E-ISSN 2250-0944
ISSN 2250-1150
doi: 10.31838/ijprt/16.02.352

Research Article

An Integrated Environmental and Ecotoxicological Assessment of Biomedical Waste Treatment Facilities in Mysuru, India

Priyadarshini N R*

*Department of Environmental Science, KSOU, Mysuru, Karnataka, India.

Email: pridanr49@gmail.com

Received: 16.06.26, Revised: 19.07.26, Accepted:17.08.26, Publication: 18.08.2026

ABSTRACT

Biomedical waste mismanagement has become a significant environmental and public health issue, especially in areas that are quickly urbanizing. This study evaluates the impact of biomedical waste treatment facilities on Mysuru's public health. In 2023 and 2024, seasonal soil, plant, and groundwater sampling was done near the Shree consulting site, Mysuru city, before and after the monsoon. Heavy metal concentrations were measured using Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP-AES), whereas physico-chemical properties were examined using standard analytical methods. The results demonstrated that seasonal variations in environmental conditions were substantial. with typically high levels of copper and cadmium. When compared to the control, plant samples showed comparatively reduced heavy metal accumulation, suggesting limited bioavailability and selective metal uptake. Groundwater samples during pre-monsoon seasons displayed higher hardness and ion concentrations (compared to normal range according to BIS IS 10500-2012) due to lower dilution and increased mineral dissolution. The study highlights the environmental issues associated with improper disposal of biological waste as well as the necessity of continuous monitoring and improved waste management strategies. To reduce contamination and safeguard the sustainability of ecosystems, it is recommended to use environmentally friendly treatment technologies and remediation strategies like phytoremediation.

Abbreviations: ICP-AES – Inductively Coupled Plasma Atomic Emission Spectroscopy; TDS – Total Dissolved Solids; EC – Electrical Conductivity; WHO – World Health Organisation.

Keywords: Biomedical Waste, Ecotoxicology, Groundwater Contamination, Heavy Metals, Icp-Aes, Soil Pollution.

INTRODUCTION

Biomedical waste generated from healthcare activities has emerged as a major environmental and public health challenge worldwide. Healthcare facilities produce a wide range of waste materials during diagnosis, treatment, immunisation, and research activities involving humans and animals. Improper segregation, treatment, and disposal of biomedical waste can result in severe environmental contamination and health hazards.[1–4] Rapid expansion of healthcare infrastructure and increasing population density in developing countries have further intensified biomedical waste generation, thereby increasing the burden on waste management systems.[5–7]

Improper biomedical waste disposal contributes to contamination of soil, groundwater, and vegetation through direct dumping, landfill leachate formation, and atmospheric emissions. Toxic constituents present in biomedical waste, including pharmaceuticals, chemical disinfectants, and heavy metals, may persist in environmental compartments for extended periods.[8–11] Heavy metals such as cadmium, lead, copper, and iron are particularly hazardous because of their non-biodegradable nature and tendency to accumulate in biological systems.[12–15] These metals can alter soil physicochemical properties, reduce soil fertility, and negatively influence microbial communities responsible for nutrient cycling and ecosystem stability.[16–18]

Groundwater contamination is a significant environmental concern, particularly in urban and peri-urban areas where groundwater serves as the primary source of drinking water. Leachates generated from biomedical waste disposal sites can infiltrate aquifers and increase concentrations of dissolved solids, nutrients, and toxic metals.[19–22] Chronic exposure to contaminated groundwater may lead to severe health complications, including neurological disorders, renal dysfunction, cardiovascular diseases, and developmental abnormalities.[23–25] Additionally, plants growing in contaminated soils may absorb heavy metals, allowing contaminants to enter the food chain and ultimately affecting human and animal health.[26–29]

India has implemented the Biomedical Waste Management Rules (2016) to regulate the segregation, treatment, transportation, and disposal of healthcare waste. However, improper waste handling practices and inadequate infrastructure continue to contribute to environmental contamination in several regions.[30–32] Environmental monitoring studies surrounding biomedical waste treatment facilities are essential to evaluate contamination levels and assess ecological risks associated with waste disposal practices.[33–35]

Mysuru, a rapidly developing urban city in Karnataka, has experienced substantial expansion in healthcare facilities and biomedical waste generation. Limited scientific data are available regarding the environmental impact of biomedical waste treatment plants in this region, as there is only one authorized Common Bio-Medical Waste Treatment Facility (CBMWTF) in Mysuru: **M/s. Shree Consultants**, located at Varuna Village, Mysuru. Therefore, the present study aims to evaluate the influence of biomedical waste disposal on soil quality, groundwater chemistry, and plant heavy metal accumulation around biomedical waste treatment facilities in Mysuru. The study also investigates seasonal variations in contamination levels and assesses potential environmental and public health risks associated with biomedical waste management practices.

MATERIALS AND METHODS

Study Area

The present study was conducted in Mysuru city, located in the southern region of Karnataka, India, between 12°18′ N latitude and 76°12′ E longitude. The city lies in an interfluvial region between the Cauvery and Kabini rivers and is characterised by an undulating terrain. Mysuru covers an approximate area of 87 km² and has experienced rapid urbanisation and expansion of healthcare infrastructure in recent years. Increased healthcare activities have contributed to a rise in biomedical waste generation, necessitating environmental monitoring around biomedical waste treatment facilities.[2,30]

Sampling locations for test were selected in and around the biomedical waste treatment plant site (CBMWTF) in Mysuru: **M/s. Shree Consultants**, located at Varuna Village, Mysuru., and for the control it was in and around Gangothri campus, Mysuru. Environmental samples were collected during pre-monsoon and post-monsoon (1st week of April– 1st week of October 2023-2024) periods to evaluate seasonal variations in contamination levels.

Sample Collection

Soil Sampling

Soil samples were collected in triplicates from multiple sampling points surrounding the biomedical waste treatment facility (CBMWTF) in Mysuru: **M/s. Shree Consultants**, located at Varuna Village, Mysuru, provides the primary collection, transportation, and processing for over 1,000 healthcare facilities across the district. Composite soil samples were obtained randomly in triplicate from surface layers to ensure representative sampling of contamination zones. Collected samples were air-dried under laboratory conditions, homogenised, and sieved through a 0.5 mm stainless steel sieve to remove debris and ensure uniform particle size.[18]

Plant Sampling

5 Plant samples (of genus *Eleusine sp.*, *Oryza sp., And Zea sp.* of *the Poaceae* family, *Abelmoschus sp.* of the *Malvaceae* family and *Coccinia sp.* of the *Cucurbitaceae family*), including roots, stems, and leaves, were collected from vegetation growing around the biomedical waste treatment site. Collected plant materials were thoroughly washed with distilled water to remove surface contaminants using 10% sodium hypochlorite exposure followed by water wash. Samples were oven dried, ground into fine powder using an agate mortar and pestle, and stored in clean polythene containers for further analysis.[25]

Groundwater Sampling

Groundwater samples were collected from bore wells located near biomedical waste treatment facilities. Samples were collected in pre-cleaned polyethene bottles following standard water sampling procedures. The samples were preserved immediately after collection to minimise physicochemical changes before laboratory analysis.[1]

Sample Preservation and Preparation

Environmental samples were preserved to prevent physical, chemical, and biological alterations between sample collection and laboratory analysis. Soil and plant samples were digested using a tri-acid mixture, followed by the addition of aqua regia to stabilise metal ions. Groundwater samples were stored under refrigerated conditions until analysis to maintain sample integrity.[18]

Physicochemical Analysis

Physico-chemical parameters, including pH, electrical conductivity, total solids, total dissolved solids, sodium, potassium, calcium, magnesium, and organic carbon, were analysed using standard analytical procedures (as per BIS IS 10500-2012 and L- ISO 8245:1999 Water Quality Guidelines). Soil pH was measured using a calibrated electronic pH meter. Total solids and total dissolved solids were determined using gravimetric methods. Exchangeable calcium and magnesium concentrations were determined using complexometric titration methods, while sodium and potassium concentrations were measured using flame photometry.[1,18]

Heavy Metal Analysis

Heavy metal concentrations in soil, plant, and groundwater samples were determined using Inductively Coupled Plasma–Atomic Emission Spectroscopy (ICP-AES) (Perkin Elmer Optima 8000). Before analysis, digested samples were filtered and diluted using distilled water. ICP-AES is widely used for accurate quantification of trace metal concentrations in environmental samples due to its high sensitivity and precision.[18,20]

Statistical Analysis

Data are represented as the mean value of test samples, n=3, ±SD, statistical analysis was performed by 1-way ANOVA with Tukey post hoc test for analysing significant differences among the mean values of the physiochemical parameters using GraphPad Prism 9.3.0.

RESULTS

Soil Physicochemical Characteristics

The physicochemical properties of soil samples collected around biomedical waste treatment facilities showed considerable seasonal variations (Table-2). Soil pH values ranged from moderately alkaline to near-neutral conditions across sampling periods ranging from 7.1 to 8.2. A gradual decline in pH from pre-monsoon to post-monsoon seasons was observed in both study years. This trend indicates the leaching of alkaline cations caused by rainfall infiltration and increased mobility of soil constituents. Such seasonal fluctuations in soil pH have been widely reported in contaminated waste disposal environments and influence heavy metal solubility and mobility.[11,18,29]

Electrical conductivity (EC) values exhibited noticeable seasonal variation. Pre-monsoon soil samples showed comparatively higher EC values, suggesting accumulation of dissolved salts due to evaporation and reduced groundwater recharge (Table-1). Post-monsoon samples displayed relatively lower EC values, indicating dilution of salts through rainfall infiltration and surface runoff. Similar seasonal variations in conductivity have been observed in soils surrounding waste disposal sites and are considered indicators of contamination levels (as per BIS IS 10500-2012).[11,27,34]

Organic carbon concentrations showed a marginal increase, ranging between 4.1-6.7%, in contrast to the normal range (Drinking water should ideally contain less than 2.0 mg \ L- ISO 8245:1999 Water Quality Guidelines) to ensure safety during post-monsoon periods. Increased organic carbon levels are associated with enhanced decomposition of plant litter and microbial activity following rainfall events. However, organic matter accumulation in contaminated soils may also introduce hazardous organic compounds and influence metal binding capacity. Elevated calcium and magnesium concentrations recorded in certain sampling sites suggest mineral dissolution processes and possible influence of biomedical waste leachate infiltration.[18,27]

Sodium concentrations showed increasing trends during post-monsoon sampling periods, indicating salt accumulation through evaporation and capillary rise mechanisms. In contrast, potassium concentrations showed slight reductions during post-monsoon seasons, suggesting leaching losses caused by rainfall infiltration. These seasonal changes highlight the influence of climatic factors and anthropogenic waste disposal on soil nutrient dynamics and contamination patterns.[27,35] (Figure 2).

Table 1.1 Physicochemical Characteristics of Groundwater Samples in Test Area, Pre- and Post-Monsoon Season – 2023-24, Collected from the Biomedical Waste Treatment site. Data are Analysed as Compared to Control and Standard Limits of Parameters by WHO (as per BIS IS 10500-2012 and L- ISO 8245:1999 Water Quality Guidelines).

Sl.no	Parametres	Pre-monsoon 2023	Post - monsoon 2023	Pre-Monsoon 2024	Post - monsoon 2024
1.	pH	8.1± 0.01	7.1± 0.02	7.9± 0.3	7.1± 0.2
2.	Electroconductivity (µS/m)	109.7± 1.0	110.6±11.0	97± 6.1	146.7± 12.2
3.	Total organic carbon (%)	4.1+ 0.02	5.9± 0.05	6.2± 0.03	6.0± 0.02
4.	Dissolved oxygen mg/L	3.1± 0.01	3.9± 0.03	5.3± 0.02	4.1± 0.02
5.	Total dissolved solids mg/L	799.8± 14.0	738± 13.6	575± 12.1	105.6± 11.0
6.	Salinity mg/L	581± 11.6	409± 10.9	551± 11.2	102.6± 10.0
7.	**Total Hardness** mg/L	318.56±10.7	355.40± 11.0	225.32± 10.6	434.93± 11.3
8.	Calcium mg/L	92.72± 2.3	59.46± 1.6	41.98± 2.0	83.95± 2.1
9.	Magnesium mg/L	24.33± 1.1	51.31± 1.2	29.78± 1.7	47.86± 2.1
10.	Chloride mg/L	100.32±10.0	56.07± 2.8	39.86± 0.2	156.35± 11.0
11.	Phosphate mg/L	8.23± 0.03	3.45± 0.02	3.68± 0.021	3.21± 0.02
12.	Nitrate mg/L	10.85± 2.1	5.148±0.2	4.418± 0.3	14.78± 3.0
13.	Nitrite mg/L	0	0	0	0
14.	Sodium mg/L	240.71±11.0	183.43± 2.0	192.06± 10.0	213.29± 11.0
15.	Potassium mg/L	37.90± 2.0	45.90± 2.3	51.86± 2.1	103.67± 12.0

Table 1.2: Physicochemical Characteristics of Groundwater Samples (control area), Pre- and Post-Monsoon Season – 2023-24, Collected from the Biomedical Waste Treatment Site. Data are Analysed as Compared to Standard Limits of Parameters by WHO (as per BIS IS 10500-2012 and L- ISO 8245:1999 Water Quality Guidelines).

Sl.no	Parametres	Control Pre-monsoon 2023	Control Post - monsoon 2023	Control Pre-Monsoon 2024	Control Post - monsoon 2024
1.	pH	8.1±0.2	7.6±0.1	7.9±0.12	7.2±0.1
2.	Electroconductivity (µS/m)	392± 12.0	310±10	390 ±11.0	311±10.1
3.	Total organic carbon (%)	0.5±0.02	1.1±0.2	0.6±0.02	1.0± 0.1
4.	Dissolved oxygen mg/L	4.1±0.2	6.8± 0.3	4.0±0.1	6.9±0.31
5.	Total dissolved solids mg/L	500±14.0	485±13.0	480±14.1	482±13.2
6.	Salinity mg/L	330 ±12.0	250±11.0	328±11.3	249±10.0
7.	**Total Hardness** mg/L	300 ±15.0	250±11.0	300 ±14.0	250±11.5
8.	Calcium mg/L	73.1 ±2.0	50 ±1.2.0	74.3 ±4.0	49.7 ±1.1
9.	Magnesium mg/L	48.4 ±3.3	35.2 ±2.8	48.6 ±3.1	35.2 ±2.7
10.	Chloride mg/L	240 ±12	201±11.3	241.2±12.2	200.1±11.4
11.	Phosphate mg/L	0.1 ±0.01	0.2± 0.02	0.12±0.011	0.3 ±0.023
12.	Nitrate mg/L	48.3±3.0	39 ±2.0	48.5 ±3.1	39.3 ±2.2

13.	Nitrite mg/L	0.04±0.002	0.1 ±0.01	0.05 ±0.004	0.2 ±0.02
14.	Sodium mg/L	135±11.0	88.1 ±10.0	136 ±12.0	88.3 ±10.2
15.	Potassium mg/L	19.1 ±2.0	30.4±4.1	19.4 ±3.0	30.3±4.0

Table 2.1: Physicochemical Characteristics of Test Soil Samples, Pre- and Post-Monsoon Season – 2023-24, Collected from the Biomedical Waste Treatment Site. Data are Analysed as Compared to Control and Standard Limits of Parameters by WHO (as per BIS IS 10500-2012 and L- ISO 8245:1999 Water Quality Guidelines.

Sl. No.	Parameters	Pre-monsoon 2023	Post - monsoon 2023	Pre-Monsoon 2024	Post - monsoon 2024
1.	pH	6.31 ± 0.2	6.88± 0. 22	6.47 ± 0.23	6.56 ± 0.27
2.	E. Cond (ds/m)	79.2± 1.3	80.6± 2.0	78.7± 2.1	88.1± 2.3
3.	Organic carbon (Percent)	2.46± 0.3	2.38± 0.2	2.33± 0.21	0.477± 0.23
4.	Calcium (mg/l)	164.5± 10.0	139.2± 11.0	178..5± 11.2	153.1± 11.3
5.	Magnesium (mg/l)	53.1± 2.1	60.2± 2.6	68.7± 3.1	54.8± 2.7
6.	Sodium (mg/l)	15.2± 3.2	13.8± 3.1	9.7± 2.7	12.3± 2.8
7.	Potassium (mg/l)	1.6± 0.02	2.9± 0.23	1.3± 0.21	2.6± 0.021

Table 2.2: Physicochemical Characteristics of Control Soil Samples, Pre- and Post-Monsoon Season – 2023-24, Collected from the Biomedical Waste Treatment Site. Data are Analysed as Compared to Standard Limits of Parameters by WHO (as per BIS IS 10500-2012 and L- ISO 8245:1999 Water Quality Guidelines.

Sl. No.	Parameters	Control Pre-monsoon 2023	Control Post - monsoon 2023	Control Pre-Monsoon 2024	Control Post - monsoon 2024
1.	pH	7.5± 0.3	6.9±0.21	7.6±0.31	6.8±0.2
2.	E. Cond (ds/m)	1.6 ±0.02	9.1 ±0.2	1.7±0.01	9.3±0.21.
3.	Organic carbon (Percent)	0.47±0.03	0.6±0.04	0.46±0.02	0.7±0.05
4.	Calcium (mg/l)	260 ±13.0	160±11.0	263±14.0	161±10.0
5.	Magnesium (mg/l)	98.1±4.0	67.1±3.0	98.3±4.1	67.2±3.2
6.	Sodium (mg/l)	190±12.0	87.0±3.0	191±13.0	88±4.0
7.	Potassium (mg/l)	265±12.0	188±10.0	264±11.0	189±10.1

Heavy Metal Accumulation in Plant Samples

Heavy metal concentrations in plant tissues showed considerable variation among plant parts and among the genus of *Eleusine sp.*, *Oryza sp. And Zea sp.* of *the Poaceae* family, *Abelmoschus sp.* of the *Malvaceae* family and *Coccinia sp.* of the *Cucurbitaceae family*. Cadmium concentrations in plant tissues remained below permissible limits recommended for plant safety. However, cadmium concentrations in soil and groundwater samples exceeded recommended limits (as per BIS IS 10500-2012), indicating environmental contamination through waste disposal activities. Cadmium is known for its high mobility in soil-water systems and poses ecological risks due to its persistence and bioaccumulation potential.[17,20,26]

Copper concentrations recorded in plant tissues remained within acceptable limits (Figure 1). However, elevated copper concentrations were detected in soil samples at several locations, suggesting accumulation within soil matrices rather than translocation to plant tissues. Copper contamination in soil may disrupt microbial activity and nutrient cycling, thereby affecting soil fertility.[16,27]

Lead concentrations were either minimal or undetectable in most plant tissues. However, groundwater samples showed elevated lead concentrations exceeding permissible limits, indicating potential risk to human health through drinking water exposure. Lead contamination is commonly associated with anthropogenic waste sources and poses severe neurotoxic effects in humans and animals.[17,23,30]

Iron concentrations were consistently elevated in plant tissues across sampling sites. High iron availability in contaminated soils may enhance plant uptake and contribute to physiological stress in vegetation. Excess iron accumulation can interfere with nutrient balance and photosynthetic efficiency in plants.[18,25]

Nickel concentrations showed variable distribution across plant tissues. Elevated nickel concentrations were recorded primarily in root tissues, suggesting localised contamination and restricted metal translocation. Zinc concentrations remained within permissible limits in most plant samples, indicating controlled uptake and essential micronutrient regulation mechanisms in plants.[24,26] (Figure 1)

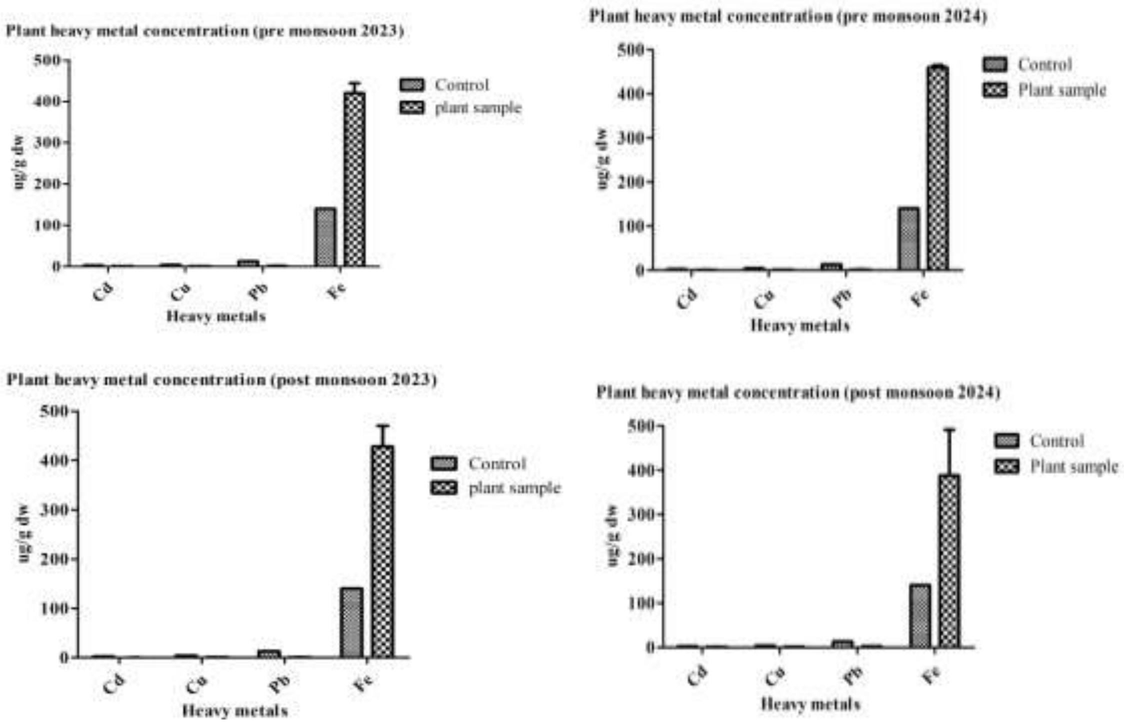


Figure 1. Heavy metal Concentrations in Plant Tissues Collected from Biomedical Waste Treatment Sites During Seasonal Sampling Periods (2023–2024).

Data are represented as the mean value of test samples, n=3, statistical analysis was performed by 2-way ANOVA, which showed a significant change in contrast to the normal range with $p<0.05$.

Heavy Metal Contamination in Soil and Water Samples

Heavy metal analysis revealed significant contamination in soil and groundwater samples surrounding biomedical waste treatment facilities. Cadmium concentrations in groundwater samples exceeded permissible limits set by as per BIS IS 10500-2012 (**Figures 2 and 3).** In most sampling sites, indicating leachate infiltration from biomedical waste disposal areas. Elevated cadmium levels in soil samples further confirm the accumulation of toxic metals within surface soil layers.[11,20,22]

Copper concentrations in groundwater samples remained within permissible limits set by as per BIS IS 10500-2012 **(Figures 2 and 3).**; however, soil samples showed elevated copper concentrations. Prolonged exposure to elevated copper concentrations may adversely affect soil microbial communities and plant growth.[16,27]

Lead contamination was particularly prominent in groundwater samples. Concentrations recorded at several sampling sites exceeded recommended limits by as per BIS IS 10500-2012 (**Figures 2 and 3).** posing serious public health risks. Soil samples also exhibited elevated lead concentrations, indicating anthropogenic contamination associated with biomedical waste disposal activities.[17,23,34]

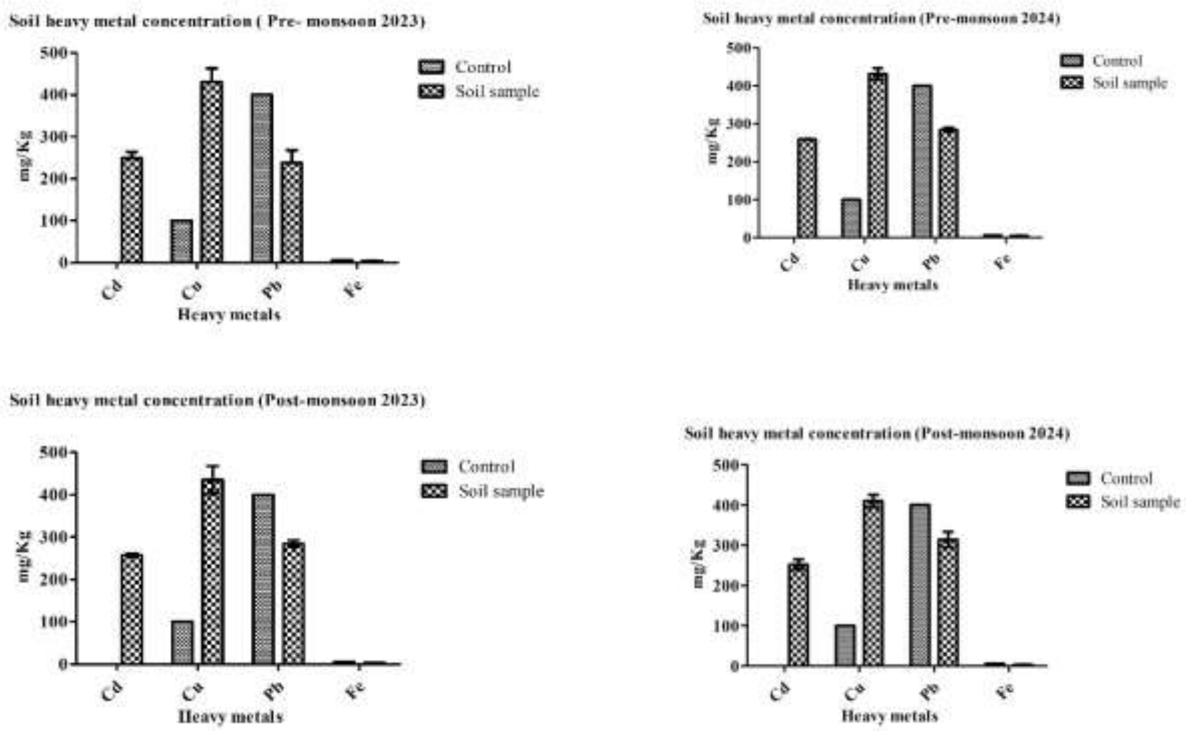
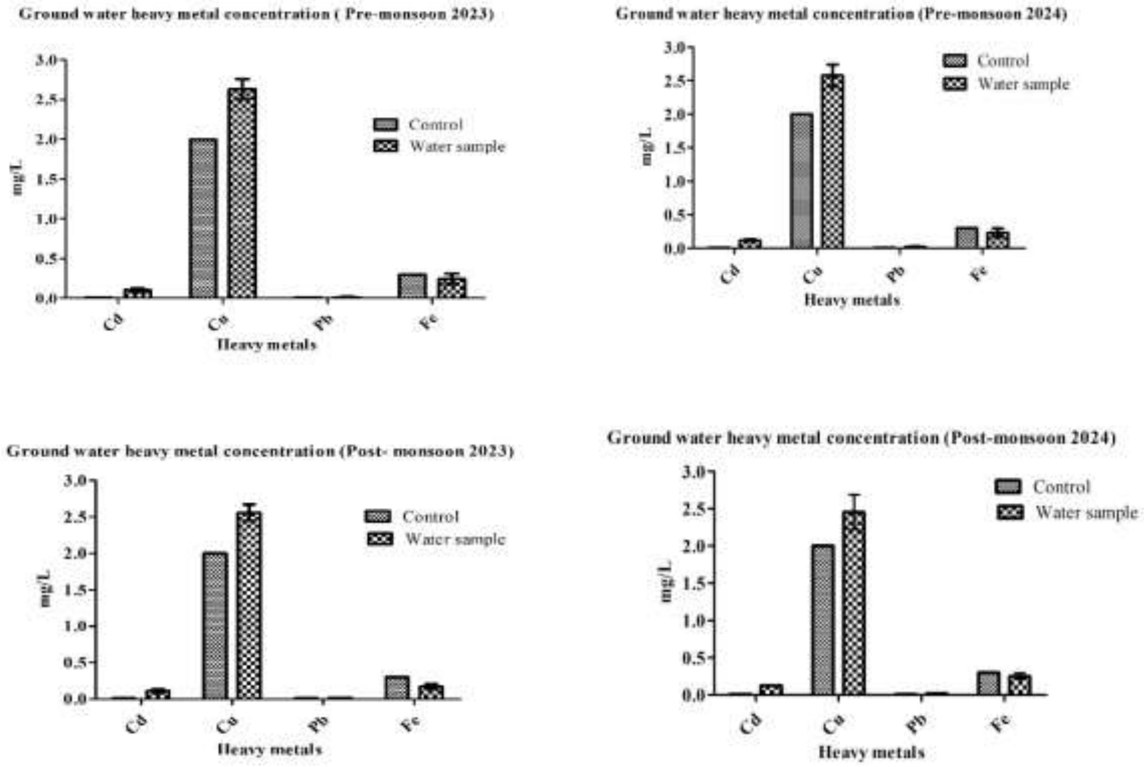


Figure 2. Comparative heavy metal concentrations in Soil samples collected from the biomedical waste treatment site during seasonal sampling periods between 2023-24. Data are represented as the mean value of test samples, n=3, statistical analysis was performed by 2-way ANOVA, which showed a significant change in contrast to the normal range with p<0.05.

Iron concentrations in groundwater samples **exceeded permissible limits (Figures 2 and 3)** across all sampling sites. Soil samples also showed significantly high iron concentrations, indicating enhanced environmental mobility and availability. Elevated iron levels in water sources may lead to health complications and deterioration of drinking water quality.[18,20]

Groundwater Quality Assessment



Groundwater analysis revealed considerable seasonal variations in physico-chemical parameters. Groundwater pH values remained slightly alkaline across sampling seasons. Electrical conductivity and total dissolved solids showed higher concentrations during pre-monsoon periods due to increased mineral dissolution and reduced dilution effects. Seasonal variations in groundwater quality are commonly influenced by rainfall recharge and anthropogenic pollution sources.[21,22,35]

Figure 3. Comparative heavy metal concentrations in groundwater samples collected from the biomedical waste treatment site during seasonal sampling periods between 2023-24. Data are represented as the mean value of test samples n=3, statistical analysis was performed by 2-way ANOVA, which showed a significant change in contrast to the normal range with $p<0.05$.

Dissolved oxygen concentrations varied among sampling sites and seasons, reflecting differences in organic matter decomposition and water aeration. Elevated bicarbonate concentrations observed during post-monsoon periods indicate increased groundwater interaction with carbonate geological formations. Groundwater hardness values were significantly higher during pre-monsoon seasons, suggesting mineral enrichment caused by reduced water recharge.[21,34]

Sodium and chloride concentrations exhibited higher levels during dry seasons, indicating evaporative concentration effects and waste leachate influence. Nitrate and phosphate concentrations showed seasonal fluctuations, suggesting potential contributions from agricultural runoff and anthropogenic contamination.[21,22]

DISCUSSION

The present study provides strong evidence of environmental contamination associated with biomedical waste treatment facilities in Mysuru city. The results revealed significant seasonal variations in soil, groundwater, and plant heavy metal concentrations, demonstrating the influence of waste disposal practices, climatic factors, and geochemical interactions on pollutant mobility (Figures 1-3). Similar environmental impacts of biomedical waste disposal have been reported in several developing countries where inadequate waste management infrastructure contributes to contamination of surrounding ecosystems.[5-7,33]

Influence of Biomedical Waste on Soil Quality

The reduction in soil pH observed from pre-monsoon to post-monsoon seasons indicates enhanced leaching of alkaline ions due to rainfall infiltration. Soil acidification increases the solubility and mobility of heavy metals, thereby enhancing ecological risks associated with contaminated soils. Previous studies have demonstrated that biomedical waste leachates significantly alter soil physicochemical characteristics, leading to deterioration of soil fertility and microbial imbalance.[11,18,29]

Electrical conductivity values showed seasonal dilution during post-monsoon periods, reflecting reduced salt accumulation due to rainfall recharge. However, localized increases in conductivity at certain sampling sites indicate continuous discharge of biomedical waste-derived contaminants (Table 2.1 and 2.2). Elevated organic carbon concentrations observed during post-monsoon seasons suggest increased microbial decomposition of organic residues, which may enhance metal complexation and influence metal bioavailability. These findings are consistent with studies indicating that organic matter plays a critical role in controlling heavy metal mobility in contaminated soils.[18,27,35]

Elevated calcium, magnesium, and sodium concentrations recorded in contaminated soils suggest mineral dissolution processes influenced by biomedical waste leachate infiltration. Increased sodium accumulation may lead to soil salinisation and structural degradation, thereby reducing agricultural productivity and affecting plant growth.[27,35]

Heavy Metal Contamination and Plant Uptake

Heavy metal contamination detected in soil and groundwater samples indicates anthropogenic pollution associated with biomedical waste disposal activities (Figure 1-3). Cadmium and lead contamination observed in groundwater samples suggests downward migration of toxic metals through soil profiles into aquifers. Cadmium is recognised as a highly toxic element capable of accumulating in biological tissues, causing kidney dysfunction and skeletal disorders. Lead exposure is associated with neurological impairment, developmental abnormalities, and cardiovascular complications.[17,23,26]

Plant samples demonstrated comparatively lower accumulation of most heavy metals except iron, indicating selective uptake mechanisms and plant defence responses. Restricted accumulation of cadmium, copper, and zinc in plant tissues may be attributed to plant physiological regulation of micronutrient absorption and limited metal translocation from roots to aerial tissues. Root tissues exhibited higher metal accumulation compared to stems and leaves, indicating phyto-stabilisation mechanisms that restrict metal movement within plant systems.[24,26,31]

Elevated iron accumulation in plant tissues indicates high environmental availability and potential physiological stress. Excess iron may interfere with nutrient balance, inhibit enzymatic activity, and reduce photosynthetic efficiency in plants. Similar findings have been reported in vegetation growing in contaminated environments exposed to waste disposal activities.[18,25]

Groundwater Contamination and Public Health Implications

Groundwater quality assessment revealed elevated concentrations of dissolved solids, hardness, and heavy metals, particularly during pre-monsoon seasons. Increased pollutant concentrations during dry seasons may be attributed to reduced dilution, evaporation-driven mineral enrichment, and continuous contaminant discharge (Table 1.1 and 1.2). Groundwater contamination near waste disposal sites has been widely documented and is considered a major public health concern in developing regions.[21,22,34]

Elevated concentrations of cadmium, lead, and iron detected in groundwater samples pose significant health risks to local communities relying on bore well water for domestic consumption. Chronic cadmium exposure may cause renal dysfunction and bone demineralisation, while lead exposure is associated with neurological toxicity and impaired cognitive development. Excess iron intake has been linked to cardiovascular disorders and liver dysfunction. These findings highlight the urgent need for groundwater monitoring and remediation strategies in contaminated regions.[17,23,20]

Seasonal Influence on Environmental Contamination

Seasonal variations played a significant role in controlling contaminant distribution patterns. Pre-monsoon samples exhibited higher concentrations of heavy metals and dissolved ions due to evaporation, reduced groundwater recharge, and concentration of contaminants. Post-monsoon samples showed comparatively lower concentrations due to rainfall dilution and enhanced groundwater recharge. However, the persistence of heavy metals even after monsoon dilution indicates long-term environmental contamination and continuous pollutant input from biomedical waste disposal sites.[21,35]

Ecological Risk and Environmental Sustainability

The accumulation of heavy metals in soil and groundwater ecosystems may lead to long-term ecological consequences, including soil fertility loss, microbial community imbalance, and contamination of agricultural produce. Although plant samples showed limited immediate heavy metal accumulation, continuous exposure may result in gradual bioaccumulation and biomagnification within food chains. Phytoremediation strategies using metal-accumulating plant species have shown promising results in reducing heavy metal contamination and restoring ecosystem balance.[24,25,31]

The findings of the present study emphasise the necessity of adopting advanced biomedical waste treatment technologies, improving waste segregation practices, and strengthening environmental monitoring systems. Implementation of eco-friendly remediation approaches such as phytoremediation, soil amendments, and groundwater purification is essential to reduce contamination and ensure environmental sustainability.

CONCLUSION

The present study demonstrates significant environmental contamination associated with biomedical waste treatment facilities in Mysuru city. Elevated concentrations of heavy metals, particularly cadmium, copper, lead, and iron, were detected in soil and groundwater samples, with several values exceeding permissible limits. Seasonal variations indicated higher contamination levels during pre-monsoon periods due to reduced dilution and increased pollutant accumulation.

Plant samples exhibited comparatively lower heavy metal accumulation, suggesting restricted bioavailability and plant-specific uptake mechanisms. However, elevated iron concentrations observed in plant tissues indicate potential physiological stress in vegetation. Groundwater contamination poses serious public health risks due to elevated concentrations of cadmium, lead, and iron detected in bore well water samples considering normal range of values as per BIS IS 10500-2012.

The findings highlight the urgent need for improved biomedical waste management practices, continuous environmental monitoring, and adoption of sustainable waste treatment technologies. Implementation of remediation strategies such as phytoremediation, soil treatment, and groundwater purification are essential to minimise contamination and protect ecological and human health. Strengthening regulatory enforcement and public awareness programs can further support sustainable biomedical waste management and environmental protection.

REFERENCES

1. World Health Organization. Safe management of wastes from health-care activities. 2nd ed. Geneva: WHO Press; 2014.
2. Ministry of Environment, Forest and Climate Change, Government of India. Biomedical Waste Management Rules. New Delhi; 2016.
3. Windfeld ES, Brooks MS. Medical waste management – A review. J Environ Manage. 2015;163:98-108.
4. Chartier Y, Emmanuel J, Pieper U, et al. Safe management of wastes from health-care activities. Geneva: World Health Organization; 2014.
5. Attrah M, Elmanadely A, Akter D, Rene ER. Medical waste management: Treatment, recycling, and disposal options. Environments. 2022;9(11):146.
6. Wei Y, Cui M, Ye Z, Guo Q. Environmental challenges from increasing medical waste during pandemics. Waste Manag. 2021;25(3-4):199-210.
7. Caniato M, Tudor T, Vaccari M. International governance structures for healthcare waste management. J Environ Manage. 2015;153:93-107.
8. Sharma HB, Vanapalli KR, Cheela VR, et al. Challenges and innovations in solid waste management during pandemics. Resour Conserv Recycl. 2020;162:105052.
9. Torkashvand J, Godini H, Kazemi M, Farzadkia M. Medical waste management status in healthcare centers. J Environ Health Sci Eng. 2021;19:391-401.
10. Singh N, Tang Y, Ogunseitan OA. Environmentally sustainable biomedical waste management. Environ Sci Technol. 2022;56(6):3218-3230.
11. Mishra S, Sharma D, Singh S. Heavy metal contamination and ecological risk

assessment around biomedical waste disposal sites. Environ Monit Assess. 2021;193:692.
12. Khan FA, Husain T, Hejazi R. Review of site remediation technologies. J Environ Manage. 2004;71:95-122.
13. Kumar A, Samadder SR. Waste to energy technologies for solid waste management. Waste Manag. 2017;69:407-422.
14. Gupta N, Yadav KK, Kumar V. Current status of solid waste management in India. J Environ Sci. 2015;37:206-217.
15. Ali SM, Pervaiz A, Afzal B, Hamid N, Yasmin A. Hazardous impacts of open waste dumping on soil and vegetation. Pak J Bot. 2014;46:193-201.
16. Li X, Poon C, Liu P. Heavy metal contamination of urban soils. Appl Geochem. 2001;16:1361-1368.
17. Tchounwou PB, Yedjou CG, Patlolla AK, Sutton DJ. Heavy metal toxicity and human health effects. Environ Toxicol. 2012;101:133-164.
18. Alloway BJ. Heavy Metals in Soils. 3rd ed. Dordrecht: Springer; 2013.
19. Wuana RA, Okieimen FE. Heavy metals in contaminated soils: Sources and remediation techniques. ISRN Ecol. 2011;2011:402647.
20. Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN. Toxicity and health effects of heavy metals. Interdiscip Toxicol. 2014;7(2):60-72.
21. Adimalla N, Li P. Health risks of fluoride and nitrate contamination in groundwater. Environ Pollut. 2019;248:120-131.
22. Saha P, Paul B. Groundwater quality and heavy metal contamination assessment. Environ Sci Pollut Res. 2021;28:35036-35050.
23. Nriagu JO, Pacyna JM. Global contamination of trace metals in environment. Nature. 1988;333:134-139.
24. Rai PK. Heavy metal phytoremediation in aquatic ecosystems. Crit Rev Environ Sci Technol. 2009;39:697-753.
25. Ali H, Khan E, Sajad MA. Phytoremediation of heavy metals. Chemosphere. 2013;91:869-881.
26. Sharma R, Agrawal M, Marshall F. Heavy metals in vegetables and human health risk assessment. Food Chem Toxicol. 2009;47:583-591.
27. Kumar V, Parihar RD, Sharma A, et al. Global evaluation of heavy metal contamination in agricultural soils. Chemosphere. 2019;221: 154-165.
28. Singh J, Kalamdhad AS. Effects of healthcare waste disposal on soil and groundwater. Environ Dev Sustain. 2020;22:7253-7270.
29. Chen H, Teng Y, Lu S, Wang Y, Wang J. Contamination features and health risk assessment of soil heavy metals. Ecotoxicol Environ Saf. 2015;113:35-42.
30. Zeng X, Xu X, Boezen HM, Huo X. Children’s exposure to heavy metals from contaminated environments. Environ Int. 2016;94:405-412.
31. Abbas M, Adil M, Ehtisham-ul-Haque S, et al. Metal accumulation and health risk assessment in vegetables grown near waste disposal sites. Environ Sci Pollut Res. 2018;25: 12040-12049.
32. Kumar S, Kumar R, Bandopadhyay A. Environmental and occupational hazards associated with healthcare waste management. Environ Health Prev Med. 2021;26:37.
33. Ferronato N, Torretta V. Waste mismanagement in developing countries. Int J Environ Res Public Health. 2019;16:1060.
34. Sharma P, Tyagi R. Groundwater contamination due to landfill leachate. Environ Sci Pollut Res. 2020;27: 11168-11182.
35. Singh P, Kumar A, Kumar S. Seasonal variation in groundwater quality and heavy metal contamination near waste disposal sites. J Environ Chem Eng. 2022;10:107152.