Journal of Pollution Monitoring, Evaluation Studies and Control
J Pollut Monit Eval Stud Contr, 3(1): 47-58 (2024)
DOI: https://doi.org/10.54117/jpmesc.v3i1.6

Groundwater Implications of Water Pollution in Pakistan: A Review on Sustainable Environmental Management of Solid Waste

Muhammad Asif[1], Mahmood Laghari[1], Kishan Chand Mukwana[2,*], Siraj Hussain[3], Imran Bashir[4], Mohammad Siddique[5], Minza Igunda Selele[6], Mohammed Abdulrahim[7], Zidani Danladi Ahmed[7], Mohammad Hasnain[3], Abdulhalim Musa Abubakar[8]

[1]Department of Energy and Environment, Faculty of Agricultural Engineering (FAE), Hyderabad, Sindh Agriculture University Tandojam, Pakistan
[2]Faculty of Environmental Engineering, QUAID-E-AWAM University of Engineering, Science & Technology (QUEST), Sakrand Road, Nawabshah, Sindh, Pakistan
[3]Department of Geological Engineering, Faculty of Engineering & Architecture, Balochistan University of Information Technology Engineering & Management Sciences (BUITEMS), Quetta, Balochistan, Pakistan
[4]School of Computing, Engineering & Digital Technologies, Teesside University (University of Bristol; School of Geographical Sciences), Middlesbrough TSI 3BX, UK
[5]Department of Chemical Engineering, Balochistan University of Information Technology Engineering & Management Sciences (BUITEMS), Quetta, Pakistan
[6]Department of Environmental Science and Technology, School of Engineering and Environmental Studies, Ardhi University, P.O. Box 35176 Dar es Salaam-Tanzania
[7]Department of Chemical Engineering, Faculty of Engineering, University of Maiduguri (UNIMAID), PMB 1069, Bama Road, Maiduguri, Borno State, Nigeria
[8]Department of Chemical Engineering, Faculty of Engineering, Modibbo Adama University, PMB. 2076, Yola, Adamawa State, Nigeria

Correspondence: kcmukwana@quest.edu.pk; Phone: 0244-9370381-85

Abstract

Water pollution is a significant environmental challenge in Pakistan, with direct implications for both public health and the economy and finding sustainable management solutions are paramount to the wellbeing of the country. This review examines the sources and effects of water contamination, particularly focusing on groundwater, which is vital for the country's population. Various pollutants, including heavy metals, pathogens, and chemical effluents, have rendered a large portion of Pakistan's surface and groundwater unsafe for human consumption. The review underscores the role of industrialization, outdated waste management practices, and rapid urbanization as major contributors to this crisis. Addressing these challenges requires the adoption of sustainable waste management practices, with a focus on the 3Rs—Reduce, Reuse, and Recycle. Furthermore, community engagement and awareness campaigns are crucial to fostering a culture of environmental responsibility. It was realized that improving solid waste management, promoting sustainable practices, and implementing stricter regulations, is capable of mitigating the harmful effects of water pollution. Most significantly, the study offers valuable insights for policymakers, environmental engineers, and researchers aiming to develop more sustainable water management solutions in Pakistan. Innovative approaches, such as the use of nanomaterial's for pollutant removal and advanced wastewater treatment technologies, are proposed as viable solutions for enhancing water quality and protecting groundwater resources.

***Keywords**: Contaminants; Solid waste; Pollutants in Pakistan; Quality of water; Groundwater*

Article History
Received: 01 Dec 2023
Accepted: 23 May 2024
Published: 16 Oct 2024

Scan QR code to view

How to cite this paper: Asif M, Laghari M, Mukwana KC, Hussain S, Bashir I, Siddique M, Selele MI, Abdulrahim M, Ahmed ZD, Hasnain M, Abubakar AM (2024). Groundwater Implications of Water Pollution in Pakistan: A Review on Sustainable Environmental Management of Solid Waste. *Journal of Pollution Monitoring, Evaluation Studies and Control*, *3*(1), 47–58. https://doi.org/10.54117/jpmesc.v3i1.6.

1. Introduction

Urbanization and industry are major environmental difficulties that are contributing to severe water contamination issues. Industrialization is a prerequisite for economic progress in any nation, and sewage from these industries is the primary cause of water contamination (Azizullah *et al.*, 2011). Industries in developing nations have been using antiquated industrial machinery, which produces hazardous solid waste and effluents. There are produced hazardous wastes and effluents that are untreated and released into surrounding water sources (Akhtar & Zhonghua, 2013; Salam *et al.*, 2021). Freshwater makes up 3% of the planet's total water. The amount of this freshwater that is fit for human consumption is extremely little (0.01%). Unfortunately, even this small amount of fresh water is under tremendous stress as a result of urbanization, rapid population growth, and unsustainable water use in industry and agriculture (Paneerselvam *et al*., 2023). In contrast to the exponential rise in global population, a UNO assessment indicates that freshwater resources are becoming increasingly scarce. Over the next twenty years, there will be significant water shortage threats in several nations in Africa, the Middle East, and South Asia. The problem is exacerbated in impoverished nations because of poor administration, a lack of knowledge, and financial limitations (Bello *et al*., 2022). Pakistan has significant problems with water contamination with other emerging nations around the globe. The country is thought to be water-stressed and is expected to experience a water crisis soon given that its current water supplies have almost completely run out (Saba *et al*., 2022). In the country, water precipitation is occurring at a slower rate than evaporation. As a result, the water level in its groundwater, rivers, and lakes keeps dropping. Two elements that make the issue worse are protracted droughts and a lack of new water reservoir building. There is a serious water shortage in practically every region of the country as a result of this decline in water supply and the ensuing rise in demand (Arenibafo, 2023). Water availability per person in the country declined from 5000 m^3 in 1951 to 1100 m^3 yearly. By 2010, there may be fewer than 1000 m^3 of water available per person as the country's population continues to increase exponentially without any new water resources being produced. The average annual water availability per person in areas beyond the Indus basin, which is now less than 1000 m^3, could get worse (Pradere *et al*., 2022). People are forced to consume brackish water in some locations due to a lack of fresh water, such as the drought-affected parts of Sindh Province.

The subsurface aquifers in Baluchistan Province are disappearing at a pace of 2.15 m per year as well as will go dry in 14 years. The combination of falling supply and increased demand in several sectors has had a negative influence on water quality and created a serious problem of water contamination (Rimantho *et al*., 2023). It is believed that the majority of the country's rivers, lakes, and groundwater aquifers have water that is unfit for human consumption. Conflicting information is presented in several reports about the country's public access to as well as the quality of water for drinking. National figures show that 56% of individuals have access to clean drinking water. According to international standards, just 25.61 percent of Pakistan's population (urban 30% and rural 23.5%) has access to safe and potable water (Fidelis *et al*., 2023). Most of the public drinking water that towns provide is tainted with dangerous chemicals or contagious microbes. Due to numerous anthropogenic activities, drinking water in densely populated cities like Quetta, Karachi, Lahore, Rawalpindi, Peshawar, and Faisalabad is contaminated and unfit for human consumption (Naveenkumar *et al*., 2023). In the country's capital, Islamabad, the situation is considerably worse. Water samples from Quetta, Hyderabad, Rawalpindi, and Islamabad were all found to be contaminated with total coliforms and fecal coliforms in 94% and 34% of the samples, respectively. The Pakistan Council of Research in Water Resources (PCRWR) investigated the quality of the country's water in depth in 23 important cities scattered throughout the four provinces. In the United States, 84–89% of water sources have water quality below what is considered acceptable for human consumption (Peng *et al*., 2023). People were obliged to purchase an expensive substitute in the form of commercially available mineral water packaged in plastic bottles because the drinking water that was readily available to the general populace was of low quality. However, due to weak regulation of processing industries, even commercially available water is not safe (Wang *et al*., 2023). Another significant obstacle to utilizing such a solution is the public's constrained purchasing power. As a result, the majority of Pakistan's population is exposed to dirty and contaminated water, which can result in a variety of water-related health issues. The fact that Pakistan's drinking water supplies are becoming increasingly polluted, with detrimental effects on the environment and public health, is a serious cause for concern (Kolawole *et al*., 2023).

This overview focuses on the main pollutants and their detrimental effects on human health to shed light on the problem of water pollution in Pakistan. Although the huge majority of Pakistan's population (about 70%) depends on ground aquifers for water, surface water is still a significant source for other domestic and drinking requirements (Bawab *et al*., 2021). To summarize the main contaminants and the quantities in groundwater as well as surface separately we focus on both groundwater and surface water sources. We also list the numerous health issues related to water that have been documented across the nation. Their presence in people's drinking water could be harmful to their health (Salim *et al*., 2023). Additionally, radionuclides and hazardous metals like arsenic are removed from water using nanomaterials. Aside from human activities, other natural factors such as animal waste, volcanic eruptions, storm, and flood sediment, and algae blooms predominantly brought on by aquaculture can also cause water pollution (Figure 1). replacing lead pipes, as was done, for instance, in Flint, Michigan, in the United States, and modernizing and upgrading drinking water and wastewater treatment facilities (Peng *et al*., 2023). Known as "forever chemicals," these substances are dispersed into the environment during industrial production and pose a risk to human health when they contaminate drinking water.

2. Major pollutants

Numerous chemicals are categorized into various classes and considered active water pollutants. Inorganic pollutants (acids, salts, and toxic metals), pathogens (bacteria, viruses, and protozoa), anions and cations (phosphate, nitrate, sulfate, Ca^{2+}, Mg^{2+}, and F^-), and water-soluble radioactive substances are the most prevalent forms of pollutants (Jeong *et al*., 2023). Additionally, it is believed that organic contaminants like oil and pesticides endanger the integrity of the water. Both people and other animals in the ecosystem will be severely harmed if the concentration of any of these compounds exceeds a set threshold. Water quality in Pakistan is seriously threatened by bacterial contamination, pesticides, harmful metals like arsenic, iron, cadmium, and nickel, and in some locations, nitrates and fluorides (Obi *et al*., 2016).

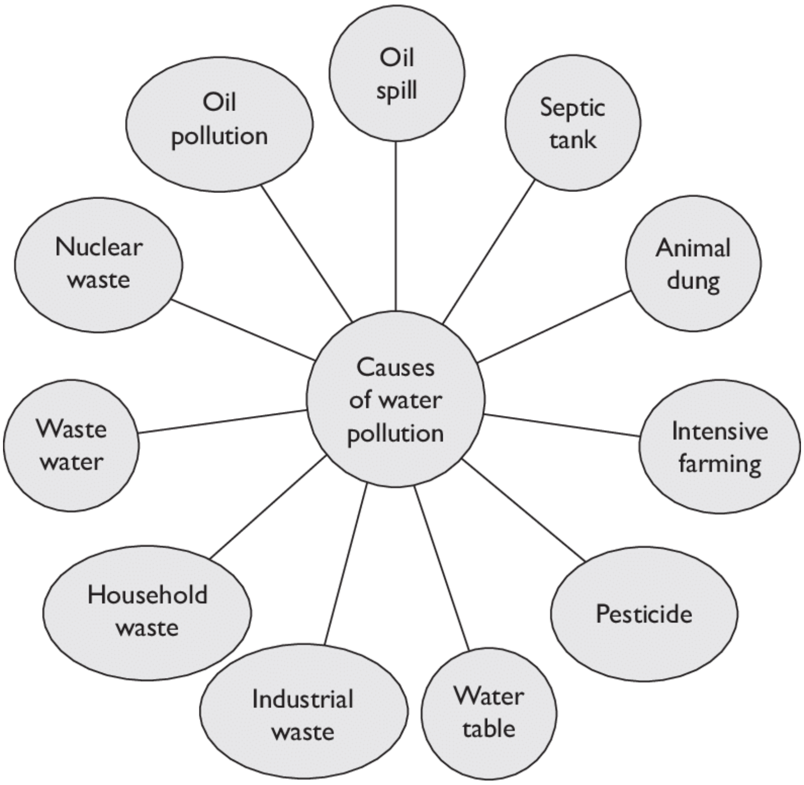

Figure 1: Major causes of water pollution
(Koul *et al*., 2022)

Table 1. Overall Water Quality Situation of Different Cities and Contamination

S/No.	City	Total No. of Samples	Safe Sample		Unsafe Sample		Types of Contamination
			No.	% Age	No.	% Age	
1.	Quetta	10	3	23	11	78	Bacteriological, Ca, Mg, Fe, Al
2.	Khuzdar	9	1	9	10	90	As, Fe, NO_3
3.	Loralai	8	1	9	10	90	Ca, Al
4.	Hyderabad	14	0	0	14	99	Bacteriological, Ca, Mg, Fe, Al
5.	Karachi	24	2	7	25	94	Ni, NO_3, Bacteriological, Ca, Mg, Fe, Al
6.	Sukkur	11	1	8	10	93	Ni, NO_3, Bacteriological, Ca, Mg, Fe, Al

Source: Saravanan *et al*. (2022)

2.1. Contamination with bacteria

In different places, water is typically subjected to microbial analysis to find fecal coliforms. Coliforms are abundant as well as harmless to the people and environment, but their presence is utilized as a sign that the water is contaminated with bacteria and germs that might cause disease. Fecal coliforms and E. coli are additional signs that water has been contaminated by humans and animals (Alam & Qiao, 2019). According to the WHO standard for public drinking water, there must be 0 counts/100 mL of water or no total or fecal coliforms (WHO, 1993). The most important potential problem with Pakistan's drinking water has been recognized as bacteriological contamination (Meena *et al*., 2023). Numerous studies have found significant bacterial contamination of the nation's drinking water. Many of the documented bacterial species are also very dangerous to human health through water supplies like rivers, lakes, and underground aquifers are incredibly contaminated with germs in the majority of the country's regions (Singh *et al*., 2022). Total coliform and, in some cases, fecal coliform were discovered in Quetta, Hyderabad samples from the water distribution networks and even at treatment facilities. Another study carried out in the same city found that 90 (100%) of water samples taken from the main reservoir, distribution lines, and consumer taps contained total coliforms and fecal coliforms (Morin-Crini *et al*., 2022). Other significant cities around the nation, such as Quetta, Hyderabad, Lahore, and Karachi, are not much different from the current conditions. According to studies, the drinking water in each of these cities was tainted with bacteria. In a different study carried out in significant cities around the nation, total coliforms, and E. coli were found in 100% of surface water samples, but in Table 1, they were only found in 65% and 35% of groundwater samples, respectively (Abu-Salama, 2007).

3. Generation and Processing of Solid Garbage

Because of the complexity of many garbage types, including municipal, commercial, industrial, agricultural, and hospital waste, protecting natural resources like groundwater from the dangers of created toxic leachate, which is particularly dangerous for the general public, can be difficult. The composition of the leachate, its volume, and the distance from the pumping well are the three main criteria that determine the amount of hazard (Roy *et al*., 2022). The disposal sites in and around Lahore are traditional, outdated, hazardous, and unplanned. Urban sprawl and fast industrialization in the city are major factors in the production of a vast volume of solid garbage (Pal & Bhatia, 2022).

In Hyderabad, as in many other cities in Pakistan, solid waste management has been a significant challenge. The city generates a substantial amount of solid waste from households, commercial establishments, and industrial sources. The waste includes organic and inorganic materials, plastics, paper, glass, and more. The waste management process typically involves several steps. Municipal workers or private contractors collect waste from households and businesses using trucks and other vehicles. The waste is often segregated into different categories at this stage. Second stage is segregation, where waste is sorted into categories such as organic waste, recyclable materials, and non-recyclable waste. This step may take place at waste collection points or a centralized facility (Altowayti *et al*., 2022). Next is disposal, where the garbage is disposed of in a waste treatment plant or a landfill. The landfill site is frequently utilized for rubbish disposal in Hyderabad. Informal recycling often takes place, where waste pickers collect recyclable materials such as plastic bottles, paper, and metal from the waste stream. Some formal recycling efforts may also be in place.

Quetta, the capital city of Balochistan province in Pakistan, faces similar challenges in solid waste management. The waste generation process and management steps are somewhat comparable to those in Hyderabad (Kulkarni, 2020). Both Hyderabad and Quetta face challenges in solid waste management, including inadequate infrastructure, lack of proper waste disposal facilities, limited recycling initiatives, and public awareness issues. These challenges contribute to environmental pollution, health hazards, and aesthetic concerns (Figure 2). Efforts have been made by local authorities and non-governmental organizations to improve waste management practices, promote recycling, and raise public awareness about responsible waste disposal. However, progress has often been slow due to various factors, including financial constraints and administrative hurdles (Kehrein *et al*., 2020). For the most up-to-date information on solid waste management in Hyderabad and Quetta. We recommend checking with local government agencies, environmental organizations, or recent news sources.

3.1. Composting

The decomposition of organic materials into compost, a nutrient-rich soil supplement, is a sustainable and environmentally favorable process known as composting. This procedure decreases greenhouse gas emissions, diverts organic waste from landfills, and creates a useful product that can enhance the fertility and health of the soil (Hossain *et al*., 2020). During composting, organic materials such as kitchen scraps (vegetable peels, fruit cores, coffee grounds), yard waste (leaves, grass clippings), and sometimes paper products (unbleached paper towels, newspaper) are collected separately from non-organic waste. This can be done at the household level or through community composting programs. The collected organic materials are usually placed in a compost bin or pile. It is important to balance the carbon (brown) and nitrogen (green) materials to facilitate decomposition. Paper, straw, and leaves are nitrogen-rich materials, whereas grass clippings and food waste are carbon-rich ones; which can be used.

Figure 2: Generation and processing of solid waste recovery
(Gautam & Agrawal, 2021)

Regular turning or mixing of the compost pile helps aerate it, providing oxygen that speeds up decomposition. Maintaining the right moisture level is also crucial – the compost should be damp but not soggy (Nanda & Berruti, 2020). Over time, microorganisms such as bacteria, fungi, and worms break down the organic materials. This process generates heat as a byproduct. The internal temperature of a well-functioning compost pile can rise significantly. Composting can take several weeks to several months, depending on the conditions and materials. When the compost is fully decomposed, it becomes a dark, crumbly, and earthy-smelling material. The final compost can be added to the garden soil as a soil amendment to enhance it, increase water retention, and give plants vital nutrients. Additionally, it can be applied to agriculture and landscaping.

3.1.1. Composting Benefits

By diverting organic waste from landfills, composting lowers the amount of waste that must be disposed of there (Figure 3). Compost adds organic matter to the soil, enhancing its structure, water-holding capacity, and nutrient content. It is established that proper composting helps reduce methane emissions from landfills, a potent greenhouse gas. Composting is known to close the nutrient loop by returning organic matter to the soil, reducing the need for synthetic fertilizers. Reducing the amount of waste delivered to landfills can help municipalities and individuals save money on waste disposal costs (Rosemarin *et al*., 2020). Both Hyderabad and Quetta, like many other cities, could benefit from implementing effective composting programs as part of their waste management strategies. Composting can be done on various scales, from small-scale backyard composting to larger municipal composting facilities. It's essential to provide education and infrastructure to encourage participation and ensure successful composting practices (Jakimiuk, 2022).

3.2. Incineration

A waste management technique called incineration involves carefully directing the burning of solid trash at high temperatures. Reduced waste volume, elimination or greatly reduced danger, and energy production through combustion are the main goals of incineration (Lin *et al*., 2022). Before incineration, solid waste is collected and transported to an incineration facility. Before incineration, the waste may undergo some preparation, such as sorting to remove recyclable materials and hazardous waste. The waste is burned in a controlled environment at higher temperatures, typically ranging from 850 to 1,200℃ (1,562 to 2,192°F). During combustion, organic materials are broken down into gases and ash. The heat generated during the process can be harnessed to produce steam, which may be used to generate electricity. The gases produced during incineration contain pollutants, including particulates, heavy metals (e.g., Cu and Zn), and potentially harmful chemicals. Incineration facilities are outfitted with cutting-edge pollution control technologies like scrubbers, filters, and electrostatic precipitators to absorb and treat these pollutants before they are released into the air to reduce the negative effects on the environment (Liu *et al*., 2020). Energy recovery is one of the principal advantages of incineration. Steam can be produced using the heat from the combustion process, which in turn drives turbines connected to generators. This electricity can be used to power the incineration facility itself or be fed into the grid. The ash generated from incineration remains after the combustion process. This ash may contain some non-combustible materials, such as metals, glass, and ceramics. Depending on its composition and local regulations, the ash may be further processed, treated, or disposed of in a designated landfill.

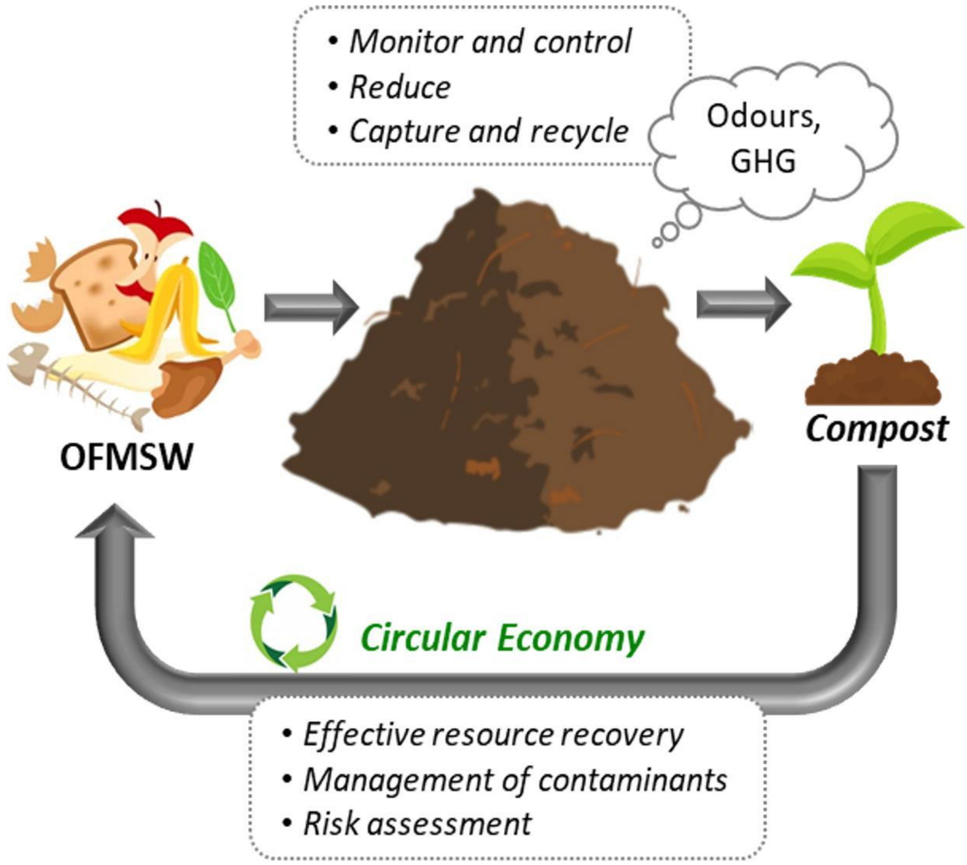

Figure 3: Composting of organic waste (Policastro & Cesaro, 2022)

3.2.1. Incineration Benefits and Challenges

Incineration significantly reduces the volume of waste, thereby minimizing the need for extensive landfill space (Figure 4). The heat produced during incineration can be used to generate electricity, contributing to energy production and potentially reducing the demand for fossil fuels. Incineration can be effective in treating hazardous waste materials, neutralizing or reducing their toxic properties. Incineration reduces the production of methane, a potent greenhouse gas, compared to landfilling organic waste. This pollution control measure can still release pollutants into the air, including dioxins, furans, and heavy metals. Properly designed and maintained facilities are crucial to minimize these emissions. Establishing and operating incineration facilities can be costly due to the need for advanced technology and pollution control equipment. Some critics argue that incineration may compete with recycling and composting efforts, directing funds away from waste management methods that are more environmentally friendly. Proper disposal of the ash generated from incineration is important, as it may still contain potentially hazardous materials (Kanhar *et al*., 2020). It's important to note that incineration is just one of several waste management options available, and its suitability depends on local circumstances, waste composition, environmental regulations, and public preferences. We advise contacting local authorities or environmental organizations for the most recent details on incineration practices in certain locales like Hyderabad and Quetta as of my most recent knowledge update in September 2021.

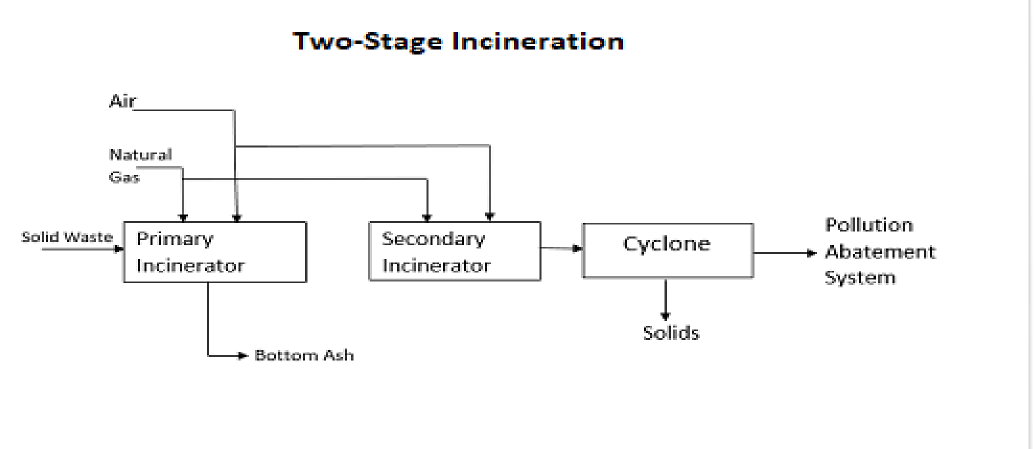

Figure 4: Schematics illustration of incinerator
(Policastro & Cesaro, 2022)

3.3. Landfilling

In less developed nations, landfilling is a popular and widely used waste management technique. To prevent soil contamination, the emission of hazardous gases into the air, and the production of an unpleasant stench, as well as contact with insects, birds, and microorganisms, landfilling is required. The ecology, human health, the condition of the soil, and the quality of the groundwater are all still seriously endangered by landfilling (Mohammadi *et al*., 2021). Landfills are a major source of the pollutants CH_4 and CO_2. Studies show that every year, landfills around the world release 30-70 million tons of methane gas. This can be used to gather LFG and effluent from landfills with high productivity to create energy. CH_4 collection is impacted by temporal degradation, which differs greatly between waste components (LFG strategy 2020), waste types, weather, and oxidation conditions. The type of waste and environmental factors has a significant impact on LFG age (Manzoor & Sharma, 2019). Solid waste is disposed of in designated places known as landfills as part of a standard waste management practice called landfilling. Landfills are engineered sites designed to safely contain and manage waste materials while minimizing environmental impact (Schnell *et al*., 2020).

Prior to landfilling, suitable locations for landfills are selected based on factors such as geology, hydrology, and distance from populated areas. The site is then prepared by clearing vegetation, grading the land, and creating barriers to prevent groundwater contamination. Solid waste is transported to the landfill and placed in specific areas called "cells." The waste is typically compacted and spread out in layers. To cut down on smells, keep pests under control, and prevent litter, each layer is covered with a layer of dirt or other materials. Leachate is a liquid that forms as water percolates through the waste, picking up contaminants. Landfills are designed with systems to collect and manage leachate, preventing it from entering groundwater or surface water sources. The collected leachate is usually treated before being discharged. As organic materials in the landfill decompose, they produce gases, including methane – a potent greenhouse gas. Many landfills have systems to collect and manage these gases. Through procedures like landfill gas-to-energy, methane can be recovered and used as a source of energy. Once a landfill cell is filled, it is covered with a final layer of soil, clay, or synthetic materials to create a barrier between the waste and the environment. The site is then closed and may be rehabilitated for other uses, such as parks or green spaces.

3.3.1. Benefits and Demerits of Landfilling:

Waste disposal in landfills provide a controlled and centralized location for waste disposal, helping prevent litter and illegal dumping. Landfills can accommodate large volumes of waste and help reduce the need for open dumping sites. A properly designed landfills incorporate systems to manage leachate and landfill gases, minimizing environmental impacts. Lastly, landfills with gas collection systems can harness methane for energy generation through landfill gas to energy (LFGTE) projects (Schnell *et al*., 2020). Landfills have the potential to emit pollutants such as leachate, greenhouse gases, and others into the environment. Land used for landfilling is unavailable for other potential uses, such as agriculture or development. Even after closure, landfills require ongoing monitoring and maintenance to ensure environmental compliance and prevent long-term impacts. Landfills can be seen as unsightly and can lead to odor and aesthetic concerns for nearby communities. In densely populated areas, finding suitable land for new landfills can be challenging.

It's important to note that the design, operation, and regulation of landfills can vary widely depending on local regulations, waste composition, and environmental conditions. Landfilling is often considered a less sustainable waste management option compared to recycling, composting, and waste-to-energy technologies. Efforts are continually made to minimize the environmental impact of landfills and explore alternative waste management practices in specific areas like Hyderabad and Quetta (Diaz-Elsayed *et al*., 2019).

4. Advantages depending on the outlook for the environment and the economy

Composting C and N were one of the useful techniques utilized to maintain nutrient availability and regulation. The BSFL's biowaste treatment will result in final goods being priced more competitively at lower prices. Current waste management involves using waste effectively, which includes recycling and value-adding (Lindamulla *et al*., 2022). Because typical feed ingredients like soy meal are more expensive on the market Based on the information provided by FAO (2016) for the years 2011–2015, fish meal, which contains 44%–65% protein, costs US$400 per ton, and BSF bio-waste treatment products, which include 64%–65% protein, cost US$1600 per ton, dry mass. Compost made from bio-waste is frequently produced and has a poor commercial value (Molayzahedi & Abdoli, 2021). The finding that processed swine manure may generate an annual income of US$33.4-46.1 per m^3 and raw swine dung can generate 95–120 kg of larval species per m^3 appears to increase the method's economic viability even further. One could consider the body form in the BSFL prepupae phase to be a significant source of protein for the system's animal waste feed. In earlier studies, processing BSFL tends to reduce the number of microorganisms (Bekezhanov *et al*., 2018).

5. Conclusion and recommendations

In Pakistan, the majority of contaminants in both surface and groundwater sources surpass the quality criteria for drinking water, making them unsafe for human use. Black soldier flies (BSF)--based biological waste management is the future of garbage disposal, according to recent studies. Using it might be one of the quick ways to handle biodegradable waste. The risk of bacterial water pollution is greatest for consumers. Except for Cu and Zn, all of the heavy metals routinely exceed the WHO-recommended standard limits. Iron, nickel, chromium, cadmium, and arsenic are all present often and in significant concentrations, which is problematic. Two of the cations that were regularly found to be above the permitted limits in reports were K^+ and Na^+. Nitrates and fluoride are problems in some places. Fluoride is a dual problem since it needs to be added to some areas where it is very low and removed from others where it is too high. In Pakistan, discharge of untreated industrial and municipal pollutants is the main driver of water pollution. Particularly in rural areas, inadequate water quality monitoring is done. If treatment facilities do exist, they do not offer the general public high-quality water, and methods of water disinfection such as chlorination are either nonexistent or insufficient. Waterborne infections have been caused by bacterial and chemical contamination of public drinking water in various regions of the nation. Due to a paucity of diagnostic tools and record-keeping, there are, nevertheless, relatively few data on illnesses connected to water. Regular nationwide surveys are required to gain a clear picture of the diseases connected to water. The suggestions given below could aid in reducing or controlling Pakistan's issues with declining water quality. To minimize the widespread contamination caused by intermittent water supply, local authorities in both rural and urban regions should have access to facilities for monitoring and purifying drinking water. Additionally, a continuous water supply system should be implemented instead of an intermittent one.

Declarations

Ethics approval and consent to participate

Not Applicable

Consent for publication

All authors have read and consented to the submission of the manuscript.

Availability of data and material

Not Applicable.

Competing interests

All authors declare no competing interests.

Funding

There was no funding for the current report.

Acknowledgments

The academic institutions of each author are acknowledged for helping with the drafting of this work.

References

Abu-Salama, M. S. M. (2007). *Spatial and temporal consolidation of drainage water quality monitoring networks: A case study from the El-Salam Canal project in Egypt*. PhD Thesis, Faculty of Environment and Technology, Leuphana University Luneburg, Germany.

Akhtar, M. M., & Zhonghua, T. (2013). Municipal solid waste and its relation with groundwater contamination in Lahore, Pakistan. *Research Journal of Applied Sciences, Engineering and Technology*, *7*(6), 1551–1560. https://doi.org/10.19026/rjaset.7.431

Alam, O., & Qiao, X. (2019). An in-depth review on municipal solid waste management, treatment and disposal in Bangladesh. *Sustainable Cities and Society*, *52*(101775). https://doi.org/10.1016/j.scs.2019.101775

Altowayti, W. A. H., Shahir, S., Othman, N., Eisa, T. A. E., Yafooz, W. M. S., Al-Dhaqm, A., Soon, C. Y., Yahya, I. B., binti Che Rahim, N. A. N., Abaker, M., & Ali, A. (2022). The role of conventional methods and artificial intelligence in the wastewater treatment: A comprehensive review. In A. Petrella (Ed.), *Processes* (Vol. 10, Issue 1832, pp. 1–31). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/pr10091832

Arenibafo, F. E. (2023). The 3Rs (reduce, reuse, recycle) of waste management–An effective and sustainable approach for managing municipal solid waste in developing countries. *6th International Conference of Contemporary Affairs in Architecture and Urbanism*

[ICCAUA, 14-15 June 2023], *6*(1), 383–398. https://doi.org/10.38027/iccaua2023en0108

Azizullah, A., Khattak, M. N. K., Richter, P., & Hader, D.-P. (2011). Water pollution in Pakistan and its impact on public health-A review. *Environmental International*, *37*(2), 479–497. https://doi.org/10.1016/j.envint.2010.10.007

Bawab, J., Khatib, J., Kenai, S., & Sonebi, M. (2021). A review on cementitious materials including municipal solid waste incineration bottom ash (MSWI-BA) as aggregates. In Ł. Sadowski (Ed.), *Buildings* (Vol. 11, Issue 179, pp. 1–19). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/buildings11050179

Bekezhanov, D., Nurmukhankyzy, D., Tinistanova, S., Kopbassarova, G., & Zhangushukova, A. (2018). Legal and environmental policy on solid waste pollution and protection. *Environmental Policy and Law*, *48*(1), 83–88. https://doi.org/10.3233/EPL-180053

Bello, A. S., Al-Ghouti, M. A., & Abu-Dieyeh, M. H. (2022). Sustainable and long-term management of municipal solid waste: A review. *Bioresource Technology Reports*, *18*(101067), 1–12. https://doi.org/10.1016/j.biteb.2022.101067

Diaz-Elsayed, N., Rezaei, N., Guo, T., Mohebbi, S., & Zhang, Q. (2019). Wastewater-based resource recovery technologies across scale: A review. *Resources, Conservation and Recycling*, *145*, 94–112. https://doi.org/10.1016/j.resconrec.2018.12.035

Fidelis, R., Guerreiro, E. D. R., Horst, D. J., Ramos, G. M., de Oliveira, B. R., & Junior, P. P. de A. (2023). Municipal solid waste management with recyclable potential in developing countries: Current scenario and future perspectives. *Waste Management & Research (WM&R)*, *00*(0), 1–21. https://doi.org/10.1177/0734242X231160084

Gautam, M., & Agrawal, M. (2021). Greenhouse gas emissions from municipal solid waste management: A review of global scenario. In *Carbon Footprint Case Studies* (pp. 123–160). Springer Singapore. https://doi.org/10.1007/978-981-15-9577-6_5

Hossain, N., Bhuiyan, M. A., Pramanik, B. K., Sabzoi, N., & Griffin, G. (2020). Waste materials for wastewater treatment and waste adsorbents for biofuel and cement supplement applications: A critical review. *Journal of Cleaner Production*, *255*(1), 120261. https://doi.org/10.1016/j.jclepro.2020.120261

Jakimiuk, A. (2022). Review of technical methods of landfill sealing and reclamation in the world. *Acta Scientiarum Polonorum. Architectura*, *21*(2), 41–50. https://sciendo.com/article/10.22630/aspa.2022.21.1.5

Jeong, E., Kim, Y.-I., Lee, J.-Y., & Raza, M. (2023). Microplastic contamination in groundwater of rural area, eastern part of Korea. *Science of the Total Environment*, *895*(165006), 1–12. https://doi.org/10.1016/j.scitotenv.2023.165006

Kanhar, A. H., Chen, S., & Wang, F. (2020). Incineration fly ash and its treatment to possible utilization: A review. *Energies*, *13*(24), 1–35. https://doi.org/10.3390/en13246681

Kehrein, P., van Loosdrecht, M., Osseweijer, P., Garfí, M., Dewulf, J., & Posada, J. (2020). A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks. *Environmental Science Water Research & Technology*, *6*(4), 877–910. https://doi.org/10.1039/C9EW00905A

Kolawole, T. O., Iyiola, O., Ibrahim, H., & Isibor, R. A. (2023). Contamination, ecological and health risk assessments of potentially toxic elements in soil around a municipal solid waste disposal facility in Southwestern Nigeria. *Journal of Trace Elements and Minerals*, *5*(100083), 1–9. https://doi.org/10.1016/j.jtemin.2023.100083

Koul, B., Yakoob, M., & Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. *Environmental Research*, *206*(112285), 1–15. https://doi.org/10.1016/j.envres.2021.112285

Kulkarni, B. (2020). Environmental sustainability assessment of land disposal of municipal solid waste generated in Indian cities – A review. *Environmental Development*, *33*(100490). https://doi.org/10.1016/j.envdev.2019.100490

Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: A review. *Frontiers in Environmental Science*, *10*(880246), 1–16. https://doi.org/10.3389/fenvs.2022.880246

Lindamulla, L., Nanayakkara, N., Othman, M., Jinadasa, S., & Herath, G. (2022). Municipal solid waste landfill leachate characteristics and their treatment options in tropical countries. *Water Pollution*, *8*, 273–287. https://doi.org/10.1007/s40726-022-00222-x

Liu, W., Jinlan, Z., Liu, H., Guo, X., Zhang, X., Yao, X., Cao, Z., & Zhang, T.-T. (2020). A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms. *Environment International*, *146*(746), 1–14. https://doi.org/10.1016/j.envint.2020.106277

Manzoor, J., & Sharma, M. (2019). Impact of biomedical waste on environment and human health. *Environmental Claims Journal*, *31*(1), 1–24. https://doi.org/10.1080/10406026.2019.1619265

Meena, M. D., Dotaniya, M. L., Meena, B. L., Rai, P. K., Antil, R. S., Meena, H. S., Meena, L. K., Dotaniya, C. K., Meena, V. S., Ghosh, A., Meena, K. N., Singh, A. K., Meena, V. D., Moharana, P. C., Meena, S. K., Srinivasarao, C., Meena, A. L., Chatterjee, S., Meena, D. K., … Meena, R. B. (2023). Municipal solid waste: Opportunities, challenges and management policies in India: A review. *Waste Management Bulletin*, *1*(1), 4–18. https://doi.org/10.1016/j.wmb.2023.04.001

Mohammadi, R., Tang, W., & Sillanpää, M. (2021). A systematic review and statistical analysis of nutrient recovery from municipal wastewater by electrodialysis. *Desalination*, *498*(114626), 1–15. https://doi.org/10.1016/j.desal.2020.114626

Molayzahedi, S. M., & Abdoli, M. A. (2021). A new sustainable approach to integrated solid waste management in Shiraz, Iran. *Pollution*, *8*(1), 303–314.

https://doi.org/10.22059/POLL.2021.330183.1175

Morin-Crini, N., Lichtfouse, E., Liu, G., Balaram, V., Ribeiro, A. R. L., Lu, Z., Stock, F., Carmona, E., Teixeira, M. R., Picos-Corrales, L. A., Moreno-Piraján, J. C., Giraldo, L., Li, C., Pandey, A., Hocquet, D., Torri, G., & Crini, G. (2022). Worldwide cases of water pollution by emerging contaminants: A review. *Environmental Chemistry Letters*, *20*(4), 2311–2338. https://doi.org/10.1007/s10311-022-01447-4

Nanda, S., & Berruti, F. (2020). Municipal solid waste management and landfilling technologies: A review. *Environmental Chemistry Letters*, *19*(2), 1433–1456. https://doi.org/10.1007/s10311-020-01100-y

Naveenkumar, R., Iyyappan, J., Pravin, R., Kadry, S., Han, J., Sindhu, R., Awasthi, M. K., Rokhum, S. L., & Baskar, G. (2023). A strategic review on sustainable approaches in municipal solid waste management and energy recovery: Role of artificial intelligence, economic stability and life cycle assessment. *Bioresource Technology*, *379*(129044). https://doi.org/10.1016/j.biortech.2023.129044

Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). Agricultural waste concept, generation, utilization and management. *Nigerian Journal of Technology (NIJOTECH)*, *35*(4), 957–964. https://doi.org/10.4314/njt.v35i4.34

Pal, M. S., & Bhatia, M. (2022). Current status, topographical constraints, and implementation strategy of municipal solid waste in India: A review. *Arabian Journal of Geosciences*, *15*(1176), 1–26. https://doi.org/10.1007/s12517-022-10414-w

Paneerselvam, B., Ravichandran, N., Li, P., Thomas, M., Charoenlerkthawin, W., & Bidorn, B. (2023). Machine learning approach to evaluate the groundwater quality and human health risk for sustainable drinking and irrigation purposes in South India. *Chemosphere*, *336*(139228). https://doi.org/10.1016/j.chemosphere.2023.139228

Peng, X., Jiang, Y., Chen, Z., Osman, A. I., Farghali, M., Rooney, D. W., & Pow-Seng, Y. (2023). Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: A review. *Environmental Chemistry Letters*, *21*(2), 1–37. https://doi.org/10.1007/s10311-022-01551-5

Policastro, G., & Cesaro, A. (2022). Composting of organic solid waste of municipal origin: The role of research in enhancing its sustainability. *International Journal of Environmental Research and Public Health (IJERPH)*, *20*(1), 1–14. https://doi.org/10.3390/ijerph20010312

Pradere, B., Mallet, R., de La Taille, A., Bladou, F., Prunet, D., Beurrier, S., Bardet, F., Game, X., Fournier, G., Lechevallier, E., Meria, P., Matillon, X., Polguer, T., Abid, N., De Graeve, B., Kassab, D., Mejean, A., Misrai, V., & Pinar, U. (2022). Climate-smart actions in the operating theatre for improving sustainability practices: A systematic review. *European Urology*, *83*(4), 331–342. https://doi.org/10.1016/j.eururo.2022.01.027

Rimantho, D., Suyitno, B. M., Pratomo, Vector Anggit Haryanto, Gunady Prasidha, I. N. T., & Puspita, N. (2023). Circular economy: Barriers and strategy to reduce and manage solid waste in the rural area at Jepara District, Indonesia. *International Journal of Sustainable Development & Planning*, *18*(4), 1045–1055.

Rosemarin, A., Macura, B., Carolus, J., Barquet, K., Ek, F., Järnberg, L., Lorick, D., Johannesdottir, S., Pedersen, S. M., Koskiaho, J., Haddaway, N. R., & Okruszko, T. (2020). Circular nutrient solutions for agriculture and wastewater – A review of technologies and practices. *Current Opinion in Environmental Sustainability*, *45*, 78–91. https://doi.org/10.1016/j.cosust.2020.09.007

Roy, H., Alam, S. R., Bin-Masud, R., Prantika, T. R., Pervez, N., Islam, S., & Naddeo, V. (2022). A review on characteristics, techniques, and waste-to-energy aspects of municipal solid waste management: Bangladesh perspective. *Sustainability*, *14*(10265), 1–25. https://doi.org/10.3390/su141610265

Saba, N., Balwan, W. K., Rasool, N., & Kour, S. (2022). Future perspective for utilization of municipal solid waste (MSW) in India: A review. *Scholars Academic Journal of Biosciences*, *10*(9), 199–204. https://doi.org/10.36347/sajb.2022.v10i09.001

Salam, M., Alam, F., Dezhi, S., Nabi, G., Shahzadi, A., Hassan, S. U., Ali, M., Saeed, M. A., Hassan, J., Ali, N., & Bilal, M. (2021). Exploring the role of black soldier fly larva technology for sustainable management of municipal solid waste in developing countries. *Environmental Technology & Innovation*, *24*(101934). https://doi.org/10.1016/j.eti.2021.101934

Salim, H., Jackson, M., Stewart, R. A., & Beal, C. D. (2023). Drivers-pressures-state-impact-response of solid waste management in remote communities: A systematic and critical review. *Cleaner Waste Systems*, *4*(100078), 1–10. https://doi.org/10.1016/j.clwas.2023.100078

Saravanan, A., Kumar, P. S., Nhung, T. C., Ramesh, B., Srinivasan, S., & Rangasamy, G. (2022). A review on biological methodologies in municipal solid waste management and landfilling: Resource and energy recovery. *Chemosphere*, *309*(136630), 1–10. https://doi.org/10.1016/j.chemosphere.2022.136630

Schnell, M., Horst, T., & Quicker, P. (2020). Thermal treatment of sewage sludge in Germany: A review. *Journal of Environmental Management*, *263*(110367), 1–21. https://doi.org/10.1016/j.jenvman.2020.110367

Singh, A., Kanoungo, A., Goyal, A., Gupta, I., & Chaudhary, A. (2022). Municipal waste management in India: A critical review of disposal system and model implementation. *Proceedings of International Conference on Innovative Technologies for Clean and Sustainable Development (ICITCSD – 2021)*, 471–489. https://doi.org/10.1007/978-3-030-93936-6_39

Wang, B., Gupta, R., Bei, L., Wan, Q., & Sun, L. (2023). A review on gasification of municipal solid waste (MSW): Syngas production, tar formation, mineral transformation and industrial challenges. *International Journal of Hydrogen Energy*, *48*(69), 26676–26706. https://doi.org/10.1016/j.ijhydene.2023.03.086

Abu-Salama, M. S. M. (2007). *Spatial and temporal consolidation of drainage water quality monitoring networks: A case study from the El-Salam Canal project in Egypt*. PhD Thesis, Faculty of Environment and Technology, Leuphana University Luneburg, Germany.

Akhtar, M. M., & Zhonghua, T. (2013). Municipal solid waste and its relation with groundwater contamination in Lahore, Pakistan. *Research Journal of Applied Sciences, Engineering and Technology*, *7*(6), 1551–1560. https://doi.org/10.19026/rjaset.7.431

Alam, O., & Qiao, X. (2019). An in-depth review on municipal solid waste management, treatment and disposal in Bangladesh. *Sustainable Cities and Society*, *52*(101775). https://doi.org/10.1016/j.scs.2019.101775

Altowayti, W. A. H., Shahir, S., Othman, N., Eisa, T. A. E., Yafooz, W. M. S., Al-Dhaqm, A., Soon, C. Y., Yahya, I. B., binti Che Rahim, N. A. N., Abaker, M., & Ali, A. (2022). The role of conventional methods and artificial intelligence in the wastewater treatment: A comprehensive review. In A. Petrella (Ed.), *Processes* (Vol. 10, Issue 1832, pp. 1–31). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/pr10091832

Arenibafo, F. E. (2023). The 3Rs (reduce, reuse, recycle) of waste management–An effective and sustainable approach for managing municipal solid waste in developing countries. *6th International Conference of Contemporary Affairs in Architecture and Urbanism [ICCAUA, 14-15 June 2023]*, *6*(1), 383–398. https://doi.org/10.38027/iccaua2023en0108

Azizullah, A., Khattak, M. N. K., Richter, P., & Hader, D.-P. (2011). Water pollution in Pakistan and its impact on public health-A review. *Environmental International*, *37*(2), 479–497. https://doi.org/10.1016/j.envint.2010.10.007

Bawab, J., Khatib, J., Kenai, S., & Sonebi, M. (2021). A review on cementitious materials including municipal solid waste incineration bottom ash (MSWI-BA) as aggregates. In Ł. Sadowski (Ed.), *Buildings* (Vol. 11, Issue 179, pp. 1–19). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/buildings11050179

Bekezhanov, D., Nurmukhankyzy, D., Tinistanova, S., Kopbassarova, G., & Zhangushukova, A. (2018). Legal and environmental policy on solid waste pollution and protection. *Environmental Policy and Law*, *48*(1), 83–88. https://doi.org/10.3233/EPL-180053

Bello, A. S., Al-Ghouti, M. A., & Abu-Dieyeh, M. H. (2022). Sustainable and long-term management of municipal solid waste: A review. *Bioresource Technology Reports*, *18*(101067), 1–12. https://doi.org/10.1016/j.biteb.2022.101067

Diaz-Elsayed, N., Rezaei, N., Guo, T., Mohebbi, S., & Zhang, Q. (2019). Wastewater-based resource recovery technologies across scale: A review. *Resources, Conservation and Recycling*, *145*, 94–112. https://doi.org/10.1016/j.resconrec.2018.12.035

Fidelis, R., Guerreiro, E. D. R., Horst, D. J., Ramos, G. M., de Oliveira, B. R., & Junior, P. P. de A. (2023). Municipal solid waste management with recyclable potential in developing countries: Current scenario and future perspectives. *Waste Management & Research (WM&R)*, *00*(0), 1–21. https://doi.org/10.1177/0734242X231160084

Gautam, M., & Agrawal, M. (2021). Greenhouse gas emissions from municipal solid waste management: A review of global scenario. In *Carbon Footprint Case Studies* (pp. 123–160). Springer Singapore. https://doi.org/10.1007/978-981-15-9577-6_5

Hossain, N., Bhuiyan, M. A., Pramanik, B. K., Sabzoi, N., & Griffin, G. (2020). Waste materials for wastewater treatment and waste adsorbents for biofuel and cement supplement applications: A critical review. *Journal of Cleaner Production*, *255*(1), 120261. https://doi.org/10.1016/j.jclepro.2020.120261

Jakimiuk, A. (2022). Review of technical methods of landfill sealing and reclamation in the world. *Acta Scientiarum Polonorum. Architectura*, *21*(2), 41–50. https://sciendo.com/article/10.22630/aspa.2022.21.1.5

Jeong, E., Kim, Y.-I., Lee, J.-Y., & Raza, M. (2023). Microplastic contamination in groundwater of rural area, eastern part of Korea. *Science of the Total Environment*, *895*(165006), 1–12. https://doi.org/10.1016/j.scitotenv.2023.165006

Kanhar, A. H., Chen, S., & Wang, F. (2020). Incineration fly ash and its treatment to possible utilization: A review. *Energies*, *13*(24), 1–35. https://doi.org/10.3390/en13246681

Kehrein, P., van Loosdrecht, M., Osseweijer, P., Garfí, M., Dewulf, J., & Posada, J. (2020). A critical review of resource recovery from municipal wastewater treatment plants – market supply potentials, technologies and bottlenecks. *Environmental Science Water Research & Technology*, *6*(4), 877–910. https://doi.org/10.1039/C9EW00905A

Kolawole, T. O., Iyiola, O., Ibrahim, H., & Isibor, R. A. (2023). Contamination, ecological and health risk assessments of potentially toxic elements in soil around a municipal solid waste disposal facility in Southwestern Nigeria. *Journal of Trace Elements and Minerals*, *5*(100083), 1–9. https://doi.org/10.1016/j.jtemin.2023.100083

Koul, B., Yakoob, M., & Shah, M. P. (2022). Agricultural waste management strategies for environmental sustainability. *Environmental Research*, *206*(112285), 1–15. https://doi.org/10.1016/j.envres.2021.112285

Kulkarni, B. (2020). Environmental sustainability assessment of land disposal of municipal solid waste generated in Indian cities – A review. *Environmental Development*, *33*(100490). https://doi.org/10.1016/j.envdev.2019.100490

Lin, L., Yang, H., & Xu, X. (2022). Effects of water pollution on human health and disease heterogeneity: A review. *Frontiers in Environmental Science*, *10*(880246), 1–16. https://doi.org/10.3389/fenvs.2022.880246

Lindamulla, L., Nanayakkara, N., Othman, M., Jinadasa, S., & Herath, G. (2022). Municipal solid waste landfill leachate characteristics and their treatment options in tropical countries. *Water Pollution*, *8*, 273–287. https://doi.org/10.1007/s40726-022-00222-x

Liu, W., Jinlan, Z., Liu, H., Guo, X., Zhang, X., Yao, X., Cao, Z., & Zhang, T.-T. (2020). A review of the removal of microplastics in global wastewater treatment plants: Characteristics and mechanisms. *Environment International*, *146*(746), 1–14. https://doi.org/10.1016/j.envint.2020.106277

Manzoor, J., & Sharma, M. (2019). Impact of biomedical waste on environment and human health. *Environmental Claims Journal*, *31*(1), 1–24. https://doi.org/10.1080/10406026.2019.1619265

Meena, M. D., Dotaniya, M. L., Meena, B. L., Rai, P. K., Antil, R. S., Meena, H. S., Meena, L. K., Dotaniya, C. K., Meena, V. S., Ghosh, A., Meena, K. N., Singh, A. K., Meena, V. D., Moharana, P. C., Meena, S. K., Srinivasarao, C., Meena, A. L., Chatterjee, S., Meena, D. K., … Meena, R. B. (2023). Municipal solid waste: Opportunities, challenges and management policies in India: A review. *Waste Management Bulletin*, *1*(1), 4–18. https://doi.org/10.1016/j.wmb.2023.04.001

Mohammadi, R., Tang, W., & Sillanpää, M. (2021). A systematic review and statistical analysis of nutrient recovery from municipal wastewater by electrodialysis. *Desalination*, *498*(114626), 1–15. https://doi.org/10.1016/j.desal.2020.114626

Molayzahedi, S. M., & Abdoli, M. A. (2021). A new sustainable approach to integrated solid waste management in Shiraz, Iran. *Pollution*, *8*(1), 303–314. https://doi.org/10.22059/POLL.2021.330183.1175

Morin-Crini, N., Lichtfouse, E., Liu, G., Balaram, V., Ribeiro, A. R. L., Lu, Z., Stock, F., Carmona, E., Teixeira, M. R., Picos-Corrales, L. A., Moreno-Piraján, J. C., Giraldo, L., Li, C., Pandey, A., Hocquet, D., Torri, G., & Crini, G. (2022). Worldwide cases of water pollution by emerging contaminants: A review. *Environmental Chemistry Letters*, *20*(4), 2311–2338. https://doi.org/10.1007/s10311-022-01447-4

Nanda, S., & Berruti, F. (2020). Municipal solid waste management and landfilling technologies: A review. *Environmental Chemistry Letters*, *19*(2), 1433–1456. https://doi.org/10.1007/s10311-020-01100-y

Naveenkumar, R., Iyyappan, J., Pravin, R., Kadry, S., Han, J., Sindhu, R., Awasthi, M. K., Rokhum, S. L., & Baskar, G. (2023). A strategic review on sustainable approaches in municipal solid waste management and energy recovery: Role of artificial intelligence, economic stability and life cycle assessment. *Bioresource Technology*, *379*(129044). https://doi.org/10.1016/j.biortech.2023.129044

Obi, F. O., Ugwuishiwu, B. O., & Nwakaire, J. N. (2016). Agricultural waste concept, generation, utilization and management. *Nigerian Journal of Technology (NIJOTECH)*, *35*(4), 957–964. https://doi.org/10.4314/njt.v35i4.34

Pal, M. S., & Bhatia, M. (2022). Current status, topographical constraints, and implementation strategy of municipal solid waste in India: A review. *Arabian Journal of Geosciences*, *15*(1176), 1–26. https://doi.org/10.1007/s12517-022-10414-w

Paneerselvam, B., Ravichandran, N., Li, P., Thomas, M., Charoenlerkthawin, W., & Bidorn, B. (2023). Machine learning approach to evaluate the groundwater quality and human health risk for sustainable drinking and irrigation purposes in South India. *Chemosphere*, *336*(139228). https://doi.org/10.1016/j.chemosphere.2023.139228

Peng, X., Jiang, Y., Chen, Z., Osman, A. I., Farghali, M., Rooney, D. W., & Pow-Seng, Y. (2023). Recycling municipal, agricultural and industrial waste into energy, fertilizers, food and construction materials, and economic feasibility: A review. *Environmental Chemistry Letters*, *21*(2), 1–37. https://doi.org/10.1007/s10311-022-01551-5

Policastro, G., & Cesaro, A. (2022). Composting of organic solid waste of municipal origin: The role of research in enhancing its sustainability. *International Journal of Environmental Research and Public Health (IJERPH)*, *20*(1), 1–14. https://doi.org/10.3390/ijerph20010312

Pradere, B., Mallet, R., de La Taille, A., Bladou, F., Prunet, D., Beurrier, S., Bardet, F., Game, X., Fournier, G., Lechevallier, E., Meria, P., Matillon, X., Polguer, T., Abid, N., De Graeve, B., Kassab, D., Mejean, A., Misrai, V., & Pinar, U. (2022). Climate-smart actions in the operating theatre for improving sustainability practices: A systematic review. *European Urology*, *83*(4), 331–342. https://doi.org/10.1016/j.eururo.2022.01.027

Rimantho, D., Suyitno, B. M., Pratomo, Vector Anggit Haryanto, Gunady Prasidha, I. N. T., & Puspita, N. (2023). Circular economy: Barriers and strategy to reduce and manage solid waste in the rural area at Jepara District, Indonesia. *International Journal of Sustainable Development & Planning*, *18*(4), 1045–1055.

Rosemarin, A., Macura, B., Carolus, J., Barquet, K., Ek, F., Järnberg, L., Lorick, D., Johannesdottir, S., Pedersen, S. M., Koskiaho, J., Haddaway, N. R., & Okruszko, T. (2020). Circular nutrient solutions for agriculture and wastewater – A review of technologies and practices. *Current Opinion in Environmental Sustainability*, *45*, 78–91. https://doi.org/10.1016/j.cosust.2020.09.007

Roy, H., Alam, S. R., Bin-Masud, R., Prantika, T. R., Pervez, N., Islam, S., & Naddeo, V. (2022). A review on characteristics, techniques, and waste-to-energy aspects of municipal solid waste management: Bangladesh perspective. *Sustainability*, *14*(10265), 1–25. https://doi.org/10.3390/su141610265

Saba, N., Balwan, W. K., Rasool, N., & Kour, S. (2022). Future perspective for utilization of municipal solid waste (MSW) in India: A review. *Scholars Academic Journal of Biosciences*, *10*(9), 199–204. https://doi.org/10.36347/sajb.2022.v10i09.001

Salam, M., Alam, F., Dezhi, S., Nabi, G., Shahzadi, A., Hassan, S. U., Ali, M., Saeed, M. A., Hassan, J., Ali, N., & Bilal, M. (2021). Exploring the role of black soldier fly larva technology for sustainable management of municipal solid waste in developing countries. *Environmental Technology & Innovation*, *24*(101934). https://doi.org/10.1016/j.eti.2021.101934

Salim, H., Jackson, M., Stewart, R. A., & Beal, C. D. (2023). Drivers-pressures-state-impact-response of solid waste management in remote communities: A systematic and critical review. *Cleaner Waste Systems*, *4*(100078), 1–10. https://doi.org/10.1016/j.clwas.2023.100078

Saravanan, A., Kumar, P. S., Nhung, T. C., Ramesh, B., Srinivasan, S., & Rangasamy, G. (2022). A review on biological methodologies in municipal solid waste management and landfilling: Resource and energy recovery. *Chemosphere*, *309*(136630), 1–10. https://doi.org/10.1016/j.chemosphere.2022.136630

Schnell, M., Horst, T., & Quicker, P. (2020). Thermal treatment of sewage sludge in Germany: A review. *Journal of Environmental Management*, *263*(110367), 1–21. https://doi.org/10.1016/j.jenvman.2020.110367

Singh, A., Kanoungo, A., Goyal, A., Gupta, I., & Chaudhary, A. (2022). Municipal waste management in India: A critical review of disposal system and model implementation. *Proceedings of International Conference on Innovative Technologies for Clean and Sustainable Development (ICITCSD – 2021)*, 471–489. https://doi.org/10.1007/978-3-030-93936-6_39

Wang, B., Gupta, R., Bei, L., Wan, Q., & Sun, L. (2023). A review on gasification of municipal solid waste (MSW): Syngas production, tar formation, mineral transformation and industrial challenges. *International Journal of Hydrogen Energy*, *48*(69), 26676–26706. https://doi.org/10.1016/j.ijhydene.2023.03.086