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RESEARCH ARTICLE

MUNICIPAL SOLID WASTE DYNAMICS IN SEMI-ARID LANDSCAPE: A CASE STUDY OF NOKHA CITY, BIKANER (RAJASTHAN)

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ABSTRACT

The rapid urbanization creates complex environmental and socio-economic challenges for smaller towns like Nokha city in Bikaner district, Rajasthan. Nokha city is located in the semi-arid zone of Rajasthan, where waste generation is increasing along with rapid urbanization. The study assesses the volume and composition of municipal waste produced in residential, commercial, and industrial sectors of Nokha city through a combination of field surveys, waste audits and interviews with local stakeholders. The findings of the quantitative analysis underscore significant inefficiencies in the existing waste management system, including limited public involvement in waste segregation and a heavy dependence on open dumping. The present investigation was carried out to assess the composition, nature, volume and physicochemical parameters of 120 samples of soil selected for the municipal solid waste from Nokha city. The study was carried out for the period of four years from 2021 to 2024. Iron levels (3.85-3.93 ppm) remained below the deficiency threshold (< 4.5 ppm), indicating marginal availability. Copper values (0.23-0.29 ppm) stayed within the sufficient range (> 0.2 ppm), while manganese (2.18-2.37 ppm) showed adequate availability (> 2.0 ppm) across all years. Based on data analysis, the study recommends localized sustainability strategies such as decentralized composting, enhanced material recovery systems and community-driven awareness initiatives.

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INTRODUCTION

Urban solid waste management has emerged as one of the most critical environmental challenges facing rapidly expanding cities in developing countries (Zohoori & Ghani, 2017).The exponential growth of urban populations, coupled with changing consumption patterns and inadequate infrastructure has created unprecedented challenges for municipal authorities in managing solid waste effectively. This phenomenon is particularly pronounced in emerging economies where urbanization often outpaces the development of supporting infrastructure and governance systems. The average amount of municipal solid waste generated by a single individual per day is referred to as per capita waste generation, typically expressed in kilograms per capita per day (kg/capita/day). According to the Municipal Solid Waste Annual Report 2021–22, India generates approximately 1,70,339 metric tons of solid waste per day. India produces around 62 million tons of municipal solid waste each year, with per capita generation levels ranging between 0.2 and 0.6 kg/day (CPCB, 2022). The variations in per capita waste generation are influenced by factors such as urban density, economic activity, and waste management practices. The untreated portion of municipal solid waste in India, estimated at 37,373 TPD or 22% of total daily generation, poses a serious environmental concern. Addressing this gap is essential to ensuring effective and sustainable waste management across the country. In comparison, the state of Rajasthan generates 7,973 TPD of municipal solid waste, of which only 1,926 TPD or approximately 24.15% is treated. According to recent data from the city-wise report of municipal solid waste management, the Nokha Municipality currently generates approximately 0.77 metric tons of solid waste per day (Swachhatam Portal, 2024). This waste is managed through an integrated waste collection and disposal infrastructure implemented by the municipality to ensure systematic handling and environmentally responsible disposal. The Nokha city has achieved approximately 55% source segregation and 100% door-to-door waste collection; however, the remaining waste is still sent to open dumpsites without any treatment. The town has also established compost pits with a processing capacity of 15 TPD for the treatment of wet waste(RSPCB, 2021).This relatively modest generation rate, when considered against the population base, suggests either efficient waste management practices or potential under reporting of actual waste volumes, a common challenge in developing urban areas. A large number of studies were carried out on solid waste management by earlier researchers (Joshi & Ahmed, 2016). The present investigation was carried out to analyze the composition, nature and present status of municipal solid waste generated in the Nokha city and its effective management. The impact of MSW on the soil of Nokha city was also assessed for the pre- and post-monsoon seasons from 2021 to 2024 for a period of 4 years. The main objectives of the study were to quantify the volume and to categorize the types of solid waste generated in Nokha City, to check the efficiency and effectiveness of existing waste management systems, including collection transportation, and disposal.

Profile of the Study Area: Nokha City is located in the Bikaner district of Rajasthan, India, at coordinates 27.56°N latitude and 73.47°E longitude. The city serves as a tehsil headquarters and is situated approximately 52 kilometers from the district headquarters, Bikaner. Nokha tehsil, comprising 145 villages, exemplifies this urban growth trajectory. The main settlement of Nokha mandi was established in 1927, having not existed during the 1901 or 1911 censuses. The first official census of Nokha city was published in 1951 and its population was 4,557. The tehsil has experienced significant demographic expansion over the decades, with its population growing from 244,767 in 1991 to 329,031 in 2001, and further increasing to 436,876 by 2011 (Census of India, 2011,2001,1951). The Nokha possesses an arid climate as it is located in the Thar Desert. The area receives an annual precipitation of 38 cm, with approximately 90% of rainfall occurring during the monsoon period from mid-June to September. The region experiences extreme temperature variations, with maximum temperatures reaching 50°C and minimum temperatures dropping to 5°C annually (Khandelwal, 2017). Agricultural activities in the southern portion of the Nokha tehsil are predominantly rainfed, dependent on seasonal precipitation patterns. Nokha tehsil possesses the highest groundwater availability in the region, with total resources estimated at 63.2686 MCM (Million Cubic Meters). Groundwater extraction for irrigation and potable water supply occurs primarily in areas where water quality standards are maintained(Mohammad & Ranga, 2023).The area provides an excellent case study for understanding the evolution of waste management systems in response to population pressures and urban development.

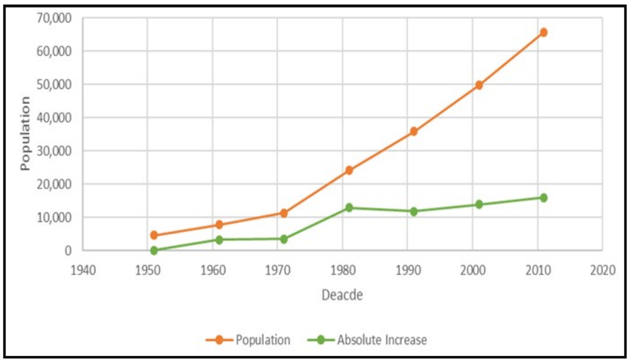

Figure 1. Decadal population increase in Nokha city (1961-2011)

The analysis shows that Nokha experienced extraordinary growth, particularly during the 1980s when the population more than doubled. The city transformed from a small settlement of 4,557 people in 1951 to a significant urban center

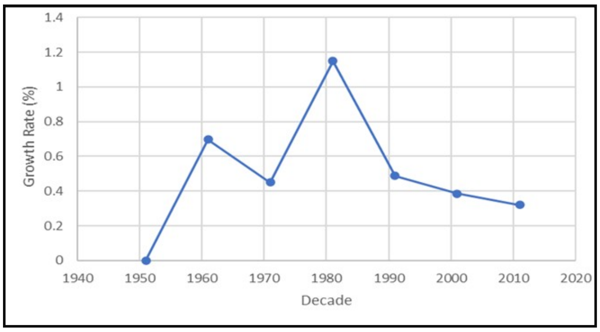

Figure 2. Nokha City Population Growth Rate (1951-2011)

of over 65,000 by 2011.The most striking finding is the 114.9% growth rate during 1971-1981, which suggests major economic or administrative changes that attracted substantial migration. Since then, growth has been steadily decelerating, indicating the city is maturing from a rapidly expanding town to a more stable urban center.This demographic transformation has significant implications for urban planning, infrastructure development, and waste management.

METHODOLOGY

The study employs a mixed-methods approach, combining both quantitative and qualitative data (Esmaeilizadeh et al., 2020). Primary data were collected through field surveys, waste sampling, and interviews with municipal officials, sanitation workers, and residents. Waste generation rates and composition were measured at household and commercial levels. Secondary data, such as municipal records and policy documents, were reviewed to evaluate existing waste management systems. Environmental and social impacts were analyzed through site observations and stakeholder feedback. The findings were used to identify key challenges and propose sustainable, practical improvements tailored to Nokha City's context.MSW samples were collected from a common municipal solid waste dumping site in Nokha city. A total of 120 samples of soil were collected from the different locations near the common solid waste dumping site of Nokha city (lat 27.556382° and long 73.463812°).These samples were collected on a twice-a-month basis from 2021 to 2024 during the pre- and post-monsoon seasons and assessed for various parameters as per standard procedures (APHA, 2017; Chandni Director et al., 2010; Maiti, 2003; US EPA SW-846, 2012).Municipal solid waste (MSW) samples were collected from various locations within the dumping site and thoroughly mixed to ensure homogeneity. A representative 1 kg sample was obtained from the homogenized waste using the coning and quartering method, then oven-dried, weighed, and subjected to physical composition analysis following standard procedures (Maiti, 2003). Each waste fraction was individually weighed to determine percentage composition by mass, ensuring statistical reliability and reproducibility of the characterization data (Mouhoun-Chouaki et al., 2019).

RESULTS AND DISCUSSION

The existing waste management system in Nokha City operates under the municipal authority with limited resources and infrastructure. Waste collection is primarily manual, using handcarts and small vehicles for transportation to open dumping sites located on the city periphery. There is a material recovery facility (MRF) with a formal segregation system in the Nokha municipality campus, and waste processing is currently limited to informal recycling by waste pickers.

Physical Composition of Municipal Solid Waste: The analysis by Zhu et al., (2008) revealed significant changes in the composition of municipal solid waste between 1996 and 2005, with projections extending to 2024. Biodegradable waste increased from 42.21% in 1996 to 47.43% in 2005 (Zhu et al., 2008)and was expected to reach 51.02% by 2024, suggesting shifting consumption patterns driven by urbanization and dietary changes. Inert waste declined sharply from 45.13% to 25.16% over the same period, stabilizing at 20.46% by 2024, indicating improvements in waste segregation. Plastic and rubber fractions experienced the most dramatic rise, from 0.60% in 1996 to 10.82% in 2024, highlighting increased plastic use and underscoring the urgent need for circular waste strategies. Paper waste initially rose from 3.63% to 8.13% between 1996 and 2005, then declined to 5.17% by 2024, reflecting changing information consumption habits.

Overall, these trends indicated that the waste stream was becoming increasingly dominated by organics and plastics, thereby underscoring the critical need for adaptive, evidence-based, and sustainable waste management policies to address emerging challenges.Based on the waste composition data spanning three decades (1996-2024), several significant trends emerge that have important implications for waste management strategies and environmental policy.The composition of MSW of any city provides an idea about the product consumption patterns of the residents of that city. The physical composition of Nokha city shows that the biodegradable waste was the most dominant (51%), followed by inert (20.461%), plastic (10.82%),other (6.04 %), and Paper (5.17%), other (6.04%) in Figure 3. It is important to note that the above half of the total waste generation in Nokha city is biodegradable in nature, which can be utilized for manure or composting. It will not only reduce the overburden and volume, but also help in meeting the fertilizer needs of the farmers of the region (Sadef et al., 2016; Suthar, 2011).

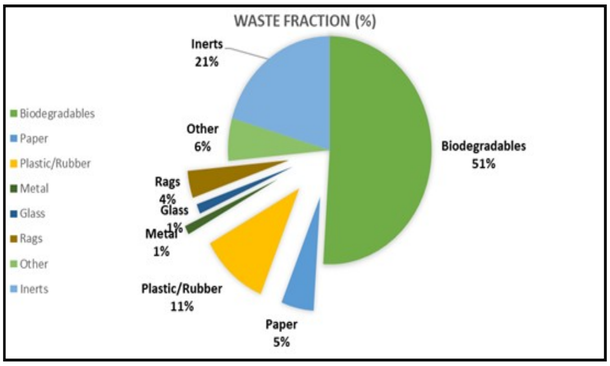

Figure 3. Physical Composition of Municipal Solid Waste of Nokha City (2021-2024)

Soil Parameter Analysis and its permissible limit: A total of 120 soil samples were assessed for the impact of MSW on physicochemical parameters of soil. These samples were collected from different locations near the common MSW dumping site. The samples were examined for the 11 selected parameters, including (pH, Electric conductivity, % organic Carbon, Phosphorus, Potassium, Zinc, Iron, Copper, Manganese) Table 1.

pH Trends: Soil pH is a key indicator of soil health, influencing microbial activity, nutrient availability, toxicity levels, and overall fertility. The soil exhibited a declining pH trend from 9.11 in 2021 to 8.40 in 2024, reflecting gradual improvement while remaining highly alkaline (>8.5). Post-monsoon pH values were consistently lower than pre-monsoon values, indicating leaching of basic cations and enhanced organic acid production during the monsoon. The elevated pH observed in the Pre-Monsoon 2021 is likely due to lower rainfall compared to the dilution in the soil by the substantial excess rainfall recorded in 2024(IMD, 2024). Similar variation in pH due to rainfall was also reported byChaudhari et al. 2018for Patan, (Gujarat); for Kadapa, (Andhra Pradesh) (Sreedhar Reddy & Naidu, 2016).

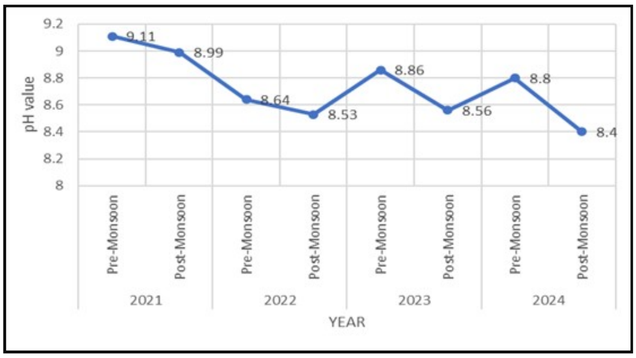

Figure 4. Average concentration of pH in the soil of Nokha city

Electrical Conductivity (EC): Soil electrical conductivity (EC) is an essential indication of salinity because it reflects the concentration of soluble salts, which can influence crop development and nutrient availability. Monitoring EC helps assess soil health and guide irrigation techniques to prevent salt accumulation (Shirsath, 2021). The soil's salt content showed big changes over the four years. In 2022, salt levels were very low (0.17 dS/m), but they jumped dramatically to 3.28 dS/m in early 2024 - that's almost 20 times higher. The soil went from having no salt problems (2021-2023) to becoming slightly salty in 2024. After the monsoon rains in 2024, the salt level dropped to 1.70 dS/m, showing that rain helped wash away some salt, but levels were still higher than in previous years. This sudden increase in salt content could be due to poor-quality irrigation water, waterlogging problems, or contamination from outside sources. While monsoon rains helped reduce the salt, they didn't completely solve the problem (Uma et al., 2016).

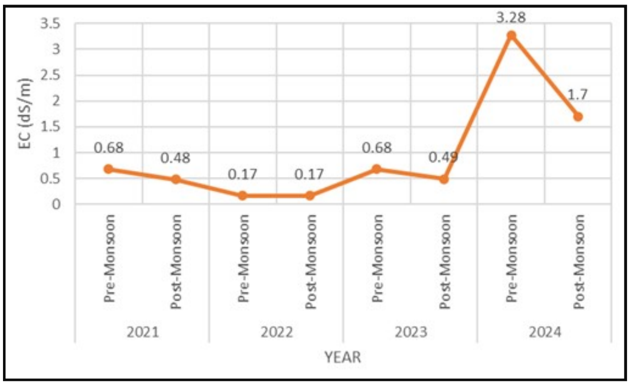

Figure 5. Average concentration of EC in the soil of Nokha city

Organic Carbon Stability: Organic carbon in MSWsoil ranged from 0.15% to 0.30%, remaining consistently low according to standards (< 0.5%). The low levels suggest rapid decomposition or inadequate waste incorporation rates.The data showed higher values in 2021-2022 (0.22-0.30%), followed by a decline in 2023-2024 (0.15-0.22%). This indicates that organic matter from MSW is decomposing faster than being replenished, or application rates have decreased.The present findings are well reported by the study carried out by (Tognetti et al., 2008). Seasonal patterns were inconsistent (IMD, 2024), with the lowest value (0.15%) occurring in pre-monsoon 2023, suggesting organic matter depletion during dry periods when decomposition exceeds organic input.

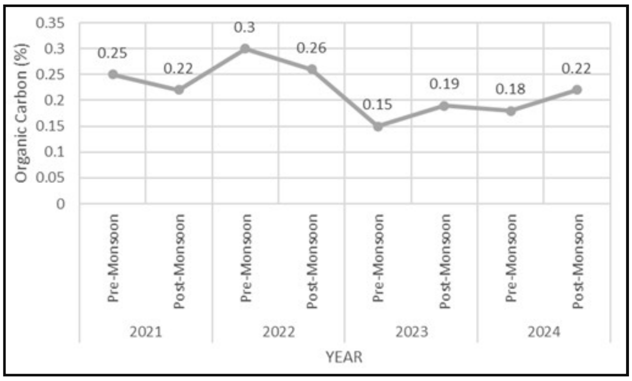

Figure 6. Average concentration of % Organic Carbon in the soil of Nokha city

Phosphorus: Available phosphorus exhibited a gradual increasing trend from 2021 to 2023, rising from 26 kg/ha to 34 kg/ha, representing a 30.8% improvement. However, 2024 showed a decline back to initial levels (27 kg/ha), suggesting either nutrient uptake by crops or leaching losses. According to soil fertility standards, all values remained in the medium to high availability range, indicating an adequate phosphorus supply for crop production (Kumar et al., 2017).

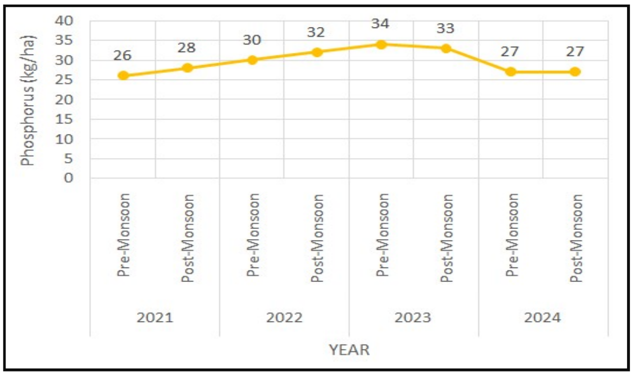

Figure 7. Average concentration of Phosphorus (P) in the soil of Nokha city

Potassium Stability: Available potassium demonstrated remarkable stability throughout the study period, fluctuating within a narrow range of 269-358 kg/ha. The coefficient of variation remained low, indicating consistent potassium availability despite seasonal and yearly variations. All values fell within the high availability category (>280 kg/ha), reflecting the beneficial effect of MSW application in maintaining potassium reserves (Uma et al., 2016).

Zinc: Zinc (Zn) is an essential micronutrient that supports enzymatic activity, protein synthesis, and overall plant growth. In waste-affected soils, monitoring Zn is crucial as its

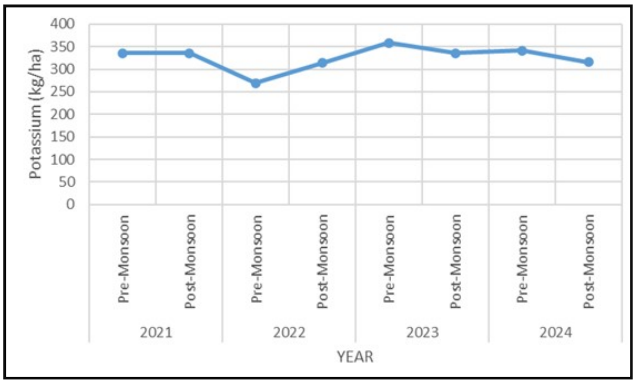

Figure 8. Average concentration of Potassium (K) in the soil of Nokha city

deficiency or excess can significantly influence soil fertility and crop productivity. Soil zinc (Zn) contents varied significantly over the research period. Pre-monsoon levels ranged from 0.48 to 0.64 ppm, whereas post-monsoon values varied from 0.35 to 0.51 ppm. Zinc levels were generally low (<0.6 ppm) in 2021, 2023, and 2024, except for 2022, when pre-monsoon levels reached 0.64 ppm. The significant post-monsoon fall in 2022 (0.35 ppm) indicates zinc leaching or redistribution during the monsoon. Overall, the data show that zinc shortage persists in the soil, which may have a negative impact on soil fertility and crop growth(Noulas et al., 2018). This anomalous increase suggests possible contamination from zinc-rich MSW components, such as galvanized materials, batteries, or industrial waste during that specific period.

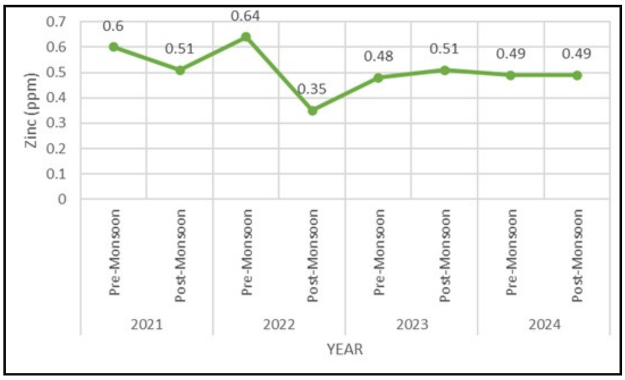

Figure 9. Average concentration of Zinc (Zn) in the soil of Nokha city

Iron: Iron concentrations consistently remained deficient (3.85-3.93 ppm) throughout the study period, falling below the critical threshold of 4.5 ppm. Values showed minimal seasonal variation, indicating stable but inadequate iron bioavailability in the soil.

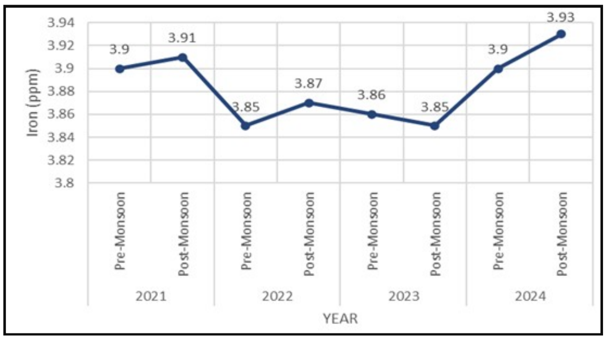

Figure 10. Average concentration of Iron (Fe) in the soil of Nokha city

Table 1. Pre-monsoon and post-monsoon soil chemical parameters cumulative data analysis (2021-2024) and their standard values (Maiti, 2003; Reeujik, 2002)

Soil Parameter	2021		2022		2023		2024		Standard Value
	Pre-Monsoon	Post-Monsoon	Pre-Monsoon	Post-Monsoon	Pre-Monsoon	Post-Monsoon	Pre-Monsoon	Post-Monsoon	
pH	9.11	8.99	8.64	8.53	8.86	8.56	8.80	8.40	7-8
EC(dS/m)	0.68	0.48	0.17	0.17	0.68	0.49	3.28	1.70	<3.0
Organic Carbon (%)	0.25	0.22	0.30	0.26	0.15	0.19	0.18	0.22	0.50 – 0.75
Phosphorus (kg/ha)	26	28	30	32	34	33	27	27	23.0 – 56.0
Potassium (kg/ha)	336	336	269	314	358	336	341	316	144 – 333
Zinc (ppm)	0.60	0.51	0.64	0.35	0.48	0.51	0.49	0.49	<0.6(Low),0.6 – 1.2 (Normal)
Iron (ppm)	3.90	3.91	3.85	3.87	3.86	3.85	3.90	3.93	<4.5(Low),4.5 – 9.0 (normal)
Copper (ppm)	0.28	0.29	0.29	0.25	0.24	0.23	0.26	0.26	<0.2(Low),0.2 – 0.4(Normal)
Manganese (ppm)	2.28	2.37	2.30	2.20	2.26	2.25	2.20	2.18	<2.0(Low),2.0 – 4.0 (Normal)

The persistent iron deficiency across all years suggests that high soil alkalinity (pH 8.40-9.11) limits iron solubility and plant uptake. Immediate iron supplementation or pH management is required to address this critical micronutrient limitation in the soil of Nokha city.

Copper (Cu): Copper concentrations remained consistently within the normal range (0.23-0.29 ppm) throughout the four-year study period, meeting the sufficiency threshold (0.2-0.4 ppm). It is reported that minimal variation with a slight decline of Cu from 2021-2022 (0.28-0.29 ppm) to 2023 (0.23-0.24 ppm), followed by stabilization in 2024 (0.26 ppm).

Copper availability remained adequate across all seasons and years, indicating successful micronutrient cycling in soil. Unlike iron deficiency, copper levels demonstrate that MSWeffectively maintains sufficient copper supply for plant nutrition without requiring additional supplementation.

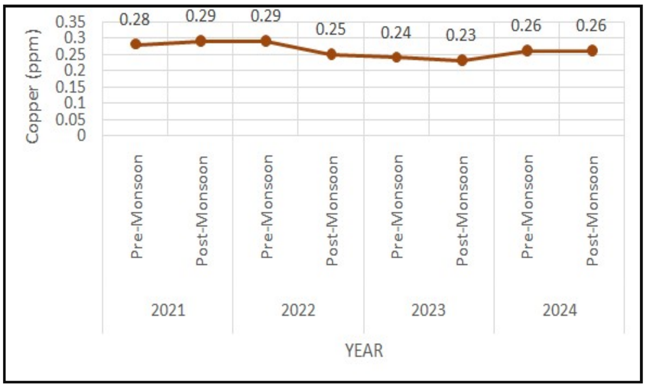

Figure 11. Average concentration of Copper (Cu) in the soil of Nokha city

Manganese: Manganese concentrations remained consistently within the normal range (2.18-2.37 ppm) throughout the four-year study period, meeting the sufficiency threshold (2.0-4.0 ppm). Values showed minimal temporal variation with a gradual declining trend from 2021 (2.28-2.37 ppm) to 2024 (2.18-2.20 ppm), approaching the lower limit of the normal range.

MSW currently maintains sufficient manganese supply, but continued decline may require future management intervention to prevent its deficiency in MSW soil. Most parameters showed consistent seasonal differences, with post-monsoon values typically lower than pre-monsoon values, likely due to leaching and dilution effects from monsoon rainfall.

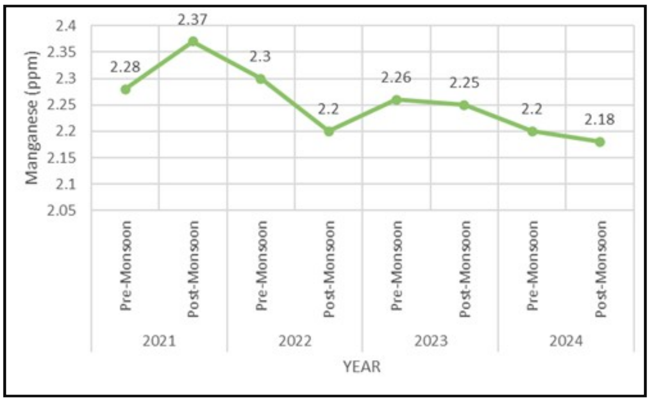

Figure 12. Average concentration of Manganese (Mn) in the soil of Nokha city

CONCLUSION

The four-year temporal analysis of soil affected by MSW revealed significant parameter variability with distinct seasonal patterns and mixed outcomes. Soil pH showed progressive improvement from highly alkaline (9.11) to moderately alkaline (8.40) levels, with consistent seasonal trends where post-monsoon values were systematically lower than pre-monsoon across all years, though remaining above optimal standards. Electrical conductivity demonstrated alarming fluctuations with pronounced seasonal effects, escalating from non-saline conditions to slightly saline levels before partial monsoon-mediated reduction, yet exceeding recommended thresholds (<3.0 dS/m). Organic carbon remained consistently deficient with irregular seasonal patterns, indicating inadequate organic matter retention despite MSW inputs. Macronutrients exhibited variable seasonal responses: phosphorus showed minor seasonal fluctuations within acceptable ranges, while potassium maintained adequate levels with slight pre-monsoon concentration effects. The study concludes that while MSW ensures adequate macronutrient supply, the distinct pre-post monsoon variability highlights critical concerns regarding persistent alkalinity, emerging salinity stress, and insufficient organic carbon accumulation, necessitating season-specific refined management strategies for sustainable soil health.

Conflict ofinterest: The authors declare that there is no conflict of interest.

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Key Points

- Seasonal fluctuation affected the availability of micronutrients in soil.
- 51% of the 0.77 MT of garbage produced daily in Nokha City is biodegradable.
- Four-year studies show growing salinity (EC up to 3.28 dS/m) and persistent alkalinity (pH 8.4–9.1).
- sustainable municipal solid waste management in semi-arid urban areas.

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