (Blahuskova et al., 2019). In addition, incineration requires less utilized land compare with other methods for disposal of HSW (Govind Kharat et al., 2018). As mentioned in the literature, burning the HSW have several benefits such as using the generated heat to warm boilers, production of energy, and separating metals for reusing (Makarichi et al., 2018). Despite the benefits noted above, however, there are also concerns related to the use of HSWIs. The most significant drawback in using the HSWIs is that they have significant environmental risks due to producing a high number of hazardous matters as residual. The hazardous emissions of HSWIs can remain in the environment for a long time and lead to health and environmental problems. The hazardous emissions of HSWIs are shown in Fig. 8 and discussed below (Table 5).

3.6.1.1. Polychlorinated dibenzo-p-dioxin and dibenzofuran (PCDD/Fs). Polychlorinated dibenzo-p-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs) are called dioxins and furans. Dioxins and furans are considered as the most toxic chemicals on human life that have been classified as a life-threatening carcinogen, which may interrupt the immune system and hormone regulation of human (McKay, 2002). The concept of total toxic equivalent (TEQ) has been developed to facilitate risk assessment and regulatory control of hazardous gas emission caused by many congers of dioxins, furans and polychlorinated biphenyls (PCBs) (Liu et al., 2013). Several studies in developing countries have conducted the evaluation of emission of dioxins and furans in the stack gas from HSWIs. Among developing countries, China has widely measured dioxin and furan in HWSIs due to the high cost and complexity of PCDD/Fs measurement (Zhou et al., 2015). For example, Li et al. and Gao et al. showed that some of HSWIs had higher levels of PCDD/Fs than current emission standard in China (0.5 ng I-TEQ Nm^{-3}) (Gao et al., 2009; Li et al., 2017). In addition, the TEQ of PCDD/Fs in Li et al.'s study (0.09–29.50 ng I-TEQ Nm^{-3}) was much lower than Gao et al. (2009) study (0.08–31.60 ng I-TEQ Nm^{-3}). According to Li et al., the emission levels of PCDD/Fs from HSWIs in China (0.031–3.463 ng I-TEQ Nm^{-3}) was lower than some other developing countries such as Colombia (7–700 ng I-TEQ Nm^{-3}) (Hoyos et al., 2008) and Poland (0.24–5.68 ng I-TEQ Nm^{-3}) (Węgiel et al., 2011). Further, the TEQ analysis showed that 1,2,3,7,8,9-H6CDF and 1,2,3,4,7,8-H6CDF were also the effective indicators of PCDD/Fs in the stack gas of HSWIs (Li et al., 2017).

3.6.1.2. PAHs. Although polycyclic aromatic hydrocarbons (PAHs) is considered to have a low water solubility, they have a high surface-assimilative to solid particles in water, air, and soil environments and also can migrate into the environment through dust, rainfall, and snow (Kim et al., 2013). In HSWIs, aluminum foil (press through-packaging), polyethylene (PE), polyester terephthalate (PET), polyvinylchloride (PVC), and polypropylene (PP) are considered as major contributors to environmental pollution by PAHs (Chen et al., 2013b). The conditions of HSWI operation significantly affect the PAHs generation and toxicity. Qin et al. showed that the PAHs emission in a fluidized bed HSWI was greatly varied within the combustion temperature from 750 to 1150 °C (Qin et al., 2018). Besides, Drwal et al. indicated that the high toxicity of PAHs is correlated to the higher molecular weight and more number of rings at PAHs' structure (Drwal et al., 2019). On the other study, Chen et al. indicated that the four or more rings PAHs was produced as fly ash that was 1800 times higher than bottom ash in HSWIs. In addition, the distribution analysis of PAHs showed that Acenaphthylene (ACY), Acenaphthene (ACE), Fluorene (FLU), Phenanthrene (PHE), Anthracene (ANT) and other PAHs were found in surrounding environment such as air and surface watershed corridors, while the four or six rings PAHs were found only as accumulated form in soil. Moreover, they suggested that increases in both free oxygen molecules and combustion temperatures can increase the PAHs decomposition (Chen et al., 2013b). Moreover, HSWIs compared to municipal solid waste incinerators (MSWIs) can produce

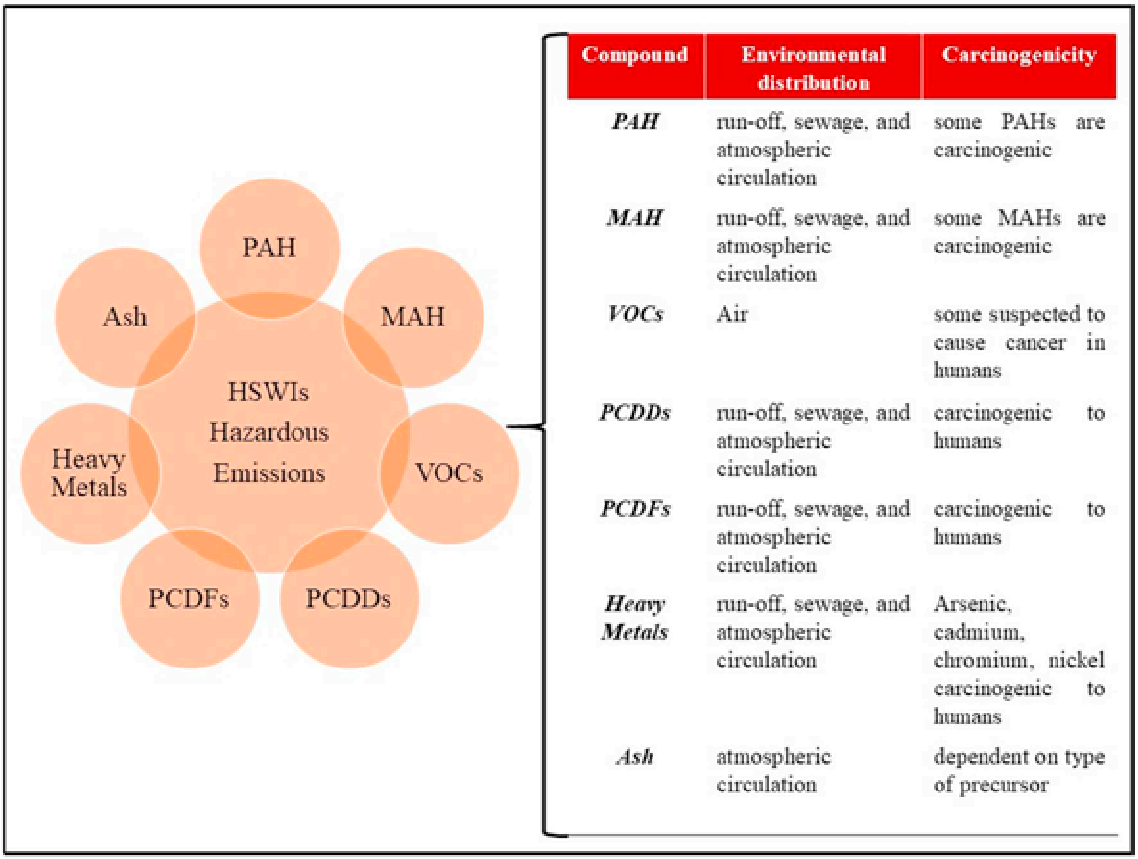

Fig. 8. Environmental distribution and carcinogenicity of hazardous emissions of HSWIs.

a high quantity of PAHs (Chen et al., 2013b). A real-time tracking study for a 1-year period showed that the average monthly concentration of alkyl-naphthalene (as the most volatile PAH) in a HSWI was 67.4 ng m^{-3} that were lower than the safe level of daily human exposure for chronic inhalation (0.003 mg m^{-3}) and may be used to evaluate the environmental contribution of alkyl-naphthalene from HSWIs in Nigeria (Adedayo Adesina et al., 2017). In the other study, Adesina et al. investigated spatiotemporal distributions of selected PAHs by sampling stack gas and ambient air around HSWIs. They showed that the concentration of phenanthrene, pyrene, anthracene, benz[*e*]acephenanthrylene, and indeno[2,1-*b*]chromene were in the range of NA and pyrene was 10.9 ng m^{-3} (Adesina et al., 2018). Furthermore, they concluded that the PAHs concentrations were affected by hydrological conditions so that, PAHs concentrations at dry season (6–10 ng m^{-3}) were higher than the wet season (2–4 ng m^{-3}) (Adesina et al., 2018). Based on the literature, the concentration of PAHs in Nigeria was several times higher than the European Union standard (1 ng m^{-3}) and the WHO guideline levels (1 ng m^{-3}) (Ravindra et al., 2008; Wang et al., 2012).

3.6.1.3. Ashes. The incineration of HSW does not only emit criteria gases (SOx, NOx, CO2, CO, etc.) into the atmosphere but also residue solid material such as bottom or fly ashes. Bottom or fly ashes from incinerators consist of heavy metals, inorganic salts, and organic compounds (Blahuskova et al., 2019). Bottom ash is a combination of heavy metals and inorganic compounds which are not destroyed during incineration. Beside, fly ash terminology refers to some toxic metals and tiny metal particles, which are suspended in the air or are insoluble in the water due to the high temperature of combustion (Blahuskova et al., 2019). Several studies identified toxic heavy metals in the generated ashes from HSWIs in developing countries. In China, Xie and Zhu (2013) indicated that the presence of heavy metal contents in fly ashes were 1.7–31 times higher than in Japan due to poor management of HSW (Xie and Zhu, 2013). According to the Valavanidis et al.'s findings, heavy metals become soluble and mobile in the form of a fly or bottom ash and as a result, the government must apply strict regulations to the disposal of HSWIs residue. Further, they showed that the presence of heavy metals with high values in leachate from HSWIs was the other important drawback of HSWIs in Greece (Valavanidis et al., 2008). In the other study, Adama et al. investigated the contribution of heavy metals (Hg, Pb, Cd, Cr, and Ag) in bottom ash and soils around 100 m of an HSWI in Ghana. They found that the soil was polluted to a radius of 60 m from the HSWI and showed also the concentration of Zn, Pb, Cr, and Cd in bottom ash were 16,417.69, 143.80, 99.30 and 7.54 mg kg^{-1}, respectively, which were above the allowable limits for disposal in a landfill. Furthermore, they concluded that HSW managers should be educated about the risks of ashes produced in HWSIs (Adama et al., 2016). In the other study, Allawzi et al. characterized the bottom ash of a HSWI and found the major elements Ca, Si, Al, Cl, Na, Fe, Ti, S, Mg, Ba, and K, while the main mineral phases were calcite, halite, sylvite, anhydrite, hematite, hydrochlorborite, cristobalite, melanterite, and chlormayenite. In addition, they showed that the metal ions concentration in the HSWI's bottom ash was increased by increasing the temperature. They concluded that the heavy metals of the bottom ash of an HSWI were less than the EPA's limitation (Allawzi et al., 2018).

3.6.2. Landfilling

In some developing countries, where hospitals lack the required means to treat wastes before disposal, direct landfilling is likely to be necessary for much of the produced materials (Aydin, 2016). Although landfilling is recognized as a cost-effective means of disposing of any solid waste, few studies have been done about HSW landfilling, especially in countries with large free lands (Macaulay and Odiase, 2016).

Table 5
Pollution emission from HSWI in developing countries.

Country	Year	Yearly capacity of HWSIs (ton)	Sample location	Emission factor	Emission	Pollutant	References
Nigeria	2018	4200	Stack gas and ambient air	NA	21.9–73 ng m^{-3}	PAHs	(Adesina et al., 2018)
China	2017	3530.33	Stack gas	1108.26 (ng TEQ ton^{-1})	3.14 (mg TEQ $year^{-1}$)	PCDD/Fs	(Li et al., 2017)
Jordan	2016	NA	Bottom ash	100–237.23 ng TEQ g^{-1}	NA	benzo(a)pyrene	(Alawi and Al-Mikhi, 2016)
Turkey	2015	NA	Particle		29–282 (ng I-TEQ Nm^{-3})	PCDD/F	(Gunes et al., 2015)
China	2015	NA	Stack gas	1.47 (ng I-TEQ Nm^{-3})	NA	PCDDs	(Chen et al., 2015)
China	2013	10,950	Stack gas	158.68	0.45	mono- to octa-CDD/Fs	(Liu et al., 2013)
		5475		158.68	1.33	mono- to octa-CDD/Fs	
Turkey	2011	13,000	Bottom ash	NA	0.21, 0.91, 0.16, 1.55, 1.61, 0.56, 0.79, and 1.65 mg kg^{-1}	Cd, Co, Cr, Cu, Fe, Mn, Ni, and Pb	(Gören, 2011)
China	2011	NA	Fly ash	2886.6	33.93	PCDD/Fs	(Wu et al., 2011)
China	2009	5 to 25 ton d^{-1}	Stack gas	0.78–473.97 µg I-TEQ ton − 1	0.08–31.60 (ng I-TEQ Nm^{-3})	PCDD/Fs	(Gao et al., 2009)
Greece	2008	14,000	Fly ash		1, 1, 198, 178, 2397 and 8234 mg kg^{-1}	Pb, Cd, Ni, Cr, Cu, and Zn	(Valavanidis et al., 2008)
			Bottom ash		2050, 5.9, 62, 84, 1100 and 5650 mg kg^{-1}	Pb, Cd, Ni, Cr, Cu, and Zn	
Colombia	2008	3849	Stack gas	NA	2.38 (mg TEQ $year^{-1}$)	PCDD/PCDF	(Hoyos et al., 2008)

The main threats of this technique include the possible pollution of soil and groundwater, requirement for large land areas, and high residual volume of waste (Idowu et al., 2019). Landfills or open dumps have been considered as one of the major challenges for groundwater resources because the leachate can release a high amount of pollutants into the groundwater resources. For instance, the impact of leachate from an unlined landfill site filled by non-infectious hospital waste on groundwater quality was evaluated by Mor et al. (2006) in India. They illustrated heavy metals concentrations (Cd, Cr, Cu, Fe, Ni, Pb, and Zn) in the landfill site were 0.06, 0.29, 0.93, 70.62, 0.41, 1.54 and 2.21 mg L^{-1}, respectively. Although they showed that the concentration of Pb, Cd, Cr and Ni from the HSW landfill site was below of detection limit in groundwater; thus, these heavy metals may be adsorbed in the soil. However, the presence of a high amount of total coliform (TC) and fecal coliform (FC) in groundwater around the HSW landfill site had made the aquifer unreliable for potable water supply (Mor et al., 2006). Similarly, a river and a lake located near an HSW landfill were studied by Erbe et al. to investigate the physicochemical, microbiological, and toxicity bioassays of water. They found that physicochemical parameters, total coliforms, and *Escherichia coli* were above acceptable levels of environmental standard in Brazil. However, the toxicity bioassays showed no immediate risk due to acute effects. It can be concluded from Erbe et al. that the chronic toxicity risks associated with the HSW landfill leachate must be detected to assess the toxicity of polluted water with greater accuracy (Erbe et al., 2011). Some studies have shown the potential risks of disposing the ash and residue from HSWIs in the land. For example, Adama et al. reported that all bottom ashes of an HSWI with a high amount of heavy metals were dumped in an open pit close HSWI. They also showed that the concentration of heavy metals of the HSWI's surrounding soils was above allowable limits for disposal in landfill and the soils were polluted to a radius of 60 m. Therefore, they recommended improving the operation of the HSWI to avoid further environmental pollution and human exposure to heavy metals. In addition, HWSM's staff should be trained in the safe handling of HSWI's residue and disposal strategies, and regulatory authority should also enforce effective guidelines for ashes and residue management in HSWI and HSW landfill site (Adama et al., 2016).

3.6.3. Microwave

Microwave method has widely been used in developed countries such as Canada, Japan, Korea, Philippines, United Kingdom (UK), and United States (US) (Edlich et al., 2006). However, because of the complexity and high cost, it has received only limited attention in developing countries. Using the microwaves in developing countries such as China and Brazil has been reported in the recent decade. Chen et al. reported that by the end of 2012, 136 non-incineration treatment facilities such as high-temperature steam, chemical disinfection, and microwave had been used in China. They showed that although these technologies can avoid the release of dioxin and furan at the national level, at the local level, it is still necessary to decide how this method meets the local HSWM needs while also reducing the impact on the environment. Therefore, with regard to low pollutant release, minimum land required, and the current tendency for enhancing environmental performance worldwide, Chen et al. recommended the application of microwave as the best available environmental techniques in China (Chen et al., 2013a). In the other study, Oliveira et al. investigated the inactivation of Bacillus atrophaeus spores in a pilot microwave instrument in a Brazilian hospital. They determined a maximum experimental inactivation of 71% for Bacillus atrophaeus spores at the operation power of 200 W/kg in 40 min of contact time. Therefore, they concluded that the microwave method was ineffective in real scale for HSW treatment, since the radiation exposure time was usually only 30 min at the average power of approximately 80 W/kg. The most important contributions of this study are that it proved that microwave could not economically provide a safe environmental level in the elimination of hazardous HSW in Brazil (Oliveira et al., 2010). However, from an environmental perspective, it is proved that microwave as a waste detoxification technique has higher sustainability and effectiveness if compared with the other HSW disposal methods such as incineration or landfilling (Falciglia et al., 2018). Similarly, the results of Soares et al. indicated that microwaving has the lowest environmental impact (12.64 Pt) followed by autoclaving (48.46 Pt) in small hospitals. Moreover, they calculated that 0.12, 1.10, and 1.53 US$ kg^{-1} was needed for waste treating by microwaves, autoclave, and lime, respectively. According to Soares et al.'s study, the microwave has best eco-efficiency performance for small amounts of hospital waste compared to autoclave and lime (Soares et al., 2013). Many researchers have argued that to manage small-scale HCFs, HSWM usually require alternative techniques such as microwave because of the problems with conventional systems, including the high costs of treatment and disposal, the varying daily HSW generated and the limitations of hospital volume for waste storage (Aydin, 2016; Caniato et al., 2015; Falciglia et al., 2018; Hong et al., 2018). Moreover, as an interesting application of microwave technology in HSWM, Wei et al. (2011) used it for the decomposition of PCDD/Fs from HSWI fly ash. They showed that with a power of 2100 W at 7 min the total elimination efficiency of PCDD/Fs was reached to 99.6 wt% and the TEQ was substantially reduced from 29.0 to 0.08 ng I-TEQ g^{-1}. They concluded that microwave could present an eco-friendly alternative to disposal for hazardous ashes compared to landfilling (Wei et al., 2017). Finally, it has conclusively been shown that the microwave disinfection has less environmental impacts such as greenhouse gas emissions, toxic air contaminants, and liquid residues when compared with incineration and chemical disinfection (Voudrias, 2016).

3.6.4. Steam sterilization technologies

The non-incineration systems such as autoclave and hydroclave have been proposed as means for treating pathogenic microorganisms in hazardous HSW. Although, the steam sterilization technologies kills or stops microorganisms' growth, however, microbial regrowth and remaining chemical hazardous risks are the major limiting factors for using these systems (Efaq et al., 2017). Therefore, researchers have suggested a supplementary treatment for autoclaved wastes before the disposal in a landfill (Efaq et al., 2017; Hossain et al., 2012). Compared with a central off-site HSWI, a central off-site autoclaving facility decreased air pollution and also showed better environmental performance (Taghipour and Mosaferi, 2009). Similarly, Karagiannidis et al. assessed several scenarios on thermal treating of infectious HSW via the multi-criteria decision method analytic hierarchy process (AHP). They demonstrated that the centralized autoclave or hydroclave plant near a hospital was an environmental scenario for treating hazardous HSW (Karagiannidis et al., 2010). Conventionally, autoclaves mainly are used in developing countries to reduce pathogenic microorganisms in hazardous HSW and disinfect or sterilize equipment. Gitipour et al. revealed that 93.93% of Tehran's hospitals treated their HSW trough autoclaving methods. They indicated that proper maintenance and operation of these devices need to be implemented. The results of Gitipour et al.'s study are consistent with (Ciplak and Kaskun, 2015; Dastpak et al., 2017; Verma et al., 2008) that indicated that the great proposition of HSWs had been treated by steam sterilization technologies such as autoclave and hydroclave. In another study in Ethiopia, Debere et al. indicated that, due to the inadequate separation of HSW at the time of autoclaving, there was a challenge in the proper implementation of HSW management (Debere et al., 2013). As concluded from the literature, HSW has many hazardous health and environmental risks and must be controlled and managed through implementing programs and policies based on sustainable development approaches. Because choosing an optimal risk minimization method is dependent on a comprehensive look at health, economic, and environmental issues.

4. Conclusion, study limitations, and future research directions

This study attempted to collect and assess the HSWM among developing countries and did not cover all relevant studies, particularly if they were published outside the peer-reviewed and English journals or before 2000. Certainly, this causes a possible bias such as providing insufficient information to readers, improperly evaluating the relevance and impact of our results, and lack of generalizability to all developing countries. It should also be noted that some studies had been conducted on dental, clinical, and laboratory waste, while we selected only those focusing on waste generated in HCFs such as a hospital. Numerous developing countries have not been considered in this study. With regard to the literature, it can be observed that some countries have conducted more studies than others. Therefore, it is excepted that the discussion of the present study is influenced by the results of studies in these countries. In addition, as the articles were published in different years and there were various sampling locations (cities) for each studied country, we were forced to calculate the average of available data for each country and analyze it for a meaningful analysis of EPI, GDP per capita, HSWGR, and HSWC. Furthermore, to make the reader better understand and avoid confusion, we did not mention the names of cities in the body of the text and reported data with the name of countries. As a result, the present study was designed to summarize the knowledge of existing health and environmental risks of HSW in developing countries and compare the quantitative and qualitative characteristics of HSW with two global economic and environmental indices, i.e., GDP per capita and EPI. Results of the present review indicated that the highest and lowest reported HSWGR belonged to Ethiopia and Nigeria, respectively. It has also been shown that all studied countries except for Serbia had higher levels of hazardous waste in their HSWC than the WHO standard. This study confirmed that GDP per capita was significantly associated with EPI, HSWGR, hazardous HSW, and non-hazardous HSW based on the Spearman coefficient of 0.47, 0.122, 0.216, and −0.346, respectively. Given these values, it should be expected that, with the increase of GDP per capita in developing countries, EPI, HSWGR, and the percentage of nan-hazardous waste will increase, whereas the share of hazardous waste from the total HSW is reduced.

Besides, the EPI published by the YCELP was used for the first time to explore HSW quantity and quality in developing countries in the present study. Findings confirmed the association between EPI with GDP per capita, HSWGR, non-hazardous HSW, and hazardous HSW by the Spearman coefficient of 0.47, 0.389, 0.118, and −0.118, respectively. There was a significant relationship between the environmental performance of developing countries with the per capita rate and composition of hospital waste production. However, it can be concluded that GDP per capita and EPI have a weak correlation with hazardous HSW and non-hazardous HSW.

Moreover, the present study summarizes previous findings and concluded that HSW has many hazardous health and environmental risks and, therefore, must be controlled and managed through implementing programs and policies based on sustainable development. The assessment of health risks in HSW revealed that several critical measures should be taken to control these risks, including life skill education, good personal hygiene habits, use of safe and adequate equipment during work, vaccination programs against viral infectious diseases, more boost for immunization against viral infectious diseases, and improvement of the occupational safety conditions.

On the other hand, the assessment of HSW environmental risks demonstrated that despite the benefits of HSW disposal methods, there are also concerns related to drawbacks in HSWIs by producing a high number of hazardous matters such as dioxin, furans, and ashes by the possible pollution of soil and groundwater and requirement for large land areas in the case of landfilling, providing a non-safe environmental level in the elimination of hazardous HSW in the case of microwave, and microbial regrowth and leaving chemical hazardous risks in the case of steam sterilization technologies.

As a final point, we believe that the present study can be a valuable lesson for policymakers in the design and application of HSWM in developing countries where many HSW disposal methods lack the advanced technology to control toxic substances used in developed countries. Nevertheless, several questions remain unanswered at present and, consequently, future studies on the current topic are recommended. The first question examines how HSWM influences the HSWGR and HSW composition in developing countries; the second is how the HSWM influences the estimation of EPI, and the third is how the costs of HSWM influence the calculation of GDP per capita. Finally, we contend that WHO should create a comprehensive and comparable performance-based framework that can be used to assess the HSWM in all countries and also monitor the implementation of the framework. This framework must include dynamic items based on the economic and environmental performance as well as the social status of countries.

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Declaration of Competing Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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