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Environmental impact of solid waste landfilling in Balochistan-A risk assessment for SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land)

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Abstract. Municipal solid waste (MSW) is one of the most common wastes that need disposal. However, landfilling is still the most commonly practiced method of waste disposal, but it poses great threats to the environment. This article will look at the major environmental effects of landfilling with a focus on Pakistan and Balochistan province in particular. Emerging projects related to improvement of waste management systems in these areas will also be discussed together with the existing solid waste management challenges. Groundwater pollution, emission of landfill gases to air and adverse effects of poor waste handling on human health and other living organisms are some of the issues that shall be covered in this review. Additionally, advancements in waste-to-energy technologies, recycling initiatives, and community-based waste management efforts aimed at mitigating these impacts shall also be considered as possible solutions in order to achieve the sustainability development goals including SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land).

Keywords. Waste landfills, organic wastes, Balochistan, infrastructure, regulatory gaps.

1. Introduction

The term “solid waste landfilling” refers to a practice of discard-making by means of designated places called landfills where waste is compressed and then covered with soil or other materials [1]. Although this method is widely used for controlling municipal wastes, it has a number of associated problems. Environmental pollution is one of these methods disadvantages that include; release of toxic gases and probable leachate contamination of soils as well as underground waters [2, 3]. Moreover, considerable land is taken up by these sites which are also home to some health hazards due to their proximity to residential areas where diseases may thrive or people can get in contact with dangerous substances [4]. Nonetheless, it remains largely a short-term solution requiring proper management so as not to damage long term eco-systems or affect future generations’ well-being adversely [5]. (Figure 1).

Figure 1. SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 11 (sustainable cities and communities), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water) and SDG 15 (life on land).

2. Types of landfills

Landfills can be classified into various types based on their design and the kinds of waste they manage, each presenting different environmental and health challenges [6].

- **Sanitary Landfills**: These are meticulously designed waste disposal facilities that utilize advanced technologies to reduce environmental harm [7]. Sanitary landfills feature protective elements like impermeable liners and leachate collection systems, which help prevent harmful chemicals and pollutants from leaking into the soil and contaminating groundwater [8]. Moreover, many of these landfills are equipped with gas collection systems to capture methane and other greenhouse gases, allowing for potential energy recovery and further minimizing their environmental impact [9]. (Figure 2).

Figure 2. Sanitary landfills.

- **Open Dumps**: Frequently found in developing nations, open dumps are unregulated waste disposal sites that lack adequate environmental protections [10]. Waste is carelessly discarded in these locations, resulting in significant pollution of air, soil, and water [11]. These areas attract pests and contribute to the spread of diseases, posing serious public health threats to surrounding communities [12]. The absence of containment measures also leads to the uncontrolled release of leachate and landfill gases, worsening environmental damage [13]. (Figure 3).

Figure 3. Open dumps.

- **Hazardous Waste Landfills**: These landfills are specifically designed for the disposal of industrial, toxic, and hazardous materials and are governed by strict regulations [14]. Hazardous waste landfills feature multiple layers of protection, including reinforced liners, monitoring systems, and rigorous oversight to ensure that harmful substances are kept away from the environment [15]. Given the nature of the waste they handle, these landfills require ongoing monitoring and management to prevent accidental releases that could result in significant environmental or health crises [16]. (Figure 4).

Figure 4. Hazardous waste landfills.

Environmental Impacts of Landfilling on Solid Waste

Landfilling has generated a number of environmental problems pertaining to air, water, soil, and ecosystems [17].

- **AIR POLLUTION:** Anaerobic decomposition of organic wastes in landfills results in methane (CH_4), an extremely potent greenhouse gas which largely contributes to global warming [18]. In instances where the collecting systems are not well developed or poorly maintained, methane is usually released to the air and boosts its impacts on global warming [19].

- **WATER POLLUTION:** Landfills generate leachate-that is, a liquid produced by water percolating through wastes. This can include dangerous elements like toxic chemicals, heavy metals, and even pathogens that may migrate into the groundwater to contaminate the local supply of water and pose potentially serious risks to human health and ecosystems [20, 21].
- **SOIL CONTAMINATION:** Decomposition of various materials in landfills can leak hazardous chemicals into the surrounding soil [22]. It affects an ecosystem, works negatively for the local agriculture, and decreases the fertility of the soil, which in return cannot be used either for farming or any other purpose [23].
- **ODOR POLLUTION:** Decomposition processes of organic waste at landfills often develop unpleasant odors that reduce the quality of life for people living in close proximity [24]. Such foul smells also distress people and give rise to ill health due to respiratory irritation and stress [25].
- **LAND DEGRADATION AND BIODIVERSITY LOSS:** Landfills require open spaces that are large enough, and this is usually the primary cause of natural habitats being destroyed [26]. This does not only mean land-use change but also is considered to be one of the causes of losing biodiversity. The clearing of ecosystems for landfill sites can have long-lasting environmental consequences [27].
- **IMPACT ON WILD LIFE**: Landfills are open to and often scavenged by wildlife, such as birds, rodents, and insects, which frequently become pests [28]. Then there is the accidental ingestion or entanglement with waste by animals that can result in injury or death [29]. Local populations of wildlife are interfered with in their natural existence and may affect species viability [30].
- **CLIMATE CHANGE:** Apart from methane generation, transportation and handling activities of waste generate carbon dioxide emission, which accelerates climate change further [31]. Energy-intense operation of landfills increases the carbon footprint in handling wastes, thereby influencing the overall environmental impact [32].

3. Challenges of solid waste in Pakistan

Pakistan faces many issues regarding the management of solid waste due to rapid urbanization and also due to lack of infrastructure [33].

- **RAPID URBAN GROWTH:** There has been rapid growth in urban development, especially in main cities of the country, that the underdeveloped infrastructure to manage solid waste has long passed. This results in the disposing of waste in illegal and unauthorized sites, further burdening the environment [34].
- **INADEQUATE INFRASTRUCTURE:** In large parts of the world, the infrastructure for collection and disposal is underdeveloped or entirely missing. In much of Balochistan, for instance, open dumps are everywhere and the limited attempts at separating recyclable and hazardous materials make the whole process inefficient and environmentally hazardous [35].
- **THE INFORMAL WASTE SECTOR:** A large part of the waste management in Pakistan is done through an array of informal waste pickers [36]. The conditions in which they work are very hazardous for their health, and the informal nature of this sector often leads to inefficient collection and processing of wastes [37].
- **POLICY AND REGULATORY GAPS:** There is no comprehensive and applicable policy related to waste management at both the federal and provincial levels [38]. The available regulations are not well enforced, resulting in severe environmental degradation and poor waste management practices [39].
- **FINANCIAL LIMITATIONS:** While municipal authorities are usually on tight budgets, investing in modern technologies and infrastructures for managing wastes remains extremely problematic [40]. Landfills and waste treatment facilities remain underdeveloped; this contributes to aggravating the problem of managing solid wastes efficiently [41].

4. Solid waste management in Pakistan

Balochistan, the largest province in Pakistan, has specific problems related to waste management due to its geographical and socio-economic features. The scattered population and inappropriate infrastructure of the province enhances the challenge of effective management of solid waste in urban and rural areas [42]. The vast areas, together with limited facilities, make waste management highly problematic in Balochistan, especially in the peripheral and less populated parts [43]. Most urban and rural areas face serious challenges in terms of proper disposal, further contributing to environmental adversities and public health [44].

5. Major challenges in Balochistan

- **INADEQUATE SERVICE OF WASTE COLLECTION:** Most cities and towns in this province lack proper waste collection mechanism and majority of the wastes are thrown in open areas. It also results in high health hazards and environmental pollution [45].

- **LACK OF MODERN LANDFILLS:** Lack of sanitary landfills and waste treatment facilities are attributed to Balochistan; most of the wastes are disposed of in open dumps that accounts for higher environmental degradation [46].
- **CULTURAL AND SOCIO-ECONOMIC BARRIERS:** Public awareness and education are sub-par on appropriate ways of waste management, which is reflected in unhealthy disposal practices contributing to aggravating waste management issues in the region [47].

6. Environmental Impacts of solid waste landfilling in Balochistan

- **WATER POLLUTION:** Being one of the primary sources of drinking water for the province, groundwater is rather highly susceptible to being polluted through leachate that threatens to emanate from waste dumps, thereby creating an utmost danger to public health [48].
- **DESERTIFICATION:** The diffusion of waste disposal sites in rural areas is a further contribution to the already largely pressing concern of desertification in the area [49]. The spreading of landfills also contributes to the loss of arable lands and exerts an additional, considerable pressure on the fragile ecosystem [50].

7. New initiatives for solid waste management in Balochistan

Several new initiatives are being pursued to address the burgeoning issues of waste management in Balochistan, focused on sustainability and infrastructure development [51].

- **BALOCHISTAN INTEGRATED WASTE MANAGEMENT PLAN (BIWMP):** The BIWMP intends to have a fully integrated waste management system in the province. In this regard, the important objectives include the construction of sanitary landfills, recycling centers, and treatment facilities of wastes within the major cities such as Quetta [52]. Furthermore, the plan plans to focus on raising public awareness and training the people to segregate and recycle waste materials for including community participation [53].
- **QUETTA SANITARY LANDFILL PROJECT:** It is also a fact that a modern sanitary landfill is currently under development in the provincial capital of Quetta. This will obviate the requirements of the city as far as ever-increasing waste management issues are concerned and, using modern technologies for the management of leachate as well as landfill gases, will avoid environmental harm normally associated with traditional landfill methods [54].
- **RECYCLING AND COMPOSTING PROGRAMS:** New recycling and composting initiatives are springing up in cities of Balochistan, which include a shift in focus from landfills to reducing the amount of waste entering [55]. These efforts target diverting organic waste for composting as well as the promotion of recycling of materials in order to decrease the environmental impact of waste disposal [56].

8. Problems with new schemes in Balochistan

- **FINANCE AND RESOURCES:** It lacks sufficient finance. Projects get delayed or short-funded, which badly affects efficiency and scope [57].
- **TECHNICAL CAPACITY**: Technical know-how regarding waste management technologies is still lacking. An example is that developing an advanced system like waste-to-energy plants or modern landfill management is tough to do [58].
- **SOCIAL AWARENESS AND EDUCATION**: Most of these programs have trouble involving the local community. Public awareness and participation are the keys. Otherwise, initiatives such as waste segregation and recycling are resisted or worse are allowed to die as no one looks after them [59].
- **GEOGRAPHIC AND LOGISTICAL CHALLENGES**: Geographic vastness coupled with sparsity makes it challenging to implement any sort of centralized system of waste management in Balochistan [60]. This also incurs logistical costs because waste is transported over large distances [61].

9. Mitigation for Pakistan and Balochistan

- **INFRASTRUCTURE INVESTMENT:** The government should increase investment in modern landfills and waste management facilities, particularly in those regions that are not as well serviced, like Balochistan [62].
- **PUBLIC-PRIVATE SECTOR PARTNERSHIPS:** Private sector investment in waste management can certainly be an important source of much-needed resources and the much-needed expertise. It may also be a catalyst for innovative solutions, like waste-to-energy systems [63].
- **STRENGTHENING REGULATIONS:** Stricter legislation and enforcement are needed to halt illegal dumping and ensure that landfills comply with environmental standards [64].
- **INVOLVING THE COMMUNITY:** Education programs and encouraging people through rewards to separate waste from household collection can further enhance waste management practices [65].

10 Conclusions

Landfilling of solid waste causes adverse impacts mainly in terms of environmental pollution such as air and water pollution, degradation of soil, and loss of biodiversity. Main challenges in Pakistan and Balochistan are due to insufficient infrastructure, inappropriate practices for waste management, financial constraints, and reliance upon open dumps, which in turn increase the risks towards health and the environment. But still, a hopeful initiative is the Quetta Sanitary Landfill and new waste management projects that focus on the modernization of the waste disposal systems, improvements in recycling, and control of leachate in waste management. Continued investment, stronger policies, and active public engagement will be critical to achieving sustainable waste management. The cooperative efforts of the government, the private sector, and the communities will result in reduced environmental harm and improved regional waste management practices.

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