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Critical Review

Assessment of Municipal Solid Waste Management Practices in Urban Centers of Pakistan: A Comprehensive Review

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Abstract: Solid waste is a problem in almost every country, but developed countries handle and manage their waste efficiently and usefully. On the other hand, developing countries are still struggling to develop an appropriate mechanism for the collection, disposal, and treatment of solid waste. Consequently, poor practices result in the deterioration of water quality. Similarly, the situation is not good in Pakistan; heaps of household garbage on streets and roadsides are very common. In this study, literature from the past 10 years has been collected to evaluate solid waste management practices, composition of waste, and per capita waste generation in different cities of Pakistan. Meanwhile, problems are also highlighted that lead to the pollution of water resources. It has been found that drinking water quality in many cities has already deteriorated due to the seepage of leachate from landfills and dumping sites deep into the soil and making its way to groundwater. Secondly, the disposal of waste into surface water bodies has also created problems. To conclude, despite the presence of local environmental laws, rules, and regulations, an important component of the environment, i.e., water, is getting polluted continuously. Presently, it might not be a worse problem, but in the coming years, it could lead to an environmental and health disaster in Pakistan. It is recommended to adopt healthy and firm waste management practices in Pakistan as being followed by developed nations and, more importantly, strong implementation of laws to contain this major crisis.

***Keywords*:** solid waste management, water resources, health effects, developed vs developing nations

1. Introduction

The utilization of municipal solid waste (MSW) is essential for sustainable development, particularly in the context of Pakistan's environmental issues and energy challenges. MSW, or waste material from human and industrial activities, has potential uses for several advantageous applications, such as the production of energy [1]. While landfilling, anaerobic digestion, composting, and incineration have been the conventional techniques used to manage MSW, some recent studies have focused on the biorefinery approach. With the development of a variety of goods with low energy consumption and trash production, this strategy seeks to maximize the value extracted from MSW [2].

MSW in particular can be used to generate electricity, which provides a way to minimize greenhouse gas emissions and help solve the problem of energy. Developed nations have already put plans in place to produce power from MSW by using techniques like gasification, pyrolysis, and incineration. The process of incinerating waste has transformed

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from being mostly utilized for reducing waste volume to one that recovers energy while also generating useful by-products and valuable energy sources [3]. In many developing countries like Pakistan, effectively using incineration technologies is still a difficulty, despite their potential. Problems like high moisture content, low energy content, and inconsistent compositions make it difficult to effectively incinerate MSW. However, these obstacles can be overcome by developments in legislation and technology, which will make MSW power generation a feasible solution to Pakistan's energy and waste management requirements [4].

Waste collection is an essential step in the waste management process. In developing countries, handling and disposing of waste in the face of resource constraints creates a fast-growing amount of solid waste. Developed countries commonly use door-to-door systems of waste collection, but because of financial incapacity as well as administrative disability in developing countries, this service can be provided to only a bounded proportion of the population [5]. Accordingly, people use open landfill sites to dump their waste. Thus, it becomes an environmental and health threat for people who used to live near these sites [6]. The urban areas of developing countries mostly experience health issues and environmental problems resulting from disorganized waste management systems [7].

Different studies have explored the fact that there is a close relationship between health and waste [8]. However, some studies have found that many health and environmental issues are mostly associated with people who used to live near dumpsites [9, 10]. A large amount of waste is generated because of the increase in production and consumption rates of things, and when the environment absorbs it, it poses serious health issues for humans [11]. In developing countries, sites for waste disposal usually appear in the surrounding urban areas, and these dumpsites become infection sources for children because of the growth of flies, mosquitoes, and insects [12]. So, this results in different health problems, such as respiratory, gastrointestinal, and generic problems, due to improper waste management [13]. Furthermore, different serious health issues, such as cervical cancer in women and lung, stomach, liver, and prostate cancer in men, are also associated with people living near these dumpsites [14]. Sharp objects such as blades, razors, and syringes are also included in improper waste disposal, which are direct and serious hazards for the disposal workers. It has been noted that about 70 million people with hepatitis C and 250 million people with hepatitis B are infected because of direct contact with infected blades and syringes [15].

Consequently, Pakistan is experiencing critical problems in solid waste management, and a lot of attention is given to these problems because of the increase in environmental susceptibility [6]. It has been analyzed in the assessment of different cities in Pakistan that the average rate of waste generation is rising from 0.283 kg to 0.613 kg per person every day, and thus the production of waste is increasing annually from 3.67% to 7.42% [16]. Moreover, Pakistan has the highest rank in South Asia for poor plastic handling. In a year, almost 55 billion plastic bags are produced, and after a single use, they make their way toward streams, lakes, and other water bodies. While many countries, such as Bangladesh, Rwanda, and France, have prohibited plastic bags, in Pakistan, a statutory regulatory order has also been released by the Environmental Protection Agency banning plastic bags in Lahore and other cities such as Islamabad and Hunza. Presently, at the provincial and federal levels, there is no constitutional direction that addresses the incrimination of single-use plastics and the management of plastic waste [17]. At the community level, bins are provided by municipal corporations in Pakistan, which are removed after being loaded. At designated points, waste containers are also offered to enable households to bring out their waste. Vehicles for waste pickup are obliged to clean their containers as soon as they are loaded. However, there is always an overflow of waste, and as a result, land dumping occurs on illegal sites or near dustbins [18].

Illegal dumping of waste into groundwater supplies and other water bodies, such as streams and canals, creates a conducive environment for reproducing mosquitoes. Thus, malaria and other infections are the result of all this [18, 19]. Due to the weak implementation of environmental regulations, several cases have been reported of dumping chemical and hazardous waste in different water bodies [20]. In Pakistan, the initial source of water contamination is sewerage. Water quality is affected by solid waste, especially in those areas that are close to dumping sites, because toxic chemicals from waste, when entered into groundwater or other drinking water sources at excessive levels, are capable of harming living organisms' health. Copper, lead, manganese, cadmium nitrate, etc. are included in chemical hazards. The people who used to live near dumping sites mostly use groundwater for domestic and drinking purposes [21]. Sometimes, the health of people is also at risk whose supply of water has become polluted due to the dumping of waste or leakage. Thus, infection risk increases. Moreover, for the survival and growth of microorganisms and pathogens, favorable conditions are created by domestic waste. People are captivated by living in these polluted areas. This is not a

natural phenomenon. The reason behind all these problems is the behavior of human beings. We have to deal with this problem and should try to get a command of it [22].

A great focus on human health and a sustainable environment is given by the Sustainable Development Goals (SDGs) and Millennium Development Goals (MDGs). As a result, to meet the MDGs, about 2.1 billion people in developing countries have gained access to systems of improved sanitation. Waste minimization is encouraged by the SDG policy through reusing and recycling activities of substantial waste. For example, SDG-3 is concerned with people's health and well-being, while the aim of SDG-6 is to improve systems of water and sanitation. At the same time, SDG-11 is concerned with the collection and management of solid waste [20].

The need to conduct this study arises from the pressing issue of inadequate solid waste management practices in Pakistan and their detrimental effects on the environment and public health. The country continues to face challenges in effectively managing its waste, leading to the pollution of water resources. This study aimed to comprehensively assess the current state of solid waste management in Pakistan, identify key problems and challenges, and highlight the implications of poor waste management practices on water quality. This review study aims to assess the current state of solid waste management practices in Pakistan, focusing on aspects such as waste composition, per capita waste generation, and the impact of poor management practices on water quality. By examining literature from the past decade, the study aims to highlight the challenges and shortcomings in waste management, particularly in relation to the pollution of water resources. Additionally, the study aims to emphasize the urgent need for improved waste management strategies and the effective implementation of environmental laws and regulations to mitigate the environmental and health risks associated with poor waste management practices.

2. Condition of solid waste in developing countries

All actions are covered by solid waste management to reduce negative effects on the environment, economy, and health. Different problems are faced by developing countries that are related to communal waste collection, disposal, and transportation. Because of random communities and unplanned development in different cities in Pakistan, the complexity of sanitary conditions has increased [23]. People are forced to live in unhygienic and polluted environments due to illiteracy and limited sources of income. One of the causes of environmental degradation is improper management of solid waste. In Pakistan, several diseases are caused by illegal dumping [1].

Due to urbanization, there is an annual increase in the generation of solid waste per capita in developing countries. Waste density, waste's physical composition, temperature, capacity of treatment, and insufficient resources have made tasks very difficult for administrative jurisdiction [24]. Many improper systems for the management of solid waste are working in Pakistan. Because of limited storage bins and improper management of solid waste, the efficiency of the collection of waste is very low [25]. Common practices are open burning and dumping. Due to improper disposal of solid waste, adverse environmental impacts are faced by inhabitants. In Pakistan, according to the Environmental Ministry, only 60% of solid waste is gathered properly. No city in Pakistan collects and disposes of solid waste properly [26].

3. Solid waste management problems in Pakistan

In Pakistan, solid waste management is a matter of huge concern because more than 5 million people die each year due to waste-related infections and diseases. Collectively, 20 million tons of solid waste are generated in Pakistan annually, and this is increasing at a rate of 2.4% with each passing year [27]. Karachi, one of the largest cities in the country, generates more than 16,000 tons of solid municipal waste daily. Major cities, including Lahore, Peshawar, and Islamabad, are dealing with enormous challenges in tackling urban waste issues [28]. Figure 1 shows some of the root factors for the worsening waste problem in Pakistan.

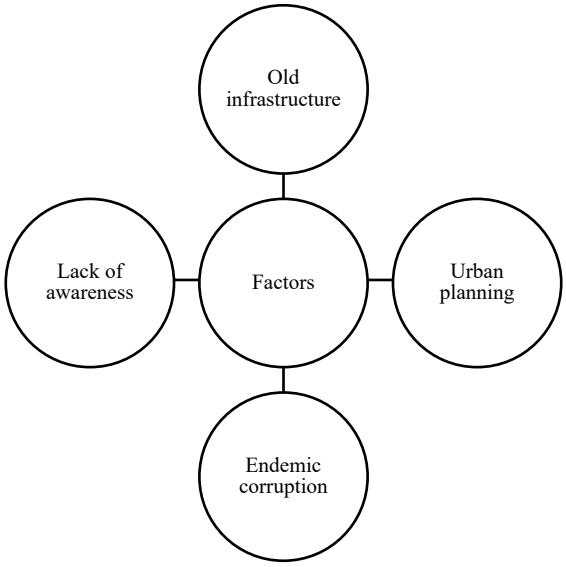

Figure 1. Key factors contributing to waste mismanagement

Being the 6th most populated country in the world, there are a lot of consumers, and that is why enormous waste is being produced. There are a wide variety of cultural, social, legislative, and economic problems in Pakistan. The amount of waste produced is far greater than the number of management facilities available, and hence mismanagement arises [29]. Major problems in the management of solid waste are:

- Lack of a proper waste collection system.
- Waste is thrown openly on streets and roads.
- No waste segregation system.
- Open burning of waste is common.
- No controlled sanitary landfills.
- Reducing the capacity of dumping sites.
- Lack of an adequate labor force to collect all garbage.
- Lack of management practice in recycling due to financial limitations.
- Lack of proper waste disposal vehicles.
- Poor implementation of environmental laws.
- No public participation on this issue.
- Lack of public awareness about the relationship between improper waste disposal and serious health and environmental problems.

Consequently, waste is continuously accumulating on canals, roadsides, and other common areas. In addition, open burning is common, which produces hazardous compounds, and nearby people get exposed to them, which threatens environmental and human health. Presently, few landfill sites are there, and among them, fewer are operating. Even Islamabad lacks a permanent landfill site [30]. Table 1 shows a comparative study to analyze solid waste management practices in different cities in Pakistan.

Table 1. A comparative study to analyze solid waste management practices in different cities of Pakistan

Title	City	Management	Reference
"Management of organic content in municipal solid waste - A case study of Lahore"	Faisalabad	Household waste is sorted out at the local level, while other solid waste in the city is not properly segregated.	
	Gujranwala	The collection of waste is done by the Tehsil Municipal Administration (TMA), whose sanitary workers collect waste from heaps, containers, and dustbins in morning and evening shifts. However, due to the limited capacity of the collection trolley, waste remains uncollected in small fractions. Furthermore, containers are poorly located in the city, despite the size of the population. That's why open heaps are common in the city.	[31]
	Lala Musa	When collected waste is transferred to a dumping site, it is scattered on roads because it remains uncovered during travel. Despite waste collection, poor management persists in the city.	
"Municipal solid waste management in Rawalpindi, Pakistan: Obstacles and prospects"	Rawalpindi	The waste collection capacity of the solid waste management (SWM) department is not sufficient to collect total municipal waste. Even if it operated at its fullest, it would only collect 61% of total solid waste. Consequently, a huge amount of waste can be seen untouched in the streets of Rawalpindi. In the rainy season, the situation becomes worse.	[32]
"Sustainable management of municipal solid waste under changing climate: A case study of Karachi, Pakistan"	Karachi	Recyclable waste is separated by waste pickers or even homeowners and is later sold at junk shops. Garbage is collected from door to door by waste pickers, who charge about Rs. 2000 (19 USD) per house per month. This waste is disposed of in huge containers, drains, and natural water streams, which results in the blockage of sewerage pipes. In the end, waste is transported to oceans with stormwater in the rainy season. Recyclable waste collected by scavengers is openly burned to recover valuable material. Despite two official landfill sites, Gond Pass and Jam Chakaro, the waste of the city is disposed of at eight other unauthorized places.	[33]
"An overview of housing conditions, characteristics and existing infrastructure of energy, water & waste systems in Quetta, Pakistan"	Quetta	Solid waste is collected from 40% of houses, and the rest use community waste bins, empty plots, or even the streets. Some people burn their waste, which turns into small fractions and spreads here and there. Smoke is produced during burning and is harmful to public health.	[16]
"Solid waste management practices under public and private sector in Lahore, Pakistan"	Lahore	Turkish companies provide shopping bags to residents to put their waste in. Filled bags are placed outside their houses and collected by workers in handcarts. After the completion of the contract, door-to-door waste collection service starts in Lahore.	[34]
"Solid waste management practices in Pakistan"	Lahore	Albayrak has been unsuccessful in collecting the whole city's waste for many reasons. That is why Koreywalas working under the Lahore waste management company are common and charge Rs. 200-300 per month. Once waste is dumped into containers, it is collected by vehicles like arm rolls, trolleys, tractors, and dumpers at the dumping site in Lahore. Moreover, sanitary workers sweep streets and roads. Lack of coordination results in mismanagement, and consequently, the city remains uncleaned.	[35]
"Solid waste management practices in Pakistan"	Bahawalpur	Sweepers at TMA collect waste from houses on donkeys and hand carts. The collected waste is transported to the dumping site. Bahawalpur Waste Management Company (BWMC) has now started servicing sanitary trucks and introduced a complaint helpline system to ensure fast and efficient waste collection operations. A new dumping site has been purchased. Presently, Bahawalpur is a safe and clean city due to BWMC.	[35]

It is important to evaluate per capita waste generation in different cities of Pakistan to point out which region is significantly generating waste in the overall country. The comparative study table provides literature on this, as shown in Table 2.

Table 2. Per capita waste production in different cities of Pakistan

Title	Year	City	Management	Reference
"Solid waste management practices under public and private sector in Lahore, Pakistan"	2016	Lahore	Lahore is the second-largest city in Pakistan in terms of population. In 2020, the population of this megacity was 12,642,000. The number is rising exponentially because the facilities are abundant. The greater the number of people, the greater the generation of MSW. The MSW of Lahore mainly comprises household waste, commercial waste, restaurant waste, and hospital waste. According to the Environment Protection Department (EPD), the MSW produced in Lahore is 2,090,620,633 kg/ year. Therefore, the per capita waste production is 0.612 kg/capita/day.	[34]
"Management of organic content in municipal solid waste - A case study of Lahore"	2015	Bahawalpur	Bahawalpur is among the largest cities in Pakistan, with a population of 408,395 according to the 1998 census. The average household size is 7.35 people. According to the estimate of the municipality, each person is responsible for ½ kg of solid waste each day. Out of that waste, 70% is lifted, while 30% remains unlifted.	[31]
"Municipal solid waste management in Rawalpindi, Pakistan: Obstacles and prospects"	2015	Rawalpindi	Per capita household income is one of the leading factors in the variance in the difference in waste consumption. Houses with lower incomes have a greater number of people (6.21 people) with an average waste production of 0.29 kg. On the other hand, high-income individuals, although a smaller number of people, produce 0.35 kg waste per head. Overall, the population of Rawalpindi was 1.77 million in 2016, and the average MSW generation rate was 0.21 kg per capita per day.	[32]
"An overview of Karachi solid waste disposal sites and environs"	2015	Karachi	Karachi is the largest city in Pakistan in terms of population. As per the data for 2021, the population of the city is 227,258,906. This large number of people produces more than 10,000 tons of solid waste daily. The per capita waste production of Karachi in 2016 was 0.57 kg/capita/day.	[36]
"Solid waste management issues in Hyderabad city"	2018	Hyderabad	Hyderabad is also the developing city of Pakistan, where urbanization is occurring rapidly. The population of Hyderabad is 2.99 million, with an average solid waste production rate per capita of 0.80 kg per day.	[37]
Influence of income level and seasons on quantity and composition of municipal solid waste: A case study of the capital city of Pakistan"	2017	Islamabad	Islamabad is the capital territory. The waste generation rate for high-, middle-, and low-income groups is 0.890, o.61, and 0.364 kg per capita. The overall rate of solid waste production per capita per day is 0.53 kg.	[38]
"Waste generation rate and composition analysis of solid waste in Gujranwala City Pakistan"	2017	Gujranwala	Gujranwala is a populated city in Pakistan, having a population of 2,027,001 according to the 2017 census. The waste generation rate has increased with the increase in population. The per capita solid waste generation rate in 2017 was 1.08 kg per day. For low-income houses, the rate is 0.33 kg/day while for high-income households, it is 0.46 kg/capita/day.	[39]

Gujranwala is one of the leading contributors to MSW. Karachi produces 9,900 tons per day, as per 2019 data. Lahore comes second in waste generation, with 7,510 tons per day, followed by Faisalabad, Rawalpindi, Hyderabad, Multan, Sargodha, Peshawar, and Quetta. Karachi is also a potential contributor to MSW. Karachi produces 9,900 tons per day, as per 2019 data. Lahore comes in second in waste generation, with 7,510 tons per day, followed by Faisalabad, Rawalpindi, Hyderabad, Multan, Gujranwala, Sargodha, Peshawar, and Quetta. Figure 2 shows per capita waste generation in different cities in Pakistan.

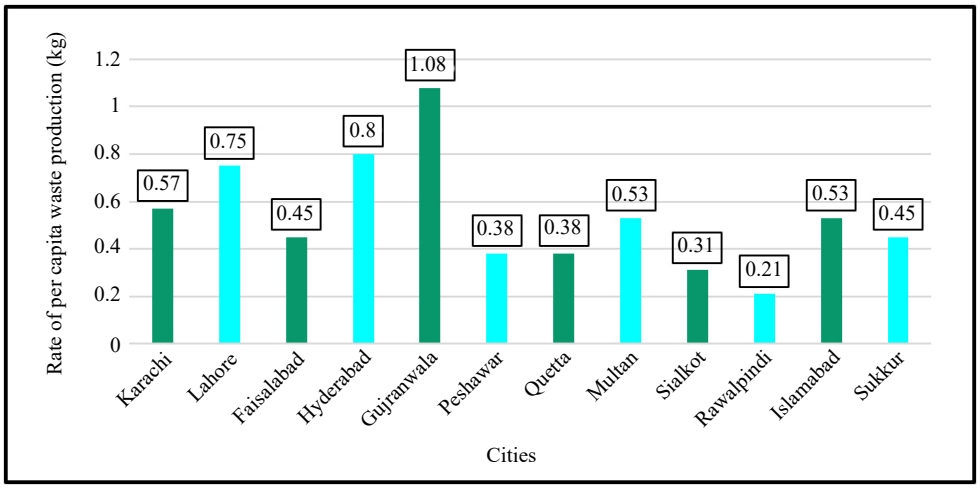

Figure 2. Per capita waste generation in different cities of Pakistan

4. Composition of solid waste

Solid waste is not properly classified in Pakistan. The composition of waste varies depending on the source. Some sectors that produce solid waste include residential, commercial, institutions, construction activities, and municipal services [40]. A broad category to separate the waste is divided into organic and inorganic. Organic waste contains all those materials that are biodegradable, while inorganic waste is all non-biodegradable stuff. Following us, the categories of solid waste fall under the categories of biodegradable and non-biodegradable material. Biodegradable waste material includes food waste, paper, cardboard, and wood. Non-biodegradable waste material comprises rubber, plastic, metal, glass, fabric, and batteries [4].

Unfortunately, there is no segregation process at the individual level to make the process of solid waste management easy. All of the waste material is collected and transported to the waste collection site. Only the hazardous waste — hospital waste — is collected and incinerated separately [5]. Since the population has increased, different materials have become available in markets to cope with the needs of the growing population. So, the composition of MSW varies greatly. According to a report from the United Nations Environmental Program on waste management in Pakistan, the following are the categories of solid waste as shown in Figure 3.

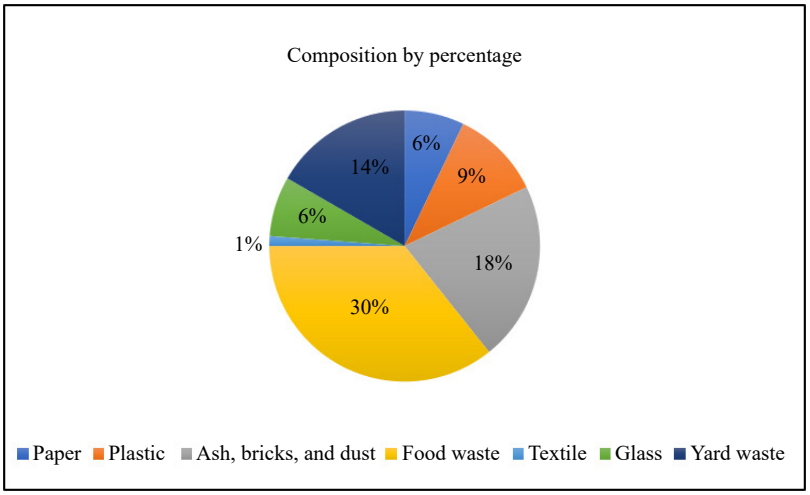

Figure 3. Percentage composition of waste categories in Pakistan

Food waste has the highest percentage — more than one quartile — followed by waste from ash, brick, and dust. Yard waste, cardboard, plastic, and metals are also on the list. The composition of MSW plays a key role in the whole process of MSW management. They are analyzing the waste composition to help authorities identify the proper segregation and treatment technique. Furthermore, it helps recover the valuable material from waste.

Out of 100% of waste, textiles account for 20%, rubber and plastic for 27%, paper and cardboard for 35%, wood for 7%, and leather for 4%–33% of waste material that is non-combustible, whereas 67% of solid waste material is combustible [6]. Another category is organic material, which is 64%, and inorganic material is 36%. Out of 36% of inorganic material, 92% is non-degradable, and only 8% of material is degradable. Karachi has the highest composition of biowaste, food waste, leaves, grass, rags, plastic, and textiles. This composition alters significantly in the case of Lahore, where plastic pollution accounts for a higher percentage of Multan city, food waste, stones, and leaves, and grass account for the largest percentage composition. Variation in the composition of solid waste material is due to different lifestyles, provision of facilities, area type — either urban or rural area — and income per capita [23, 41].

5. Impact of poor SWM on water quality

Uncollected solid waste, especially from streets and roadsides, obstructs the runoff of storm water, which results in the formation of stagnant water bodies that are breeding sites for diseases like diarrhea, malaria, cholera, and chest pain. However, direct dumping of waste into river water, lakes, and seas results in the accumulation of toxic compounds that enter the food chain through animals and plants relying on it. Higher levels of heavy metals and organic and inorganic pollutants have already been found in the surface as well as groundwater, which is located in the vicinity of landfills. This means that the leachate of waste percolates into the natural water system [22].

The leachate becomes concentrated as it seeps deeper into the landfill and becomes a light brown to black color with an extremely harmful odor. This concentrated leachate has a high polluting potential due to the presence of organic pollutants and high levels of ammonium nitrate/nitrite. Once this liquid enters groundwater or any other aquatic environment, it has acute and chronic impacts. Chemicals in leachate not only penetrate soil but also reach closely located natural water bodies. These chemicals alter the chemistry of water, which destroys the entire ecosystem, for example, through spawn decay and fish habitat destruction [42]. Toxic metals can lead to their bioaccumulation and consequently affect human beings.

Table 3 shows a comparative study to analyze the characteristics of water quality after being affected by poor solid waste management practices. A water pollutant is a physical or chemical substance present in higher concentrations that is capable of harming living organisms. The presence of chemical elements such as manganese, copper, lead, phosphate, cadmium, and nitrate makes drinking water highly hazardous. Groundwater, as a public health concern, should be free from chemical, biological, and physical pollutants. People living in and near dumping sites mainly depend on groundwater for drinking and other purposes. Health risk increases as the distance between waste dumping or landfill sites and the public community decreases because waste from hospitals, municipalities, poultry, and many other places is being dumped there, and leakage from these sites and favorable conditions give rise to microbial and pathogenic growth [22]. Table 4 shows rules and regulations in Pakistan related to environmental protection.

Table 3. A comparative study to analyze characteristics of water quality after being affected by poor solid waste management practices

Title	City	Effects of poor solid waste management on water resources	Parameters						Reference
			pH	Turbidity	TDS	Metal & non-metals	Total hardness	Total coliform	
				NTU	mg/l	mg/l	mg/l		
"Effects of solid waste on the heavy metal composition of soil and water at Nathiagali-Abbottabad"	Nathia-Gali	Water samples and tap water collected near the dumping site were found to be contaminated with coliform, and according to the WHO, there should be no coliform in 100 ml of water, while the pH was also below the WHO standard, i.e., 6.5-8.5.	6.11	-------	290	-------	-------	> 300 in 100 ml water	[43]
"An overview of Karachi solid waste disposal sites and environs"	Karachi	Surface water near Gond Pass (landfill site) was found to be contaminated and not good for drinking or agricultural purposes.	7.6	--------	3,672	Na = 968.6 K = 48	Ca = 280 Mg = 24	-------	[36]
"A case study of groundwater contamination due to open dumping of municipal solid waste in Faisalabad"	Faisalabad	Open dumping has resulted in the contamination of groundwater with leachate.	8.2	3.0	1,403	As = 94	187	+ve	[44]
"Impacts of landfill sites on groundwater quality in Lahore, Pakistan"	Lahore	Due to the lack of implementation of environmental laws, the groundwater aquifer is getting polluted with time due to the penetration of leachate by Mahmood Booti (the dumping site).	7.6	1.5	512.1	Cl = 72.0	Ca = 52.8 Mg = 30.7	+ve	[45]
"Municipal solid waste and its relation with groundwater contamination in Multan, Pakistan"	Multan	Landfill leachate has changed the chemistry of groundwater, and it needs treatment before use.	8.0	1.07	347.1	As = 96 Cl = 35 Fe = 0.02	142.0	---------	[46]
"Impact of municipal solid waste on groundwater quality in Jhang city, Pakistan"	Jhang	A high concentration of several parameters was present in groundwater near dumping sites, which indicates poor water quality and is unfit for drinking.	7.8	5.97	1,079	Cl = 218.4 As = 0.004	600	--------	[47]
"Assessment of municipal solid waste landfilling practices on groundwater quality and associated health risks: A case study of Mardan-Pakistan"	Mardan	MSW has contaminated groundwater quality, and leveling of land due to MSW is unsafe.	8.2	8.96	1,206	Na = 276 K = 7.6	573	--------	[48]

Table 4. Rules, regulations, and laws related to waste in Pakistan

Laws	Year	Scope
Pakistan Environmental Protection Act (PEPA)	1997	Environmental protection, such as water, air, etc. Dealing with hazardous waste, such as organic and inorganic matters in hospitals, agriculture, and industries. All social conditions that affect the life of the community.
Rules for hazardous substances	2003	Plan of waste management concerning toxic waste.
Rules for management of hospital waste	2005	Holding the establishment of healthcare for the management of waste. Duties and responsibilities are held, such as planning, segregating, collecting, storing, and reusing.
National Environmental Quality Standard (NEQ)	2000	Samples are tested and analyzed by factories to ensure that NEQs are met.
Ordinance of Punjab Local Government (PLGO)	2001	Industries self-monitor and reporting. Collecting, transporting, and disposing of waste.
SWM of Lahore By-Laws	2005	Duties and responsibilities are set, such as collecting, removing, and prohibiting the refusal of deposition, etc., in local places.

6. Current projects and activities

According to the United Nations Environment Programme (UNEP), more or less, there are six recent plans and activities taking place in Pakistan towards an efficient waste management system. The following are the current projects:

1. With the support of the Japan International Corporation Agency (JICA), solid waste management guidelines have been prepared.
2. Conversion of agricultural waste to efficient energy is a project of UNEP.
3. North Sindh Urban Services Corporation (NSUSC) Limited is assisting the Sindh government in the design and treatment of water supply and solid waste management.
4. Urban Unit Punjab is conducting awareness sessions and seminars on sanitation, wastewater, SWM, etc.
5. Lahore Compost Limited is dealing with organic waste with the cooperation of the city district government of Lahore (CDGL).
6. Small-scale solid waste collection and recycling are being carried out by several non-governmental organizations (NGOs).

7. Efficient practices in other countries/solutions

The amount of solid waste generated differs from country to country. An increase in urbanization affects waste generation rates. The management of solid waste is very important, and due to rapid urbanization, it fails. The main environmental problem is the management of solid waste because of its impacts on the environment and people. However, the proper management of solid waste protects the environment as well as the health of citizens. There is a significant difference in waste generation rates between developing and developed countries [49-50].

7.1 *Waste collection*

The basic element of solid waste management is the collection of waste. In Mexico, due to the rise in solid waste production, the demand for the services of solid waste collection also increases. The government executes the services of solid waste collection, but in some areas, waste is not collected. So, the people of these areas can either either burn their waste it or throw it in open dumping sites. As a result, the service of solid waste collection is now done by private contractors who are doing their duty efficiently, and solid waste collection is managed properly [51].

Solid waste collection starts with waste bins that have material that is no longer useful. Around the globe, many kinds of solid waste collection are followed. The waste is collected from door to door from the houses or is collected

from a specific point in the community [50]. There are mainly two kinds of waste collection methods. In the mixed collection method, all the domestic waste is mixed, which decreases the chance of recycling. In a separate collection method, there is categorization of the elements of solid waste, so there is a chance of recycling. This also decreases the amount of waste for dumping [52].

7.2 *Waste dumping on streets*

Prohibited dumping of solid waste on the streets is becoming a serious urban issue globally. Citizens are dumping waste on street corners, footpaths, or on roads instead of throwing it in appropriate waste bins. Such banned dumping of solid waste poses a threat to the health of people and also degrades the quality of the environment. To improve waste management, there is a need for effective systems that ensure high-quality cleanliness in the community [53].

7.3 *Recycling and reuse of waste*

Many environmental complications, such as ecosystem damage, natural resource depletion, environmental contamination, and damage to human health, are caused by ineffective and unsuitable solid waste treatment. These problems can be lessened if solid waste can be recycled or reused [54]. Some scrap material in the solid waste can be recycled, and new products will be formed. The recyclable material is collected, treated, processed, and then used in the formation of a new product. Energy is saved and pollution will be avoided by adopting the recycling method. Similarly, some materials can be reused, which reduces the natural resource intake and amount of waste [52].

7.4 *Incineration*

Incineration leads to the burning of waste products, which results in ash production and air pollution. For the treatment of waste, the incineration method is used. This method turns the waste into ash and is also known as heat treatment. During the process of incineration, ash is produced as a by-product and is of two kinds. One is bottom ash, and the other is fly ash. The bottom ash is disposed of in landfills and can be utilized for clinker making as a raw material. The bottom ash is also used in the construction of roads [55].

There are many applications for the fly ash produced by incinerator plants. But bottom ash utilization is less, and if it is disposed of in landfills, then it will cause many other environmental issues. The bottom ash is utilized in the creation of bricks but is not consumed directly because of the high quantity of silica present in it. The bricks that have bottom ash in them are effective and are used in the construction industry [56]. The volume of solid waste can be decreased with the help of the incineration method, and this keeps the environment safe from hazardous waste. However, it is not utilized for energy recovery [1].

7.5 *Sanitary landfills*

The disposal of MSW through landfills is a very cost-effective and simple method, but there are some possible environmental hazards associated with landfills [49]. Around the world, the main dumping facilities for waste are landfill sites. Most of the MSW is disposed of in landfills, so it becomes a source of pollution. The economical solid waste management option is landfill sites [57].

Proper mechanisms and legislation must be followed and prepared for the disposal and handling of waste. Out of all the possible ways of waste management, sanitary landfills are the most commonly used method all over the world because they are designed especially for the dumping of non-hazardous and solid waste. Sanitary landfills also prevent environmental risks and health problems [15]. Usually, the landfill rate in developed countries is higher. Through sanitary landfills, China disposed of about 120 million tons of MSW [58].

The most practical way to disposal of solid waste is by dumping it in sanitary landfills. In developed countries, GIS is used for the selection of landfill sites so that landfills have less impact on the environment. Many health issues are related to solid waste collection sites. Similarly, health issues are also related to sanitary landfills, so proper site selection of landfills is very important [59].

Poor solid waste management leads to the contamination of water, soil, and air due to inadequate collection

systems and their ineffective disposal. There are masses of waste in areas where waste is not collected, and due to their inappropriate disposal, it affects the community and the health of citizens. Toxic and hazardous chemicals affect the quality of soil and groundwater. Hazardous waste also releases many toxic gases into the environment, which is causing air pollution [60].

7.6 *Energy from solid waste*

Sustainable approaches are suggested for solid waste management in China, which can recover energy from MSW. During the energy recovery from waste, harmful impacts on the environment need to be controlled, which is a great challenge. Some new heat treatment technologies are proposed for recovering energy from solid waste. These technologies minimally impact the environment and recover more energy. Another technique, biomass gasification, can recover energy from solid waste and reduce the impact and emissions of gases [53]. Additionally, waste-to-energy (WTE) technologies are becoming more and more popular around the world as a sustainable substitute for conventional energy sources. Developed countries have effectively included WTE facilities into their waste management initiatives, lowering their dependency on fossil fuels and minimizing their negative effects on the environment. Pakistan can learn from these countries' experiences executing WTE initiatives, including the difficulties experienced and the methods used to overcome them. Furthermore, an examination of WTE technological alternatives across national boundaries offers useful knowledge about the viability and effectiveness of diverse strategies [22]. Pakistan will be able to develop specific approaches for efficient MSW management and energy recovery by taking ideas from the experiences of others. Pakistan can optimize waste treatment systems, improve energy recovery, and support global efforts towards sustainable development by utilizing international experience and best practices [61].

7.7 *Treatment*

MSW treatment is a global issue, and Pakistan can benefit from the innovative techniques being implemented by other countries. Numerous studies on MSW management have been carried out all around the world, providing valuable information and practical experiences that might direct Pakistan's waste treatment strategy [62]. By utilizing techniques like pyrolysis, gasification, and incineration, countries including the United States, China, Europe, and others have made significant improvements in the thermal processing of MSW. These countries have created advanced waste-to-energy facilities that use MSW as a renewable energy source and have useful energy efficiency levels. Pakistan may improve its own waste management infrastructure by learning from the modern technologies and operating procedures used in these countries [63].

8. Development in future

For Pakistan's future to be sustainable, the development of MSW management is crucial. Future MSW management development in Pakistan should give priority to a number of important areas in order to solve present issues and meet changing demands. Firstly, better trash collection and segregation systems are urgently required. Improving the quality of recyclable materials and lessening the load on landfills can be achieved by putting in place effective collection systems and educating the public about waste separation at the point of generation [64]. In addition, increasing resource recovery and reducing environmental impacts require investing in contemporary waste treatment technologies. Utilizing advanced techniques like anaerobic digestion, composting, and waste-to-energy systems can help recover value from MSW while reducing its volume and toxic emissions. These technologies also offer chances to produce renewable energy, which will help Pakistan become more resilient to climate change and maintain energy security [40].

Furthermore, to guarantee the efficient management of waste streams at all levels, from collection to disposal, integrated MSW management infrastructure development is necessary. This involves the establishment of sanitary landfills with gas collection and leachate systems, composting plants, and recycling facilities in order to reduce health risks and pollute the environment [23]. Moreover, implementing sustainable MSW management targets depends on promoting cooperation between public institutions, business sector partners, and regional communities. Community engagement programs can encourage civic engagement and behavioral change in waste management practices, while

public-private partnerships can help mobilize resources, expertise, and creative solutions [26]. Future developments in MSW management in Pakistan should align with international best practices by giving priority to the concepts of the circular economy. These principles are needed to reduce waste generation, optimize resource efficiency, and promote material reuse and recycling. In addition to helping Pakistan's immediate waste management issues, a complete approach can support long-term environmental sustainability, economic expansion, and improvements in society [6].

9. Recommendations

It is recommended to take several key actions and strategies to improve solid waste management practices in Pakistan. Firstly, proper rules and regulation solely for solid waste management should be developed. Then the enforcement of existing laws and regulations related to waste management and environmental protection should be ensured for compliance and accountability among stakeholders. Additionally, promoting public awareness and community engagement programs could foster behavioral changes towards responsible waste disposal and recycling practices. Investing in modern waste treatment technologies, such as anaerobic digestion, composting, and waste-to-energy systems, may be proposed to enhance resource recovery and reduce environmental pollution. Moreover, the development of partnerships between government agencies, private sector entities, and civil society organizations will mobilize resources, expertise, and innovation for effective waste management solutions. Emphasizing the principles of the circular economy, including waste reduction, reuse, and recycling, is likely to be advocated to promote sustainable development and environmental resilience.

10. Conclusion

In conclusion, Pakistan faces significant challenges in solid waste management, leading to detrimental impacts on the environment and public health. The escalating rates of waste generation, coupled with inadequate waste collection systems, improper disposal practices, and a lack of public awareness, exacerbate these challenges. The composition of solid waste varies across different regions, reflecting diverse lifestyles and consumption patterns. Poor solid waste management not only pollutes water resources but also poses serious health risks, including the spread of diseases and contamination of groundwater. Through a review of laws, regulations, current projects, and international practices, it's evident that Pakistan is actively engaged in addressing its waste management challenges. The legal framework, including laws such as the PEPA and ordinances like the PLGO, provides a foundation for regulating and managing various aspects of waste, from hazardous materials to healthcare waste. Additionally, the establishment of national environmental quality standards underscores Pakistan's commitment to ensuring that industrial activities adhere to environmental regulations. Furthermore, insights from efficient practices and solutions implemented in other countries offer valuable lessons for Pakistan. From waste collection methods to energy recovery techniques, there is a wealth of knowledge that can inform and improve Pakistan's waste management efforts. Moving forward, it is imperative for Pakistan to continue implementing and refining its waste management strategies, leveraging both domestic expertise and international best practices. By adopting innovative technologies, improving infrastructure, and strengthening regulatory frameworks, Pakistan can mitigate the environmental and health risks associated with waste while also harnessing its potential as a resource for energy and recycling. Ultimately, effective waste management is essential for promoting sustainable development and safeguarding the well-being of present and future generations in Pakistan.

Declaration of competing interest

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

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