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ASSESSMENT OF WATER QUALITY AND HEAVY METAL POLLUTION IN LEACHATE FROM MUNICIPAL DUMPING GROUND LOCATED IN DEEPOR BEEL, A RAMSAR SITE

OCENA KAKOVOSTI IN ONESNAŽENOSTI S TEŽKIMI KOVINAMI IZCEDNE VODE Z ODLAGALIŠČA KOMUNALNIH ODPADKOV NA OBMOČJU RAMSARSKEGA OBMOČJA DEEPOR BEEL

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Abstract

Municipal waste is a collection of residential, industrial, institutional, commercial, construction, and demolition waste collected by a municipality and disposed at a particular site. In poor urban areas, a large proportion of leachate is discharged, untreated directly into the closest water body. The Boragaon Garbage Dump is located inside the eastern part of Deepor Beel Wildlife Sanctuary, the only Ramsar site in Assam, Northeast India. The Boragaon Municipal Garbage dump directly releases its landfill leachate into the Deepor Beel, which increases the concentration of toxic substances in its water. In the present study, the water quality parameters and heavy metal concentration (EC, TDS, turbidity, pH, Na^+, K^+, Cl^-, F^-, BOD, DO, SO_4^{2-}, PO_4^{3-}, NO_{3-}, As, Be, Cd, Ca, Cr, Cu, Fe, Mn, Mg, Ni, Pb and Zn) of the water in the outlets of Boragaon Garbage dump released into the Deepor Beel were assessed using standard methods for a one-year period. The results found were quite surprising, with very high levels of EC (8740±120 μScm^{-1}), turbidity (693±1 NTU), BOD (458.6±1.86 mg/L), TDS (917.4±2.23 mg/L), K (53.9±0.24 mg/L), Cl^- (502.28±2.96 mg/L), Al (7.21±0.06 mg/L), As (129.42±0.22 µg/L), Ni (0.102±0.002mg/L) and Pb (32.4±1 µg/L). These large amounts of physiochemical properties and heavy metals concentration in water may cause detrimental effects on the ecological communities of the Deepor Beel and the nearby human population. This Ramsar site needs an immediate solution such as the relocation of the dumping ground and better management of the existing waste to rectify the problem of deteriorating water quality, otherwise the water quality will be past the point of recovery within a decade.

Keywords: Assam, landfill leachate, management, physio-chemical parameters, toxicity, wetland.

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Izvleček

Komunalni odpadki so odpadki iz gospodinjstev, industrije, gradbeništva in rušenja objektov ter institucionalni in komercialni odpadki, ki jih zbira občina in odlaga na določenem odlagališču. Na revnih mestnih območjih se velik del izcedne vode brez čiščenja odvaja neposredno v najbližje vodno telo. Odlagališče Boragaon se nahaja v vzhodnem delu naravnega rezervata Deepor Beel, edinega ramsarskega območja v Assamu, na severovzhodu Indije. To odlagališče komunalnih odpadkov izpušča izcedne vode neposredno v Deepor Beel, kar povečuje koncentracijo strupenih snovi v vodi. V tej raziskavi so bili s standardnimi metodami ocenjeni parametri kakovosti vode in koncentracije težkih kovin (električna prevodnost, skupne raztopljene trdne snovi, motnost, pH, Na^+, K^+, Cl^-, F^-, biokemijska potreba po kisiku, raztopljeni kisik, SO_4^{2-}, PO_4^{3-} , NO3-, As, Be, Cd, Ca, Cr, Cu, Fe, Mn, Mg, Ni, Pb in Zn) v vodi na iztoku iz odlagališča Boragaon v Deepor Beel v obdobju enega leta. Ugotovljeni rezultati so bili precej presenetljivi, saj so bile ugotovljene zelo visoke vrednosti električne prevodnosti (8740±120 µScm-1), motnosti (693±1 NTU), biokemijske potrebe po kisiku (458,6±1,86 mg/L), skupnih raztopljenih trdnih snovi (917,4±2. 23 mg/L), K (53,9±0,24 mg/L), Cl- (502,28±2,96 mg/L), Al (7,21±0,06 mg/L), As (129,42±0,22 µg/L), Ni (0,102±0,002 mg/L) in Pb (32,4±1 µg/L). Te velike vrednosti fizikalno-kemijskih parametrov in visoke koncentracije težkih kovin v vodi lahko škodljivo vplivajo na ekološke združbe na območju Deepor Beel in okoliško prebivalstvo. To območje, zaščiteno v okviru Ramsarske konvencije, potrebuje takojšnjo rešitev, kot je odstranitev odlagališča in boljše ravnanje z obstoječimi odpadki, da se odpravi slabšanje kakovosti vode – sicer bo v desetih letih prenehalo obstajati.

Ključne besede: Assam, izcedne vode z odlagališč, ravnanje z odpadki, fizikalno-kemijski parametri, toksičnost, mokrišče.

1. Introduction

Wetlands, renowned as paradises for biological diversity and among the most productive habitats on Earth, face unprecedented challenges due to the global surge in population (Ramsar Convention Secretariat, 2013). India, boasting a total wetland area of 15.3 million hectares, hosts approximately 757,000 wetlands, covering about 4.7% of its total land area (National Wetland Atlas, 2011). However, the majority of issues plaguing India's wetlands are a direct consequence of the population explosion, more specifically due to per capita waste production (Abubakar et al., 2022).

In India, over 50 million tons of solid waste are collected annually from urban areas, contributing to the deterioration of wetlands as this waste is often dumped near these crucial ecosystems (Shekdar, 2009). The improper disposal of waste near wetlands leads to the release of odor, biogas, and a substantial amount of leachate containing heavy metals (HMs) (Da Silva et al., 1996; Pekey et al., 2004; Azhar et al., 2015). This leachate, mainly consisting of dissolved organic matter, inorganic compounds, heavy metals, and xenophobic organic substances, poses severe environmental risks, adversely affecting the soil, groundwater, and surface water in the area (Bouzayani et al., 2014; Azhar et al., 2015; Dhamodharan et al., 2019).

The consequences of this environmental degradation are manifold, leading to eutrophication, higher water temperatures, loss of biodiversity, and the depletion of ecosystem services (Wahl et al., 1997; Dorioz et al., 1998; Leblanc et al., 1997; Holland et al., 1995; Davis and Froend, 1999; Cheela et al., 2021; Mohan and Joseph, 2021; Bhat et al., 2022). Moreover, the release of landfill leachate, a liquid formed from water percolating through decomposing waste, contains infectious agents like bacteria such as *Escherichia coli*, *Cryptosporidium sp.*, and *Salmonella sp.*, as well as other viruses posing risks for public health. These pathogens can contaminate water, soil, and groundwater, leading to the spread of diseases (Smith et al. 2018) such as tuberculosis, pneumonia, diarrhea, tetanus, whooping cough, kidney and heart diseases, infertility, and cancer (Arnold et al., 1957; Scarlett-Kranz et al., 1987; Wankhede and Wanjari, 2021). Exposure to heavy metals through bioaccumulation in food and drinking water can lead to adverse health effects, including anaemia, weakness, and damage to the kidneys, reproductive organs, and brain. Children are particularly vulnerable to these effects compared to adults. Additionally, cadmium (Cd) is a highly toxic carcinogen that poses harm to various bodily systems (Hutton 1987; Jarup and Akesson 2009; Jaishankar et al. 2014, Ademola et al., 2020).

The Deepor Beel located in Kamrup district of Assam is one of the largest freshwater wetlands in the Brahmaputra Valley of Lower Assam, India (Deka and Goswami, 1992). It is a prime representative wetland type found within the biogeographic province of Burma Summer Forest (RIS, 2002). Connected with the river Brahmaputra in the north by the Khanajan rivulet, this covers a total area of 589 ha area with depth ranging from 1 m to 4 m with a 12-km buffer area (NWA, 2013). It was declared a wildlife sanctuary in the year 1989, a wetland of international importance under the Ramsar Convention on wetlands in 2002, and an Important Bird Area (IBA) in 2003 (Saikia and Saikia, 2011). It hosts 234 species of birds, 24 species of mammals, 58 species of aquatic macrophytes, diatoms (65), zooplankton (171), bryozoans (5), molluscs (15), aquatic insects (55), prawns (3), crabs (2), fish (68), amphibians (11), reptiles (33), and mammals (24) (Bhattacharjya et al., 2021). This lake act as a major storm water storage basin and watershed for Guwahati City (MoEF, 2008). Guwahati, the capital city of Assam, India, has a municipal waste dumping facility where 420 to 450 tons of solid waste are dumped each day (Chakraborty et al., 2014). The part of Deepor Beel near Boragaon was chosen as the dumping site of municipal waste for the Guwahati City. Given that it serves as the city’s sole watershed, this has become a matter of significant concern. However, the ecosystem of Deepor Beel is currently under severe pressure. Therefore, we aim to study the water quality of the wetland with the following objectives:

1. Assessment of water quality and trace metals in Deepor Beel near Boragaon Garbage Dump, Guwahati, Assam.

2. Comparative analysis of the parameters gathered from secondary sources for the last two decades.

2. Materials and methods

2.1 Study area

The study was conducted in Deepor Beel, located in the southwest corner of Guwahati, India (Singhal et al., 2022). Deepor Beel (26° 7' 1.2"N and 91° 39' 28.8"E), a Ramsar Site and a perennial freshwater lake covering approximately 4000 hectares, was formed by a former Brahmaputra River channel (Nikita et al., 2023). This wetland receives water from the Brahmaputra River through a connected canal known as Khana Jan, serving both as an inlet and an outlet (Bhattacharjya et al., 2021). Deepor Beel directly supports the livelihoods of around 800 households through fisheries, with an annual fishing value of INR 11,64,69,375 (Dutta and Sharma, 2020). Annually, the city receives 152 to 324 cm of rain, with heavy rains from July until mid-October. Winter lasts from mid-October to March, with lows as low as 11 °C. Summer lasts from April to June, with temperatures reaching 38 °C. Throughout the year, humidity levels range from 76 to 94%, with July and August being the most humid months. During the late winter month of February and the pre-monsoon season of March-April, humidity is low, ranging between 71-78% in the morning and 50-57% in the evening (Singhal et al., 2022). The wetland is also a Wildlife Sanctuary, hosting 200 bird species, including 70 migratory birds. In 2008, the eastern side of Deepor Beel (26° 6'48.00"N and 91°40'39.52"E), was selected as the municipal waste dumping site for the Guwahati City (Figure 1). This Municipal Waste dumping facility near Boragaon in Deepor Beel receives 800 metric tons of solid waste each day (Singhal et al., 2022). Anthropogenic stressors have developed in recent years due to ongoing operations such as construction, dumping of mixed solid waste, and the release of untreated sewage, such as from the Pamohi River (Action plan for Deepor Beel Priority-III, 2019).

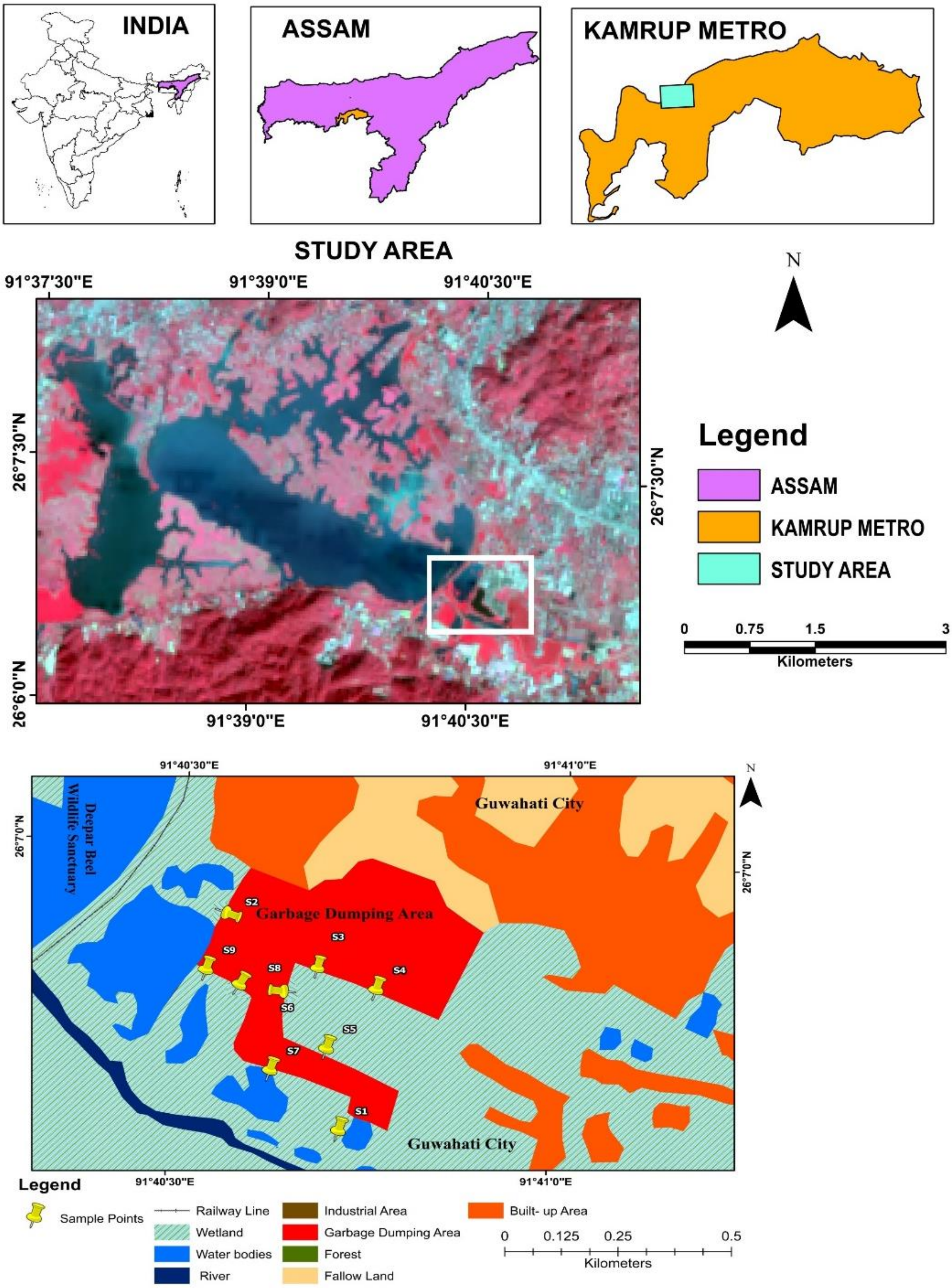


Figure 1: *Map showing study area (Boragaon garbage dump) as well as sample collection sites.*

Slika 1: *Karta z območjem raziskave (odlagališče Boragaon) in mesti vzorčenja.*

***Table 1:** Leachate sample collection sites at the Boragaon garbage dump, Deepor Beel, Assam*

***Preglednica 1:** Mesta vzorčenja izcedne vode na odlagališču Boragaon, Deepor Beel, Assam.*

Sample collection area	Water Sample Collection Site	Geographical location
Deepor Beel, Assam	S1	26°6'38.20"N, 91°40'44.28"E
	S2	26°6'56.66"N, 91°40'41.07"E
	S3	26°6'51.82"N, 91°40'41.58"E
	S4	26°6'49.44"N, 91°40'46.59"E
	S5	26°6'45.28"N, 91°40'45.97"E
	S6	26°6'36.14"N, 91°40'47.64"E
	S7	26°6'42.68"N, 91°40'38.61"E
	S8	26°6'49.12"N, 91°40'36.73"E
	S9	26°6'50.35"N, 91°40'33.08"E

2.2 Sample Collection

At the Boragaon Garbage Dumping Site, diverse categories of municipal waste are deposited at distinct locations within the facility. Consequently, a total of nine sampling points (Figure 1 and Table 1) within the water body and were systematically chosen through random selection across the leachate points. This strategic sampling approach aimed to comprehensively encompass all conceivable sites of potential toxic contamination stemming from the garbage deposit in Deepor Beel, as depicted in Figure 2. The samples were collected in 2019 over two seasons, namely summer (July) and winter (December). A total of 5 samples were collected from each sampling sites at an interval of 6 days. Samples were collected in middle of the month from a depth of 0.3 m to ensure the regular sampling pattern. The study sites were sampled between 08:00 AM to 11:00 AM to minimize the influence of the fluctuation in water quality throughout the day (Choudhury and Gupta, 2017; Roy and Majumdar, 2022). To remove suspended particles, samples were filtered through Whatman No. 42 filter paper and stored in 1 L glass (sterile) sample containers (Borosil).

2.3 Physiochemical experiments

Physiochemical parameters like electrical conductivity (EC), total dissolved solid (TDS), turbidity and pH were estimated in situ, using a multiparameter water quality analyzing device (model: Systronics-371). Sodium and potassium were estimated in the laboratory under a flame photometer (model: Systronics-128) following standard methods (APHA, 2017; Choudhury and Gupta, 2017). Fluoride samples were estimated under an ion meter (Model: Orionstar A214), biochemical oxygen demand (BOD) was estimated in Oxitop (Model: WTW, i IS 6), dissolved oxygen (DO) was estimated immediately using the Winkler method (APHA, 2017), and nitrate (NO_3) was assessed using a UV-visible spectrophotometer (Model: Genesys 10 S, Thermofisher).

2.4 Heavy metals analysis

To estimate the heavy metals such as aluminum (Al), arsenic (As), beryllium (Be), cadmium (Cd), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), magnesium (Mg), nickel (Ni), lead (Pb), and zinc (Zn), water samples were collected from the sampling sites in 1-L sterilized glass bottle (Borosil). Samples were then filtered and acidified with concentrated nitric acid (HNO3) to a pH below 2.0 and stored below 4 °C until analysis (Mays and Edwards, 2001). All the heavy metals were estimated using an atomic absorption spectrophotometer (AAS) (Model: iCE3500, Thermofisher) following the standard method (EPA method 3050B; APHA, 1998) at the North Eastern Regional Institute of Water and Land Management (NERIWALM), Tezpur, Assam.

Figure 2: *Landfill leachate outlets in Deepor Beel: A. Discharge of leachate through pipes from the Boragaon garbage recycling unit; B. Direct run off from the Boragaon municipal garbage dump.*

Slika 2: *Odtoki izcedne vode z odlagališča na območju Deepor Beel: A. Odvajanje izcedne vode po ceveh iz enote za recikliranje odpadkov Boragaon; B. Neposredno odtekanje z odlagališča komunalnih odpadkov Boragaon.*

3. Results and Discussion

The maximum water quality parameters (WQP) and heavy metals concentrations of landfill leachate leaching into Deepor Beel were higher than the WQP of wetlands with no signs of pollution (Soni and Thomas, 2014; Mashagbah, 2015; Gaur et al., 2022; Maansi et al., 2022; Kushwah et al., 2023) and also out of the desirable limit for drinking water according to BIS (2012), WHO (2017), and NERIWALM (2019), which indicates that the quality of water in the lake is detrimental for local biodiversity as well as the nearby human population. All the water analysis data of all the recorded samples are shown in the Appendices (1 & 2) and heavy metal concentrations in Figure (3 & 4). These analyses are discussed under each of the individual WQP and compared to BIS (2012), WHO (2017), NERIWALM (2019) as well as with the earlier studies conducted on WQP of Deepor Beel and other wetlands (Table 2).

In our current study, it is evident that all the water quality parameters deteriorated significantly during the winter season compared to the summer season. This seasonal variation can be attributed to the direct flow of rainwater through uncovered garbage during heavy summer rainfall, resulting in substantial leachate formation and its subsequent inflow from the Boragaon Garbage dump into Deepor Beel. Various parameters such as pH, EC, turbidity, SO_4^{2-}, PO_4^{3-}, NO_3^-, BOD, K^+, Cl^-, Fl^-, TDS, Al, As, Fe, Ca, Cr, Pb, Be, Mn and Ni exceeded the permissible limits as per the guidelines set by BIS (2012), WHO (2017) and NERIWALM (2019).

3.1. Physicochemical properties

3.1.1. pH

The pH values of the water samples from Deepor Beel range between 8.14±0.03 and 13.7±0.19. The average pH during the summer season was slightly higher at 11.09±0.06 compared to the winter season's 10.85±0.11. The pH values were high due to higher DO and hence increased respiration in winter, generating more CO_2 (Roy and Majumder, 2022). The pH value of the analyzed samples from the study area were higher than the standard level recommended by BIS (2012), WHO (2017), and NERIWALM (2019). The pH values reported in our study are also higher than those found in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Kapil and Bhattacharyya (2013), Islam et al. (2014), Sayed et al. (2015), the Pollution Control Board (PCB), Guwahati (2016-17), Choudhury and Gupta (2017), Deb et al. (2019), Roy and Majumder

(2022), and the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), King Abdullah Canal (Mashagbah, 2015), Tawang reservoir (Gaur et al., 2022), Sukhna Lake (Maansi et al., 2022) and Gompti river (Kushwah et al., 2023).

3.1.2. Electrical conductivity (EC)

The EC values of the samples vary from 1170±10 μScm^{-1} to 8740±120 μScm^{-1}, with a higher value during the summer season (4420±80μScm^{-1}) than the winter season (3190±38 μScm^{-1}). The EC was found much higher than the standard value set by WHO (2017) and earlier studies in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Sayed et al. (2015), Choudhury and Gupta (2017), Deb et al. (2019), Roy and Majumder (2022) and the Pollution Control Board, Guwahati (2016-17). It was also higher than the values found in the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), King Abdullah Canal (Mashagbah, 2015), Tawang reservoir (Gaur et al., 2022), Sukhna Lake (Maansi et al., 2022) and Gompti river (Kushwah et al., 2023).

3.1.3. Turbidity

Turbidity values range from 12.2±0.58 NTU to 693.8±1.24 NTU, with a slightly higher average value during the summer season (418.4±1.48 NTU) than the winter season (408.33±1.31NTU). The values of turbidity recorded during the study were very high compared to earlier studies on Deepor Beel by Deb et al. (2019), Roy and Majumder (2022) and the Pollution Control Board, Guwahati (2016-17). They were also higher than the turbidity levels found in the surface water of the Gompti river (Kushwah et al., 2023) and the standard levels recommended by BIS (2012) and WHO (2017).

3.1.4. Dissolved oxygen (DO)

The DO levels fluctuate between 2±0.02mg/L and 9.62±0.06 mg/L with a higher average during the summer (5.15 ±0.07 mg/L) than the winter (3.98±0.03 mg/L). The standard value of DO was 5 mg/L, the level required to sustain fish and other aquatic life (Adeniji, 1986; Ayodele and Ajani 1999; Adakole, 2000). The DO values depend on temperature, hence during the summer the DO values remain low and in winter the values are comparatively higher (Roy and Majumder, 2022). But our results show the opposite, which was due to maximum pollutant in the water. The organic load in the form of sewage waste increased the value of DO (Ahmed and Wanganeo, 2015; Bhat et al., 2015). Our results were almost similar to the earlier study in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Islam et al. (2014), Deb et al. (2019) but lower than Sayed et al. (2015), the Pollution Control Board, Guwahati (2016-17), and Choudhury and Gupta (2017). It was also higher than the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), Sukhna Lake (Maansi et al., 2022) and the Gompti river (Kushwah et al., 2023).

3.1.5. Sulphate (SO_4^{2-})

The values for SO_4^{2-} range from 0.137±0.002 mg/L to 382.78±1.22 mg/L, with an average slightly higher (242.36±0.78 mg/L) during the summer season than the winter season (231.57±0.67 mg/L). This was higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Sayed et al. (2015), and the Pollution Control Board, Guwahati (2016-17) as well as the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), Tawang (Gaur et al., 2022), Sukhna Lake (Maansi et al., 2022), and Lake Baikal (Pastukhov et al., 2023), but lower than the King Abdullah Canal (Mashagbah, 2015). It was also higher than the standard levels recommended by WHO (2017), BIS (2012) and NERIWALM (2019).

3.1.6. Phosphate (PO_4^{3-})

PO_4^{3-} values range between 0.02±0.001mg/L and 19.52±0.09mg/L, with a slightly higher average in summer (12.33±0.74 mg/L) than in winter (11.48±0.1 mg/L). This was much higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Choudhury and Gupta (2017), the Pollution Control Board, Guwahati (2016-17), Deb et al. (2019), Roy and Majumder (2022) and also the standard level recommended by NERIWALM (2019), but lower than the surface water of Tawang (Gaur et al., 2022). Due to higher organic load, phosphate content of lake was always found higher than the admissible level (0.03 mg/L) (Roy and Majumder, 2022). According to Jacobson (1991), even a slightly high concentration of phosphate supports algal growth and indicate pollution.

3.1.7. Nitrate (NO_3^-)

NO_3^- values range between 4.91±0.02 mg/L to 72±0.95 mg/L, with a higher average during the summer season (29.77±0.32 mg/L) than in winter (27.48±0.19 mg/L). This was higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), the Pollution Control Board, Guwahati (2016-17), Choudhury and Gupta (2017), Deb et al. (2019), Roy and Majumder (2022), the standard level recommended by WHO (2017), BIS (2012), NERIWALM (2019) and the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), Tawang (Gaur et al., 2022), and Sukhna Lake (Maansi et al., 2022). The high value of nitrate in the study site was due to effluents from livestock facilities, septic systems, domestic sewage, fertilizers, and household waste (Muniyan and Ambedkar 2011; BIS, 2012; Vyas and Bhawsar, 2013).

3.1.8. Biochemical oxygen demand (BOD)

BOD values range from 10.9±0.12 mg/L to 458.6±1.86 mg/L, with the average value higher (273.83±1.05 mg/L) during the summer season than during the winter (266.14±0.91 mg/L). This was much higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), the Pollution Control Board, Guwahati (2016-17), Choudhury and Gupta (2017), Deb et al. (2019) and Roy and Majumder (2022), the standard level recommended by NERIWALM (2019), and the surface water of the Gompti river (Kushwah et al., 2023).

3.1.9. Sodium (Na^+)

The Na^+ values range between 21.4±1.03 mg/L to 175.04±1.30 mg/L, being higher (137.63±0.84 mg/L) in the summer season than the winter season (100.09±1.01 mg/L). This was much higher than the values recorded in Deepor Beel by Sharma and Sharma (2005), Sayed et al. (2015), Deb et al. (2019) and the Pollution Control Board, Guwahati (2016-17). It was also higher than the values found in the surface water of Tawang (Gaur et al., 2022), but lower than those recorded in the King Abdullah Canal (Mashagbah 2015) and Lake Baikal (Pastukhov et al., 2023). Additionally, it exceeded the standard level recommended by WHO (2017).

3.1.10. Potassium (K^+)

The K^+ values range between 6.02±0.10 mg/L and 53.9±0.24 mg/L, with the average value higher in summer (23.79±0.28 mg/L) than winter (21.82± 0.22mg/L). It was higher than the values reported by Sayed et al. (2015), Sharma and Sharma (2005), Deb et al. (2019) and the Pollution Control Board, Guwahati (2016-17) for Deepor Beel. It also exceeded the values recorded for the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), King Abdullah Canal (Mashagbah, 2015), Tawang (Gaur et al., 2022), Gompti (Kushwah et al., 2023) and Lake Baikal (Pastukhov et al., 2023). Additionally, it was above the standard level recommended by WHO (2017).

3.1.11. Chloride (Cl^-)

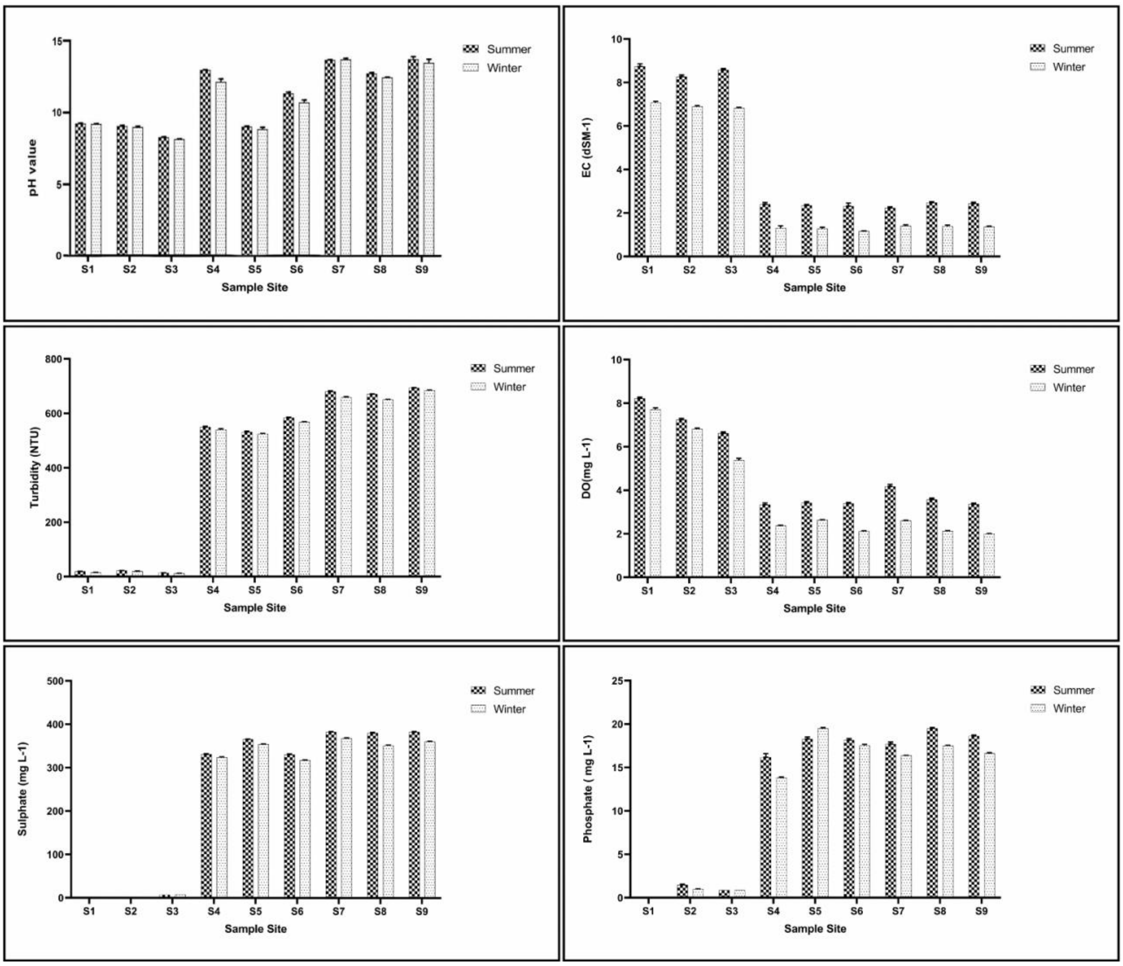
Cl^- values range between 251.18±1.34 mg/L and 502.28±2.96 mg/L, with the average value higher in the summer season (325.56±2.067mg/L) than the winter (311.53±1.04 mg/L) season. This was much higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Islam et al. (2014), Sayed et al. (2015) and the Pollution Control Board, Guwahati (2016-17). It also exceeded the standard levels recommended by BIS (2012), WHO (2017) and NERIWALM (2019). Compared to other bodies of water, it was higher than the values for the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), Tawang (Gaur et al., 2022), Sukhna Lake (Maansi et al., 2022), Gompti (Kushwah et al., 2023) and Lake Baikal (Pastukhov et al., 2023), but lower than the King Abdullah Canal (Mashagbah, 2015).

3.1.12. Fluoride (F^-)

The F^- values range between 0.25±0.01mg/L and 2.12±0.02 mg/L, with the average value of fluoride being higher during summer (0.94±0.01 mg/L) compared to winter (0.87±0.02 mg/L). This was higher than the values recorded in Deepor Beel by Sayed et al. (2015) and the Pollution Control Board, Guwahati (2016-17). It also exceeded the standard levels recommended by WHO (2017) and NERIWALM (2019), as well as the values for the surface water of Gompti (Kushwah et al., 2023). However, it was lower than the values recorded for Tawang (Gaur et al., 2022).

3.1.13. Total dissolved solid (TDS)

The TDS values range between 4.39±0.01 mg/L and 917.4±2.23 mg/L, with the average value of TDS being higher (581.53±3.54 mg/L) during the summer season compared to winter (534.8±1.2 mg/L) season. This was higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Sayed et al. (2015), the Pollution Control Board, Guwahati (2016-17), Choudhury and Gupta (2017), and Deb et al. (2019), as well as the standard level recommended by WHO (2017). It also exceeded the values for the surface water of Dakor Pilgrimage Wetland (Soni and Thomas, 2014), Tawang (Gaur et al., 2022), Sukhna Lake (Maansi et al., 2022), Gompti (Kushwah et al., 2023) and Lake Baikal (Pastukhov et al., 2023).



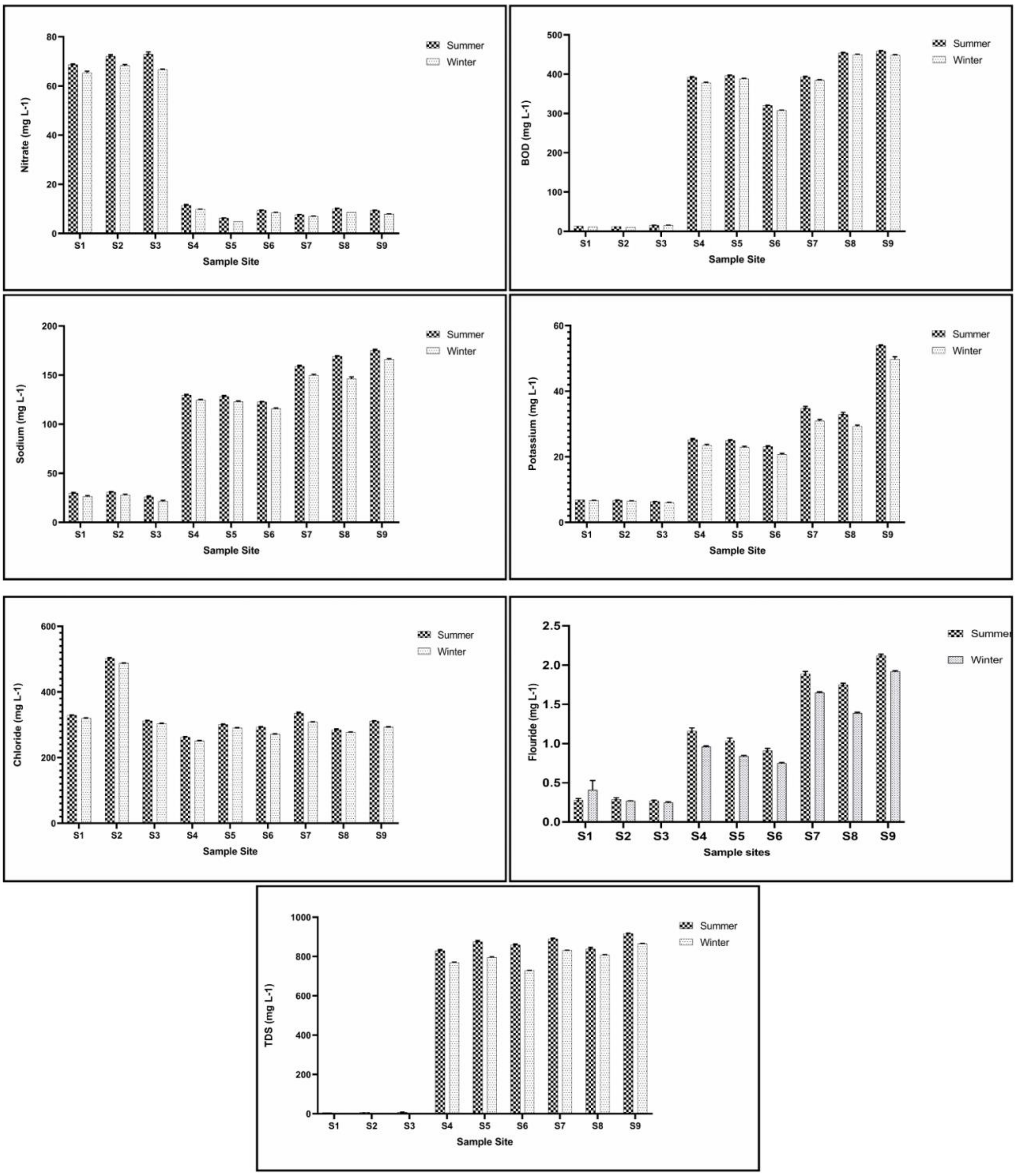
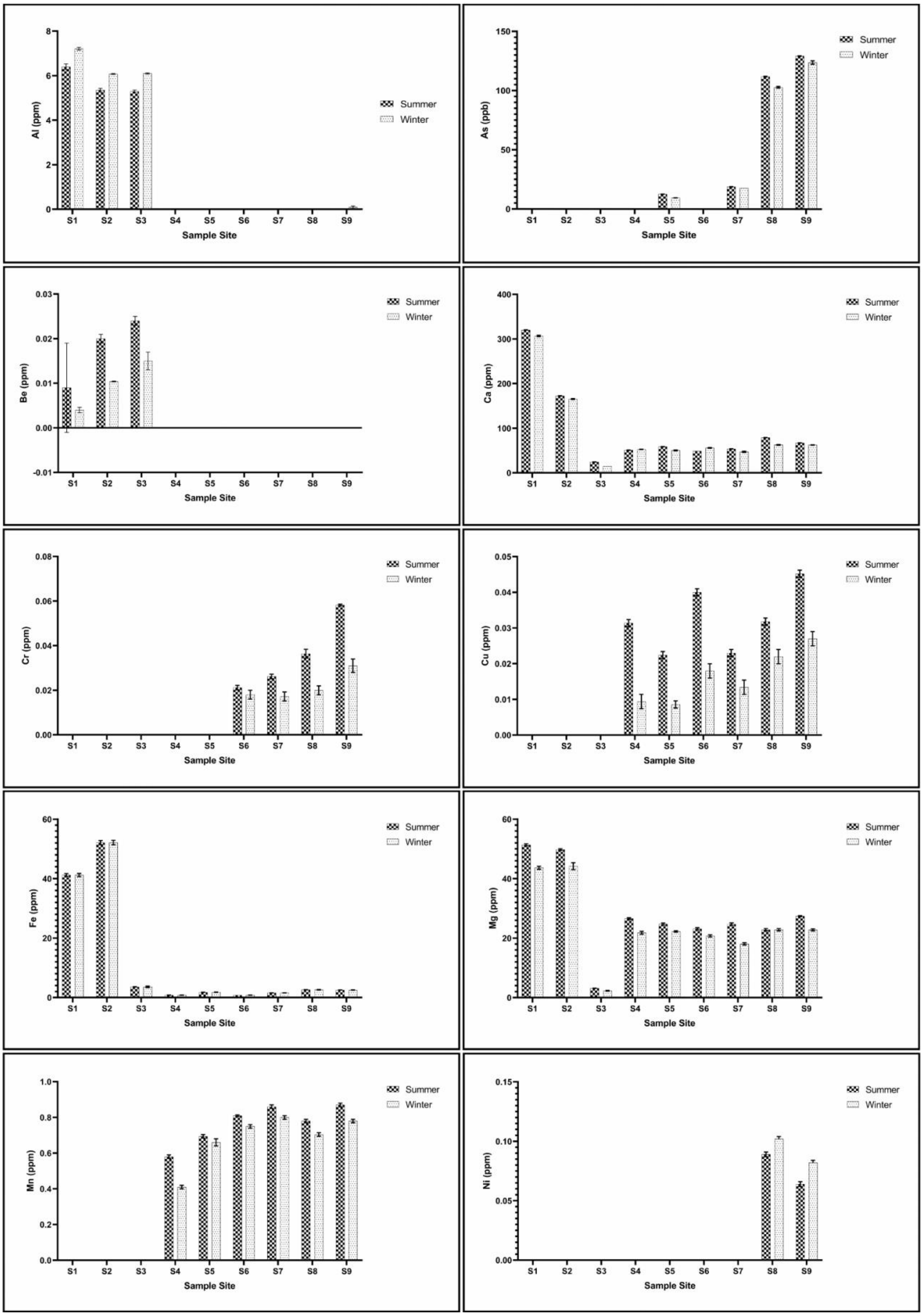


Figure 3: *Histogram charts showing the concentrations of physicochemical properties of water samples from Deepor Beel near the Boragaon Garbage dump during winter (December) and summer (July) season with standard error.*

Slika 3: *Histogrami, ki prikazujejo koncentracije fizikalno-kemijskih lastnosti vzorcev vode z območja Deepor Beel v bližini odlagališča Boragaon med zimsko (december) in poletno (julij) sezono s standardno napako.*


Al (ppm)
As (ppb)
Be (ppm)
Ca (ppm)
Cr (ppm)
Cu (ppm)
Fe (ppm)
Mg (ppm)
Mn (ppm)
Ni (ppm)
Sample Site
S1 S2 S3 S4 S5 S6 S7 S8 S9
Summer
Winter

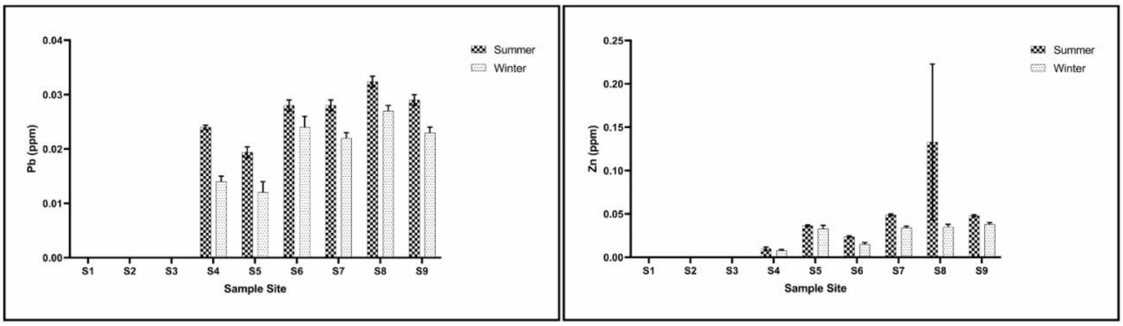


Figure 4: *Histogram charts showing the concentrations of heavy metals of water samples from Deepor Beel near the Boragaon Garbage dump during winter (December) and summer (July) season with standard error.*

Slika 4: *Histogrami, ki prikazujejo koncentracije težkih kovin v vzorcih vode z območja Deepor Beel v bližini odlagališča Boragaon v zimski (december) in poletni (julij) sezoni s standardno napako.*

3.2. Heavy metals

3.2.1. Aluminum (Al)

The Al values in the water samples from Deepor Beel ranged from 0.019±0.0003 to 7.21±0.06 mg/L. The average Al value during the summer season was recorded higher at 2.17±0.02 mg/L compared to the winter season's 1.89±0.03 mg/L. All naturally occurring waterways and water systems include aluminum. It can appear as dissolved or undissolved organic and inorganic substances, and the pH level was a significant component, which affects how it appears. The values found in the present study were higher than the standard value of Al in drinking water recommended by WHO (2017). They also exceeded the values recorded for the surface water of Lake Baikal and Irkutsk Wetland by Alicva et al. (2011), Sklyarova (2011), Vetrov et al. (2013) and Pastukhov et al. (2023).

3.2.2. Arsenic (As)

The As values ranged between 9.614±0.03 to 129.42±0.22 µg/L, with a higher average value during the summer (30.33±0.07µg/L) compared to winter (63.583±0.55 µg/L). The values found in the present study were much higher than the standard value of arsenic in drinking water recommended by WHO (2017) and NERIWALM (2019). It was also higher than the values recorded in Deepor Beel by Kapil and Bhattacharyya (2013), the Pollution Control Board, Guwahati (2016-17), and Deb et al. (2019). Additionally, it exceeded the values recorded for the surface water of Lake Baikal and Irkutsk Wetland by Alicva et al. (2011), Sklyarova (2011), Vetrov et al. (2013) and Pastukhov et al. (2023).

3.2.3. Beryllium (Be)

The Be values ranged between 4±0.6 µg/L and 24±1 µg/L. The average Be value was higher in the winter season (6±0.1µg/L) compared to the summer season (3±0.4 µg/L). The values recorded in the present study were lower than the standard value of Be in drinking water recommended by WHO (2017). Be value found in Deepor Beel was higher than the Beijing-Hangzhou Grand Canal, Zaozhuang (Zhuang et al., 2016)

3.2.4. Cadmium (Cd)

During the study Cd values were found as below detection limit (BDL) whereas in earlier studies the Cd value in Deepor Beel were found between 0.002 to 0.23 ± 0.05 mg/L (Kapil and Bhattacharyya, 2013; Pollution Control Board, Guwahati, 2016-17; Choudhury and Gupta, 2017). Cd value higher in Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023).

3.2.5. Calcium (Ca)

The Ca values ranged from 15.02 ± 0.09 mg/L to 320.1 ± 0.44 mg/L, with lower values recorded during the summer season (97.17 ± 0.28 mg/L) compared to the winter season (90.96 ± 0.85 mg/L). These values were much higher than those recorded in Deepor Beel by Sharma and Sharma (2005, 2009), Islam et al. (2014), Sayed et al. (2015), the Pollution Control Board, Guwahati (2016-17) and Deb et al. (2019). They also exceeded the values for the surface water of Lake Baikal and Irkutsk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023) and Lake Loktak (Mayanglambam and Neelam, 2020) but were lower than those recorded in the Dakor Pilgrimage Wetland (Soni and Thomas, 2014). Additionally, the values were higher than the recommended level of calcium in drinking water by BIS (2012) and WHO (2017).

3.2.6. Chromium (Cr)

The Cr values ranged from 17.2±2 µg/L to 58.2±0.4 µg/L and the Cr value was higher in the summer season (17±1 µg/L to 16.2±1 µg/L) than the winter season. This was lower than the values recorded in Deepor Beel by Kapil and Bhattacharyya (2013), Choudhury and Gupta (2017), Deb et al. (2019) and the surface water of Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023). The recorded values were slightly higher than the recommended levels of Cr in drinking water as per WHO (2017), BIS (2012) and NERIWALM (2019).

3.2.7. Copper (Cu)

The Cu values ranged between 8.6±1 µg/L to 45.2±1 µg/L, with a higher average value during the summer season (20±1 µg/L) than the winter season (10±1 µg/L). The value recorded in the present study was lower than the values recorded in Deepor Beel by Kapil and Bhattacharyya (2013), Choudhury and Gupta (2017), the Pollution Control Board, Guwahati (2016-17), Deb et al. (2019) and the surface water of the Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023). The recorded values were slightly higher than the recommended levels of Cu in drinking water as per BIS (2012), WHO (2017) and NERIWALM (2019).

3.2.8. Iron (Fe)

The Fe values ranged from 0.749±0.01 mg/L to 56.23±0.7mg/L, and the average value was higher during the summer (11.89±0.15mg/L) compared to the winter (12.57±0.16mg/L). The value recorded in the present study was higher than the values recorded in Deepor Beel by Sayed et al. (2015), Choudhury and Gupta (2017), the Pollution Control Board, Guwahati (2016-17), Deb et al. (2019), Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023). The recorded values were slightly higher than the recommended levels of Fe in drinking water as per BIS (2012), WHO (2017) and NERIWALM (2019).

3.2.9. Magnesium (Mg)

The Mg values ranged from 2.315±0.13 mg/L to 51.36±0.36 mg/L, with a higher average value during the summer (28.19±0.29 mg/L) compared to the winter (24.29±0.49 mg/L). The value recorded in the present study was higher than the values recorded in Deepor Beel by Sharma and Sharma (2005; 2009), Sharma (2011), Islam et al. (2014), the Pollution Control Board, Guwahati (2016-17) and the surface water of Dakor Pilgrimage Wetland(Soni and Thomas, 2014), Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023) and Loktak lake (Mayanglambam and Neelam, 2020), but lower than the Sukhana wetland (Maansi et al., 2023) and King Abdullah Canal (Mashagbah, 2015). However, the recorded values were slightly higher than the recommended levels of Mg in drinking water as per BIS (2012) and WHO (2017).

3.2.10. Manganese (Mn)

The Mn values ranged from 0.41±0.01mg/L to 0.87±0.01mg/L, with a higher average value during the summer (0.51±0.01 mg/L) compared to the winter (0.46±0.01 mg/L) season. The value recorded in the present study was lower than the values recorded in Deepor Beel by Kapil and Bhattacharyya (2013) and the surface water of Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023). The recorded values were slightly higher than the recommended levels of Mn in drinking water as per BIS (2012) and WHO (2017).

3.2.11. Nickel (Ni)

The Ni values ranged from 0.064±0.002mg/L to 0.102±0.002 mg/L, with the average value higher in the summer season (0.02±0.0004 mg/L) than the winter season (0.015±0.0004 mg/L). The value recorded in the present study was lower than the values recorded in Deepor Beel by Kapil and Bhattacharyya (2013), Choudhury and Gupta (2017), the Pollution Control Board, and Guwahati (2016-17), and higher than the recommended levels of Ni in drinking water as per BIS (2012) and WHO (2021). Results of the present study was higher than the surface water of Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023).

3.2.12. Lead (Pb)

The Pb values ranged from 12±2 µg/L to 32.4±1 µg/L, with the average value higher during the summer season (27±10 µg/L) than the winter season (10±1 µg/L). The value recorded in the present study was lower than the values recorded in Deepor Beel by Kapil and Bhattacharyya (2013), Choudhury and Gupta (2017), the Pollution Control Board, Guwahati (2016-17), Deb et al. (2019) but higher than the surface water of Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023). The recorded values were slightly higher than the recommended levels and higher than the recommended levels of Pb in drinking water as per WHO (2017), BIS (2012) and NERIWALM (2019).

3.2.13. Zinc (Zn)

Zn values ranged from 0.008±0.001mg/L to 0.133±0.09 mg/L, with the average value higher in the summer (0.034±0.01 mg/L) than the winter (0.02±0.002 mg/L). The value recorded in the present study was higher than the values recorded in Deepor Beel by the Pollution Control Board, Guwahati (2016-17), Choudhury and Gupta (2017), Deb et al. (2019) and Lake Baikal and Irkustk Wetland (Alicva et al., 2011; Sklyarova, 2011; Vetrov et al., 2013; Pastukhov et al., 2023) and lower than Kapil and Bhattacharyya (2013), WHO (2017) and NERIWALM (2019).

3.2.14. Comparative analysis with earlier studies on Deepor Beel

These findings exceed the data reported in all earlier studies conducted in Deepor Beel (Sharma and Sharma, 2005, 2009; Sharma 2011; Kapil and Bhattacharjya 2012; Islam et al., 2014; Sayed et al., 2015; Choudhury and Gupta 2017; Deb et al., 2019; Dash et al., 2020, 2021; Roy and Majumder 2022; the Pollution Control Board, Guwahati 2016-17), emphasizing the current state of water quality deterioration and heavy metal pollution in this ecosystem. However, the previous studies in Deepor Beel did not all sample at the same locations. While some studies (Sayed et al. 2015; Deb et al. 2019; Choudhury and Gupta 2017; Islam et al. 2014) did take some samples near garbage sites (Table 2), our study strategically sampled points where leachates directly contaminated the water of Deepor Beel. The significant differences between the values observed at various sampling points in our study compared to those in previous studies could be attributed to this difference in sampling location.

Leachate generation in landfills is predominantly attributed to rainfall, which percolates through the waste, collecting dissolved and suspended components from decomposing materials. This process involves various physical and chemical reactions (Reinhart and Townsend, 1998). Leachate serves as a potent indicator of the composition, degradation processes, and environmental impact of landfilled materials. Studying leachate provides invaluable insights into the efficiency of landfill management practices and the potential risks posed by leachate contamination to surrounding ecosystems and groundwater resources. By understanding leachate characteristics and behavior, more effective waste treatment methods and regulatory frameworks aimed at mitigating environmental pollution and safeguarding public health can be formulated.

In the present study, the alkaline pH observed signifies Deepor Beel's eutrophic state, likely resulting from the accumulation of salts, minerals, and leachate-derived substances (Whitemore et al., 2006). Elevated levels of EC and turbidity suggest the influence of hydrous oxides of Fe and Mn (Krenkel, 1974). The study identifies increased concentrations of heavy metals such as Fe, sourced from various origins including eroding roofing sheets, steel, iron cookware, and natural deposition (Agoro et al., 2020). High sulphate and phosphate levels, conducive to algal growth, indicate substantial pollution in Deepor Beel, posing potential health risks (Jacobson, 1991; NERIWALM, 2019).

During the summer season, elevated nitrate levels are linked to reduced biological activities, associated with lower dissolved oxygen levels and increased temperatures (Roy and Majumder, 2022). Excessive fluoride concentrations lead to health issues such as dental and skeletal fluorosis (Mallishery et al., 2020). The notable BOD levels indicate increased oxygen consumption due to the oxidation of a large volume of waste discharged from the municipal sewage area (Hossain, 1988).

The presence of heavy metals, including Pb, Cd, Zn, Cu, As, Al, Ca, Fe, Mg, Mn, and Ni, raises concerns due to potential phytotoxicity and the risk of entering the food chain, posing threats to both human and animal health (Iordache et al., 2022). Arsenic, specifically, is identified as highly toxic in Assam, posing risks to aquatic life (Kapil and Bhattacharyya, 2013; Goswami et al., 2022). Various heavy metals, such as lead and nickel, have the potential to cause a range of health effects in humans and animals, including renal, cardiovascular, neurological, reproductive, and immunological issues, as well as various cancers (Awofolu et al., 2005; NERIWALM, 2019).

The excess presence of calcium in Deepor Beel can lead to hypercalcemia, affecting the aquatic ecosystem and causing the regular death of aquatic organisms (Deb et al., 2015; Roy and Majumder, 2022). During the monsoon season, the expanded water volume reaches surrounding villages, disseminating harmful diseases caused by polluted water to the human population.

The study suggests that the present metals Fe, Pb, As, and Cd may derive from wastewater and industrial waste, impacting EC values due to high concentrations of dissolved solids (Ojok et al., 2017; Nguyen et al., 2021; Luvhimbi et al., 2022). High TDS indicates the presence of inorganic salts and trace organic substances in water, affecting its taste, color, and properties (WHO/FAO, 2003; Meride and Ayenew, 2016).

The findings emphasize the need for continuous monitoring of parameters like pH, TDS, EC, DO, BOD, NH_4^+, NO_3^-, Fe, Cl^-, Pb, and As, as their concentrations fluctuate over time and have increased in recent decades. Addressing water quality deterioration and heavy metal pollution in Deepor Beel requires comprehensive environmental management strategies, particularly considering the contributions of wastewater from domestic, agricultural, and industrial sources (Muangthong and Shrestha, 2015; Atwebembeire et al., 2019).

Table 2: *Comparison of present values with earlier records of water analysis in Deepor Beel.*

Preglednica 2: *Primerjava sedanjih vrednosti in starejših podatkov analiz vode z območja Deepor Beel.*

Parameter	Sharma and Sharma, 2005	Sharma and Sharma, 2009	Sharma, 2011	Kapil and Bhattacharyya, 2013	Islam et al., 2014	Sayed et al., 2015	Choudhury and Gupta, 2017	Deb et al., 2019	Dash et al., 2020	Dash et al., 2021	Roy and Majumde, 2022	PCB, 2016-17 (Water)	PCB, 2016-17 (Sediment)	Present Study	WHO, 2017	BIS, 2012	NERIWALM, 2019
pH	7.0±0.2	6.9±0.2–6.9±0.2	6.9±0.2–6.9±0.2	2.9–8.3	7.2–8.3	6.1–7.3	6.2–7.2	6.6±0.0 7.6±0.0	-	-	5.5–8.2	6.0–9.0	4.2–7.2	8.1±0.0–13.7±0.2	6.5-9.5	6-5–8-5	6.5-8.5
EC (µScm^-1^)	103.8±14.6	96.8±15.5–99.2±13.2	96.8±15.5–99.2±13.2	-	-	168–266	163.8±1.7–734.7±9.7	-	-	-	77.0–228.0	63–301	-	1170±10–8740±120	500	-	-
Turbidity (NTU)	-	-	-	-	3.5–12.6	-	-	9.9±0.1–93.7±0.1	-	-	11.3–33.9	2–52	-	12.2±0.6–693.8±1.2	5	5	-
DO (mg/L)	6.4±1.9	6.7±1.6–7.0±1.1	6.7±1.6–7.0±1.1	-	1.4–8.9	0.1–12.5	0.6±0.2–9.7±0.3	4.2–5.6	-	-	3.3–8.5	0.8–11	-	2±0.0–9.62±0.1	-	-	-
Sulphate (mg/L)	9.0±2.7	9.9±3.4–10.2±3.2	9.9±3.4–10.2±3.2	-	-	2.0–22.8	-	-	-	-	-	5.4–66.1	-	0.1±0.0–382.8±1.2	250	200	<100
Phosphate (mg/L)	0.1±0	0.2±0.1–0.2±0.1	0.2±0.1–0.2±0.1	-	-	-	1.1±0.2–2.2±0.7	0.0±0.0–0.3±0	-	-	0.1–0.5	0.1–6.7	-	0.0±0.0–19.5±0.1	-	-	<0.1
Nitrate (mg/L)	0.7±0.2	0.7±0.1–0.7±0.1	0.7±0.1–0.7±0.1	-	-	-	0.0±0.0–2.1±0.1	0.0–0.1	-	-	1.5–5.8	0.6–3.1	-	4.91±0.02–72.92±0.95	50	45	<30
BOD (mg/L)	2.2±0.6	3.1±0.6–3.2±0.5	3.1±0.6–3.2±0.5	-	-	-	-	3.8±0.7–10.1±0.3	-	-	46.1–261.7	0.5–35	-	10.9±0.1–458.6±1.9	-	-	<3
Sodium (mg/L)	13.4±1.9	-	-	-	-	9.8-13.3	-	30.5±0.5	-	-	-	2.2–29.2	-	21.4±1.0–175.0±1.3	200	-	-
Potassium (mg/L)	4.5±0.7	-	-	-	-	1.4-7.0	-	4.3–13.0±0.0	-	-	-	0.1–12.6	-	6.0±0.1–53.9±0.2	20	-	-

Chloride (mg/L)	24.7 ±4.4	0.2 ±0.1 –0.2 ±0.1	34.6 ±5.2 – 35.1 ±5.0	-	24.8–31.1	50 – 90	-	-	-	-	-	4 – 30	-	251.2±1.3–502.3±2.9	250	200	<200
Fluoride (mg/L)	-	-	-	-	-	0.2–0.9	-	-	-	-	-	0.2–0.9	-	0.3±0.0 – 2.1±0.0	1.5	-	<1.0
TDS (mg/L)	1.6±0.5	2.37 ±0.29 – 2.57 ±0.30	2.37 ±0.29 – 2.57 ±0.30	-	-	39 – 98	106.6±0.17–489.0±17.58	220	-	-	-	40 – 180	-	4.39±0.01–917.4±2.23	500	-	-
Al (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0±0.0–7.2±0.1	0.1–0.2	-	-
As (µg/L)	-	-	-	0.0 – 12.9	-	-	-	1.73	-	-	-	0.0–2.9	-	9.6±0.03 – 129.4±0.2	0.01	-	<0.002
Be (mg/L)	-	-	-	-	-	-	-	-	-	-	-	-	-	0.0±0.6–0.0±0.0	0.0	-	-
Cd(mg/L)	-	-	-	0.0 – 0.1	-	-	0.0±0.0–0.2 ±0.1	-	35.1–127.1	48.2–118.7	-	0.0–0.0	0.5–0.9	BDL	0.0	0	<1.0
Ca (mg/L)	19.7 ±1.8	20.1 ±2.2 – 22.1 ±1.8	20.1 ±2.2 - 22.1 ±1.8	-	11–17.3	1–6.8	-	7.9±1–41.9±0.7	-	-	-	16 –7	-	15.0±0.1 – 320.1±0.4	200	75	-
Cr (mg/L)	-	-		0.0 – 0.6	-	-	0.0±0.0–1.9±0.0	0.0–0.1	137.0 – 240.7	152.5 – 234.9	-	-	5.3–62.8	0.0±0.0–0.1±0.0	0.1	0.1	<0.05
Cu (mg/L)	-	-	-	0.0 – 0.1	-	-	0.0±0.0–0.0±0.0	-	18.1–68.4	24.8–60.9	-	0.0–0.0	4.4-49.7	0.0±0.0–0.0±0.0	2	0.5	<0.5
Fe (mg/L)	-	-	-	-	-	0.1–2.9	0.1±0.0–2.0±0.0	3.4	7503.9–10197.2	7751.6–9093.2	-	0.6–5.3	-	0.8±0.0–56.2±0.8	0.2–0.3	0.3	<0.3
Mg (mg/L)	3.9±0.5	4.0±0.7–4.2±0.9	4.0±0.7–4.2±0.9	-	7.53–11.76		-	-	7039 – 16880	7392–8221.4	-	10 – 32	-	2.3±0.13 – 51.4±0.4	150	30	-
Mn (mg/L)	-	-	-	0.0 – 1.5	-	-	-	-	320.7 –	335.8 – 419.9	-	-	-	0.4±0.0–0.9±0.0	0.1	0.1	-

									437.6								
Ni (mg/L)	-	-	-	0.0 – 1.4	-	-	0.0±0.0–0.1±0.0	-	-	-	-	0.1–0.1	29.7 – 95.5	0.1±0.0–0.1±0.0	-	0.02	<0.05
Pb (mg/L)	-	-	-	0.0 – 0.6	-	-	0.0±0.0–0.3±0.1	0.2	150.3 – 264.0	152.5 – 161.8	-	0.0–0.0	13.3 – 31.0	0.0±0.0–0.0±0.0	0.01	0.01	<0.05
Zn (mg/L)	-	-	-	3.4	-	-	0.0±0.0–0.1±0.0	1.7	-	-	-	0.0 0.1	42.0 – 151.5	0.0±0.0–0.0±0.1	0.01 - 0.05	-	<0.1

4. Conclusion

This study clearly determines the impact of municipal solid waste (MSW) leachate in the water quality of Deepor Beel. Our results suggest that the water quality of Deepor Beel was very poor during the study period, with further, high deterioration during summer.

Our observations revealed that the garbage dump receives various types of waste from hospitals, agricultural fields, industries, garages (motor parts and oils/grease), households, and the municipality itself. This includes pharmaceuticals, plastics, clothing, iron, batteries, paints, etc. The difference in values recorded at different sampling sites is primarily due to their locations and the types of waste being dumped there. However, our study did not analyze the composition of waste in different dumping zones. This could be an important parameter for future studies.

The water of Deepor Beel has also exhibited a gradual deterioration as evident from the earlier studies. To address the pressing issue of waste management and pollution control, it is imperative to implement a multifaceted approach, and considering the rising population and urban expansion, it is essential to assess and augment the number of MSW collection sites, along with the addition of large-scale MSW transfer stations.

We suggest that a comprehensive approach to MSW management should be implemented. This should involve organizing a responsible agency to oversee the establishment of sorting standards and waste collection. A crucial step would be to implement a mandatory four-classification system for MSW sorting, including hazardous waste, recyclable materials, household food waste, and residual waste. To effectively manage MSW, two primary treatment and disposal methods should be considered: recycling, incineration, composting, and landfilling. It is also recommended to construct wet waste treatment plants to align with MSW sorting regulations.

Furthermore, this strategy encompasses the establishment of a recycling facility within the landfill to repurpose discarded materials into usable products. Specifically, for organic waste, biogas and biofuel production can be integrated, along with the creation of organic fertilizers. Non-renewable plastics can be repurposed to produce bricks, reducing their environmental impact. Additionally, deploying an air purification plant within the landfill can help mitigate the release of harmful pollutants into the atmosphere. To deter illegal dumping and littering, imposing substantial fines and enforcing strict regulations is essential. Additionally, adopting an efficient bin collection technique that segregates organic and inorganic materials is pivotal in promoting responsible waste management and environmental sustainability. These measures collectively contribute to a comprehensive waste management system that enhances resource efficiency and minimizes environmental degradation. Hence, the state requires a better management plan for the waste generated, such as has been effectively implemented in Shanghai, China (Xiao et al., 2020).

The sanctuary boasts an exceptional diversity of avifauna, which has unfortunately experienced a decline in recent decades. To safeguard the biodiversity of the lake, rigorous enforcement of wildlife protection legislation is imperative, alongside vigilant monitoring of encroachment and other illicit activities. These findings underscore the need for policymakers to strengthen the country's waste disposal and management infrastructure, aiming to mitigate the ecological impact of industrial waste on freshwater bodies. A Comprehensive data is essential for assessing the health risks associated with industrial waste, particularly its effects on freshwater reservoirs, which play a vital role in replenishing the region's aquifers.

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References

Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., Al-Gehlani, W. A. G., Alrawaf, T. I. (2022). Environmental Sustainability Impacts of Solid Waste Management Practices in the Global South. *International Journal of Environmental Research and Public Health,* **5(19)**: 12717. https://doi.org/10.3390/ijerph191912717.

Abd El-Salam, M. M., Abu-Zuid, G. I. (2015). Impact of landfill leachate on the groundwater quality: A case study in Egypt. *Journal of Advanced Research* **6(4),** 579–586. https://doi.org/10.1016/j.jare.2014.02.003.

Aburto, N. J., Hanson, S., Gutierrez, H., Hooper, L., Elliott, P., Cappuccio, F. P. (2013). Effect of increased potassium intake on cardiovascular risk factors and disease: systematic review and meta-analyses. *British Medical Journal* **346(3)**. https://doi.org/10.1136/bmj.f1378.

Adakole, J. A. (2000). The effects of domestic, agricultural and industrial effluents on the water quality and biota of Bindare stream, Zaria – Nigeria. Unpublished PhD Thesis.Department of Biological Sciences, Ahmadu Bello University, Zaria, Nigeria.

Ademola, O.J., Alimba, C.G., Bakare, A.A. (2020) Reproductive toxicity assessment of Olusosun municipal landfill leachate in *Mus musculus* using abnormal sperm morphology and dominant lethal mutation assays. *Environmental Analysis Health and Toxicology* **35(2),** e2020010. https://doi.org/10.5620/eaht.e2020010.

Adeniji, H. A. (1986). Some limnological precautions for fish farmers.Kainji Lake Research Institute Annual Report, pp 54 – 56.

Agoro, M. A., Adenji, A. O., Adefisoye, M. A., Okoh, O. O. (2020). Heavy Metals in Wastewater and Sewage Sludge from Selected Municipal Treatment Plants in Eastern Cape Province, South Africa. *Water* **12**, 27–46. https://doi.org/10.3390/w12102746.

Ahmed, A., Wanganeo, A. (2015). Phytoplankton succession in a tropical freshwater lake, Bhoj wetland (Bhopal, India): spatial and temporal perspective. *Environmental Monitoring and Assessment* **187(4)**:192. https://doi.org/10.1007/s10661-015-4410-0.

Alam, P., Sharholy, M., Ahmad, K. (2020). “A Study on the Landfill Leachate and Its Impact on Groundwater Quality of Ghazipur Area, New Delhi, India” in A. Kalamdhad, Ed., Recent Developments in Waste Management. Springer, Singapore. https://doi.org/10.1007/978-981-15-0990-2_27.

Alieva, V.I., Grebenshchikova, V.I., Zagorulko, N.A.(2011). Long-term monitoring and modern methods for studying the microelement composition of the waters of the Angara River. *Ecological Engineering* **3**, 24–34.

Al-Mashagbah, A.F. (2015). Assessment of Surface Water Quality of King Abdullah Canal, Using Physico-Chemical Characteristics and Water Quality Index, Jordan. *Journal of Water Resource and Protection* **7**, 339–352.

Arnold, E., Greenberg, Kupka, E. (1957). Tuberculosis Transmission by Waste Waters: A Review. *Sewage and Industrial Wastes* **29(5)**, 524–537. https://doi.org/10.2307/25033338.

Atwebembeire, J., Andama, M., Yatuha, J., Lejju, J. B., Rugunda, G. K., Bazira, J. (2019). The physico-chemical quality of effluents of selected sewage treatment plants draining into River Rwizi, Mbarara Municipality, Uganda. *J Water Resource Protocol* **11**, 20–36.

Awofolu, O. R., Mbolekwa, Z., Mtshemla, V., Fatoki, O. S. (2005). Levels of trace metals in water and sediment from Tyume River and its effects on an irrigated farmland. *Water SA* **31(1)**, 87. https://doi.org/10.4314/wsa.v31i1.5124.

Ayodele, I. A., Ajani, E. K. (1999). Essentials of fish farming (aquaculture). Odufuwa printing works, Nigeria.

Azhar, S. C., Aris, A. Z., Yusoff, M. K., Ramli, M. F., Juahir, H. (2015). Classification of river water quality using multivariate analysis. *Procedia Environmental Sciences* **30**, 79–84.

Bhat, N. A., Wanganeo, A., Raina, R. (2015). Seasonal dynamics of phytoplankton community in a tropical wetland. *Environmental Monitoring and Assessment* **187**, 4136.

Bhat, R. A., Singh, D. V., Qadri, H., Dar, G. H., Dervash, M. A., Bhat, S. A., Unal, B. T., Ozturk, M., Hakeem, K. R., Yousaf, B. (2022). Vulnerability of municipal solid waste: An emerging threat to aquatic ecosystems. *Chemosphere* **287**:132223.

Bhattacharjya, B. K., Saud, B. J., Borah, S., Saikia, P. K. (2021). Status of Biodiversity and limno-chemistry of Deeporbeel, a Ramsar site of international importance: Conservation needs and the way forward. *Aquatic Ecosystem Health and Management* **24(4)**, 64–74.

Bouzayani, F., Aydi, A., Abichou, T. (2014). Soil contamination by heavy metals in landfills: measurements from an unlined leachate storage basin. *Environmental Monitoring and Assessment* **186**, 5033–5040. https://doi.org/10.1007/s10661-014-3757-y.

Bureau of Indian Standards, (2012). Indian standard drinking water—specification. Retrieved January 6, 2023 from https://law.resource.org/pub/in/bis/S06/is.10500.2023.

Chakraborty, A., Goswami, A., Deb, A., Das, D., Mahanta, J.(2014). Management of waste generated in Guwahati City and the incorporation of geocells at the landfill site. *Journal of Civil Engineering and Environmental Technology* **1**, 5–7.

Cheela, V. R., John, M., Biswas, W. K., Dubey, B. (2021). Environmental impact evaluation of current municipal solid waste treatments in India using life cycle assessment. *Energies* **14(11)**: 3133.

Choudhury, D., Gupta, S. (2017). Impact of waste dump on surface water quality and aquatic insect diversity of DeeporBeel (Ramsar site), Assam, North-East India. *Environmental Monitoring and Assessment* **189**, 540. https://doi.org/10.1007/s10661-017-6233-7.

Da Silva, M. R., Lamotte, M., Donard, O., Soriano-Sierra, E., Robert, M., (1996). Metal contamination in surface sediments of mangroves, lagoons and Southern Bay in Florianopolis Island. *Environmental Technology* **17**, 1035–1046.

Dash, S., Borah, S. S., Kalamdhad, A. S. (2020). Application of positive matrix factorization receptor model and elemental analysis for the assessment of sediment contamination and their source apportionment of DeeporBeel, Assam, India. *Ecological Indicators* **114**, 106291. https://doi.org/10.1016/j.ecolind.2020.106291.

Dash, S., Borah, S. S.,Kalamdhad, A. S. (2021). Heavy metal pollution and potential ecological risk assessment for surficial sediments of DeeporBeel, India. *Ecological Indicators* **122**, 107265. https://doi.org/10.1016/j.ecolind.2020.107265.

Davis, J. A., Froend, R. (1999). Loss and degradation of wetlands in southwestern Australia: underlying causes, consequences, and solutions. *Wetlands Ecology and Management* **7**, 13–23.

Deb, S., Saikia, J., Kalamdhad, A. J., (2019). Ecology Of DeeporBeel Wetland, A Ramsar Site Of Guwahati, Assam With Special Reference To Algal Community. *European Journal of Biomedical and Pharmaceutical sciences* **6(5)**, 232–243.

Deka, S. K., Goswami, D. C. (1992). Hydrology, sediment characteristics and depositional environment of wetlands: A case study of DeeparBil, Assam. *Journal of Assam Science Society* **34**, 62–84.

Dhamodharan, A., Abinandan, S., Aravind, U., Ganapathy, G. P., Shanthakumar, S. (2019). Distribution of Metal Contamination and Risk Indices Assessment of Surface Sediments from Cooum River, Chennai, India. *International Journal of Environmental Research* **13**, 853–860.

Dorioz, J. M., Cassell, E. A., Orand, A., Eisenman, K. G. (1998). Phosphorus storage, transport and export dynamics in the Foron River Watershed. *Hydrological Processes* **12**, 285–309.

Dutta, J., Sharma, S.(2020). Valuing Fishing Activity of Deepor Beel. *Space and Culture, India* **7(4),** 122-132. https://doi,org/10.20896/saci.v7i4.607.

Gaur, N., Sarkar, A., Dutta, D., Gogoi, B.J., Dubey, R., Dwivedi, S.K. (2022). Evaluation of water quality index and geochemical characteristics of surface water from Tawang India. *Scientific Reports* **12(1)**: 11698. https://doi.org/10.1038/s41598-022-14760-3.

Ghosh, S., Majumder, S., Roychowdhury, T. (2019). Assessment of the effect of urban pollution on surface water-groundwater system of Adi Ganga, a historical outlet of river Ganga. *Chemosphere* **237,** 124507. https://doi.org/10.1016/j.chemosphere.2019.124507.

Goswami, R., Neog, N., Thakur, R. (2022). Hydrogeochemical assessment of ground quality for drinking and irrigation in Biswanath and Sonitpur district of the Central Brahmaputra Plain, India. *Frontiers in Water* **4**. Advance online publication https://doi.org/10.3389/frwa.2022.889128.

Holland, C. C., Honea, J., Gwin, S. E., Kentula, M. E. (1995). Wetland degradation and loss in the rapidly urbanizing area of Portland, Oregon. *Wetlands* **15**, 336–345.

Hossain, M.M., 1988. Some water quality characteristics of the Karnafully river estuary. *Mahasagar Bulletin of the National Institute of Oceanography* **21,** 183–188.

Hutton, M. M. (1987). "Human health concerns of lead, mercury, cadmium and arsenic" in T. C. Hutchinson, K. M. Meema, Eds., Lead, Mercury, Cadmium and Arsenic in the Environment. John Wiley & Sons Ltd, 53–68.

Iordache, A. M., Nechita, C., Zgavarogea, R., Voica, C., Varlam, M., Ionete, R.E. (2022). Accumulation and ecotoxicological risk assessment of heavy metals in surface sediments of the Olt River, Romania. *Scientific reports* **12(880)**. https://doi.org/10.1038/s41598-022-04865-0.

Islam, M., Ahmed, A. M., Barman, B., Deka, S., Debnath, D. (2014). Studies on physio-chemical properties of water in some selected sites of DeeporBeel (Ramsar site), Assam, India. *The Clarion* **3(2)**, 25–32.

Jacobson, C. (1991). Water, Water Everywhere: Water Quality Factors. Hach Co., Loveland.

Jaishankar, M., Tseten, T., Anbalagan, N., Mathew, B.B., Beeregowda, K.N. (2014) Toxicity, mechanism and health effects of some heavy metals. *Interdisciplinary Toxicology* **7(2),** 60–72. https://doi.org/10.2478/intox-2014-0009.

Jarup, L., Akesson, A. (2009) Current status of cadmium as an environmental health problem.*Toxicology and Applied Pharmacology* **283(3),** 201–208.

Kapil, N., Bhattacharyya, K. G. (2013). Spatial, Temporal and Depth Profiles of Trace Metals in an Urban Wetland System: A Case Study with Respect to the DeeporBeel, Ramsar Site 1207, India. *Environment and Pollution* **2(1)**, 51–72.

Krenkel, P. A. (1974). Sources and Classification of Water Pollutants. In: I. N. Sax (Ed.), Industrial Pollution (pp: 197–219). Litton Educational Publishing.

Kushwah, V.K., Singh, K.R., Gupta, N., Berwal, P., Alfaisal, F.M., Khan, M.A., Alam, S., Qamar, O. (2023). Assessment of the Surface Water Quality of the Gomti River, India, Using Multivariate Statistical Methods. *Water* **15**, 3575. https://doi.org/10.3390/w15203575.

Leblanc, R. T., Brown, R. D., Fitzgibbon, J. E. (1997). Modeling the effects of land use change on the water temperature of unregulated urban streams. *Journal of Environmental Management* **49**, 445–469.

Luvhimbi, N., Tshitangano T. G., Mabunda J. T., Olaniy F. C., Edokpayi J. N. (2022). Water quality assessment and evaluation of human health risk of drinking water from source to point of use at Thulamela municipality, Limpopo Province. *Scientifc Reports* **12, 6059**. https://doi.org/10.1038/s41598-022-10092-4.

Ly, K., Larsen, H., Duyen, N.V. (2013). Lower Mekong Regional Water Quality Monitoring Report. Vientiane: Mekong River Commission.

Maansi., Jindal, R., Wats, M.(2022). Evaluation of surface water quality using water quality indices (WQIs) in Lake Sukhna, Chandigarh, India. *Applied Water Science* **12(2)**. https://doi.org/10.1007/s13201-021-01534-x.

Maiti, S., De, S., Hazra, T., Debsarkar, A., Dutta, A. (2016). Characterization of Leachate and Its Impact on Surface and Groundwater Quality of a Closed Dumpsite – A Case Study at Dhapa, Kolkata, India. *Procedia Environmental Sciences* **35,** 391–399. https://doi.org/10.1016/j.proenv.2016.07.019.

Mallishery, S., Sawant, K., Jain, M. (2020). Fluoride Toxicity: A Review on Dental Fluorosis and Its Prevalence in India. *IOSR Journal of Dental and Medical Sciences* **19(1)**, 14, 48–53.

Mayanglambam, B., Neelam, S.S. (2020). Physicochemistry and water quality of Loktak Lake water, Manipur, India. *International Journal of Environmental Analytical Chemistry* **102**, 1638 – 1661.

Mays, P.A., Edwards, G.S.(2001). Comparison of heavy metal accumulation in a natural wetland and constructed wetlands receiving acid mine drainage. *Ecological engineering*, **16(4)**: 487-500.

Meride, Y., Ayenew, B. (2016). Drinking water quality assessment and its efects on resident's health in Wondo genet campus, Ethiopia. *Environmental Systems Research*, **5**, 1.

Ministry of Environment and Forests (MoEF). (2008). Report on visit to DeeporBeel in Assam: a wetland included under national wetland conservation management programme of the Ministry of Environment and Forests. Guwahati: Govt. of India. Retrieved November 25, 2022 from https://planningcommission.gov.in/reports/E_F/Deepor Beel.

Ministry of Natural Resources and Environment. State of the National Environment in 2018: Water Environment of River Basins. Hanoi: Viet Nam Publishing House of Natural Resources, Environment and Cartography.

Mohan, S., Joseph, C. P. (2021). Potential hazards due to municipal solid waste open dumping in India. *Journal of the Indian Institute of Science*, **101(4),** 523-36.

Muangthong, S., Shrestha, S. (2015). Assessment of surface water quality using multivariate statistical techniques: case study of the Nampong River and Songkhram River, Thailand. Environmental Monitoring Assessment, **187**: 548.

Muniyan, M., Ambedkar, G. (2011). Seasonal variations in physicochemical parameters of water collected from Kedilamriver, at VisoorCuddalore District, Tamil Nadu, India. *International Journal of Environmental Biology* **1**, 15–18.

National Wetland Atlas. (2011). Retrieved January 15, 2023 from https://saconenvis.nic.in/publication%5CNWIA_National atlas.

National Wetland Atlas. (2013). Wetlands of International Importance under Ramsar Convention (2013) Space Applications Centre, ISRO, Ahmedabad, Loktak Lake, pp 117–123

Nguyen, T. G., Huynh, T. H. N. (2022). Assessment of surface water quality and monitoring in southern Vietnam using multicriteria statistical approaches. *Sustainable Environment Research* **32(20),** 1-12. https://doi.org/10.1186/s42834-022-00133-y.

Nguyen, T. G., Minh, V. Q. (2021). Evaluating surface water quality and water monitoring parameters in the Tien River, Vietnamese Mekong Delta. *Jurnal Teknologi* **83**, 29–36.

Nikita, R., Ghosh, A., Yash Kumar, C., Mandal, A., Saini, N., Dubey, S.K., Gogoi, K., Rajts, F., Belton, B., Bhadury, P. (2023). Dataset of biological community structure in Deepor Beel using eDNA approach-A RAMSAR wetland of Assam, India. *Data Brief*, **7(52),** 109786. https://doi.org/10.1016/j.dib.2023.109786.

North Eastern regional Institute of Water and Land Management. (2019). Retrieved June 25, 2020 from https://neriwalm.gov.in.

Ojok, W., Wasswa, J., Ntambi, E. (2017). Assessment of seasonal variation in water quality in River Rwizi using multivariate statistical techniques, Mbarara Municipality, Uganda. *Journal of Water Resource Protection* **9**, 83–97.

Pastukhov, M.V., Poletaeva, V.I., Hommatlyyev, G.B. (2023). Hydrochemical Characteristics and Water Quality Assessment of Irkutsk Reservoir (Baikal Region, Russia). *Water* **15**, 4142. https://doi.org/10.3390/w15234142.

Pekey, H., Karakaş, D., Ayberk, S., Tolun, L., Bakoglu, M. (2004). Ecological risk assessment using trace elements from surface sediments of Izmit Bay (Northeastern Marmara Sea) Turkey. *Marine Pollution Bulletin* **48**, 946–953.

Pimparkar, A. M., Patil, S., Patil, B. D.,Kadam, A. (2023). Comparative assessment of wetland water quality from rural and urban area of Aurangabad District, Maharashtra, India using water quality index. *HydroResearch* **6**, 269–278. https://doi.org/6.10.1016/j.

the Pollution Control Board, 2016-17. Retrieved June 20, 2023, from https://pcbassam.org/.

Przydatek, G., Kanownik, W. (2019). Impact of small municipal solid waste landfill on groundwater quality. *Environmental Monitoring and Assessment* **191**:169. https://doi.org/10.1007/s10661-019-7279-5.

Rafiul, A., Zia, A., Sirajum, M. S., Khadiza T. K. N. (2021). Assessment of surface water quality around a landfill using multivariate statistical method, Sylhet, Bangladesh. *Environmental Nanotechnology, Monitoring & Management* **15,** 2215–1532. https://doi.org/10.1016/j.enmm.2020.100422.

Ramsar Convention Secretariat (2013). The Ramsar convention manual: a guide to the convention on wetlands (Ramsar, Iran, 1971) (6th ed.). Retrieved

January 10, 2023 from https://www.ramsar.org/sites/default/files/documents/library/manual6-2013-e.

RIS, Information sheet on Ramsar wetlands (RIS) Guwahati: world wildlife fund for nature (2002).

Robert, S., Luckins, N., Menon, R. (2023). Quality deterioration of an Indian urban water source near an open dumping site. *Water Practice & Technology* **18(5),** 1284–1299. https://doi.org/18.10.2166/wpt.2023.056.

Roy, R., Majumder, M. (2022). Assessment of water quality trends in DeeporBeel, Assam, India. *Environment, Development and Sustainability* **24**, 14327–14347. https://doi.org/10.1007/s10668-021-02033-4.

Saikia, P. K., Saikia, M. K. (2011). Biodiversity in DeeporBeelRamsar Site of Assam India: Faunal Diversity. Lap Lambert Academic Publisher.

Sayed, A., Kumar, S. R., Ajay, K. S. (2015). Water quality analysis of Disposal site and its adjacent area of Guwahati, Assam, India. *International Research Journal of Environment Sciences* **4(5)**, 12–17.

Scarlett-Kranz, J. M., Babish, J. G., Strickl, D., Lisk, D. J. (1987). Health among municipal sewage and water treatment workers. *Toxicology and Industrial Health* **3(3)**, 311–319. https://doi.org/10.1177/074823378700300303.

Sharma, B. K. (2011). Zooplankton communities of DeeporBeel (a Ramsar site), Assam (N.E.India): ecology, richness, and abundance. *Tropical Ecology* **52**, 293–302.

Sharma, B. K., Sharma, S. (2005). Faunal Diversity of Rotifers (Rotifera: Eurotatoria) of DeeporBeel, Assam (Northeast India) - A Ramsar Site. *Journal of the Bombay Natural History Society* **102(2)**, 169–175.

Sharma, B. K., Sharma, S. (2009). Microcrustacea (Crustacea: Branchiopoda) of DeeporBeel, Assam, India: richness, abundance and ecology. *Journal of Threatened Taxa* **1(8)**, 411–418.

Shekdar, A. V. (2009). Sustainable solid waste management: an integrated approach for Asian countries. *Waste Management* **29**, 1438–1448.

Singhal, A., Gupta, A.K., Dubey, B., Ghangreker, M.M. (2022). Seasonal characterization of municipal solid waste for selecting feasible waste treatment technology for Guwahati city, India. *Journal of the air & waste management association* **72(2),** 147–160 https://doi.org/10.1080/10962247.2021.1980450.

Sklyarova, O.A.(2011). Distribution of trace elements in the water column of middle Baikal. *Geography and Natural Resources* **32**, 34–39.

Smith, J., Jones, A., Johnson, B. (2018). Microbial Contamination of Landfill Leachate: Implications for Public Health. *Environmental Science and Technology* **42(7)**, 2316–2322. https://doi.org/10.1021/es071929u.

Soni, H.B., Thomas, S. (2014). Assessment of surface water quality in relation to water quality index of tropical lentic environment, Central Gujarat, India. *International Journal of Environment* **3**, 168-176.

Vetrov, V.A., Kuznetsova, A.I., Sklyarova, O.A.(2013). Baseline Levels of Chemical Elements in the Water of Lake Baikal. *Geography and Natural Resources* **34**, 228–238.

Vyas, V., Bhawsar, A. (2013). Benthic community structure in Barna stream network of Narmada River basin. *International Journal of Environmental Biology* **3**, 57–63.

Wahl, M. H., McKellar, H. N., Williams, T. M. (1997). Patterns of nutrient loading in forested and urbanized coastal streams. *Journal of Experimental Marine Biology and Ecology* **213**, 111–131.

Wankhede, P., Wanjari, M. (2021). Health Issues and Impact of Waste on Municipal Waste Handlers: A Review. *Journal of Pharmaceutical Research International* **33(46B)**, 577–581. https://doi.org/10.9734/JPRI/2021/v33i46B32979.

Wen, Z., Chen, Q., Gao, X., Zhou, F., Wang, M., Liu, Y. (2016). Characterization of surface sediments from the Beijing-Hangzhou Grand Canal (Zaozhuang section), China: assessment of beryllium enrichment, biological effect, and mobility. *Environmental Science and Pollution Research* **23**, 13560–13568.

Whitemore, T. J., Brenner, M., Kolasa, K. V., Kenney, W. F., Riedinger, M. A., Whitmore, J. H., Curtis, Smoak. J. M. (2006). Inadvertent alkalization of a Florida Lake caused by increased ionic and nutrient loading to its watershed. *Journal of Paleolimnology* **36**, 353–370.

World Health Organization. (2017). Guidelines for Drinking−Water Quality: 4th Ed. Incorporating the First Addendum. Switzerland.

Xiao, S., Dong, H., Geng, Y., Francisco, M. J., Pan, H., Wu, F. (2020). An overview of the municipal solid waste management modes and innovations in Shanghai, China. *Environmental Science and Pollution Research* **27(24)**, 29943–29953. https://doi.org/10.1007/s11356-020-09398-5.

Appendix 1: *Concentrations of physicochemical properties of water samples from Deepor Beel near the Boragaon Garbage dump during winter (December) and summer (July) season (all values are expressed in Mean ± Standard Error Mean)*

	Sample sites																		WHO, 2017
Sample Collection site	S1		S2		S3		S4		S5		S6		S7		S8		S9		
Parameters	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
*p*H value	9.20±0.03	9.23±0.03	8.98±0.06	9.04±0.07	8.14±0.03	8.27±0.04	12.30±0.21	12.96±0.02	8.83±0.14	9.01±0.05	10.70±0.17	11.32±0.10	13.69±0.08	13.65±0.03	12.44±0.03	12.71±0.07	13.45±0.26	13.70±0.19	6.5-9.5
EC (dSM^{-1})	7.08±0.05	8.74±0.12	6.90±0.04	8.27±0.08	6.83±0.03	8.58±0.06	1.31±0.10	2.40±0.09	1.28±0.07	2.35±0.04	1.17±0.01	2.32±0.14	1.41±0.05	2.23±0.05	1.39±0.06	2.48±0.04	1.37±0.03	2.44±0.06	500
Turbidity (NTU)	15.40±0.51	19.20±0.58	19.80±0.73	22.00±0.45	12.20±0.58	14.20±0.37	540.40±3.08	549.40±2.99	524.80±1.43	531.8±2.71	568.00±1.48	584.40±1.36	659.20±1.98	680.40±2.36	650.60±0.93	670.40±1.29	684.60±1.03	693.80±1.24	5
DO (mg/L)	7.72±0.07	8.22±0.06	6.82±0.04	7.24±0.07	9.38±0.09	9.62±0.06	2.38±0.01	3.34±0.08	2.64±0.01	3.42±0.07	2.12±0.02	3.39±0.05	2.61±0.01	4.18±0.09	2.13±0.02	3.58±0.06	2.00±0.02	3.36±0.05	-
Sulphate (mg/L)	0.24±0.01	0.29±0.01	0.14±0.00	0.17±0.00	7.54±0.14	7.42±0.04	323.98±1.22	331.10±1.20	354.40±0.72	365.55±0.67	317.58±0.81	330.68±1.35	368.05±1.01	382.76±1.03	351.65±1.07	380.48±1.5	360.56±1.05	382.78±1.22	250
Phosphate(mg/L)	0.02±0.00	0.03±0.00	1.02±0.02	1.48±0.09	0.87±0.00	0.87±0.00	13.81±0.1	16.19±0.41	19.52±0.09	18.29±0.22	17.54±0.13	18.16±0.17	16.39±0.02	17.72±0.22	17.52±0.05	19.52±0.09	16.62±0.10	18.63±0.12	-
Nitrate (mg/L)	65.35±0.64	68.67±0.33	68.27±0.51	72.11±0.67	66.66±0.24	72.92±0.95	9.90±0.01	11.47±0.35	4.91±0.02	6.22±0.11	8.58±0.08	9.39±0.11	7.02±0.09	7.64±0.09	8.72±0.02	10.15±0.13	7.88±0.11	9.36±0.11	50
BOD (mg/L)	11.52±0.12	13.56±0.12	10.90±0.12	12.81±0.08	15.68±0.14	15.68±0.14	378.00±1.70	392.20±1.71	388.20±1.59	396.40±1.60	307.80±1.16	320.60±1.08	384.80±1.43	393.20±1.43	449.80±1.02	454.20±1.39	448.60±1.21	458.60±1.86	-
Sodium (mg/L)	26.40±0.93	29.80±0.73	27.80±0.97	30.80±0.58	21.40±1.03	26.00±0.84	124.59±0.67	129.70±0.72	122.81±0.87	128.10±1.31	115.80±0.73	122.60±0.51	149.88±0.93	159.04±0.96	146.21±2.00	169.40±0.63	165.90±1.00	175.04±1.30	200
Potassium (mg/L)	6.70±0.07	6.91±0.02	6.56±0.08	6.78±0.06	6.02±0.10	6.34±0.04	23.50±0.30	25.25±0.34	22.89±0.35	24.97±0.26	20.75±0.32	23.11±0.28	30.99±0.40	34.75±0.60	29.31±0.37	32.90±0.66	49.70±0.81	53.90±0.24	20

Chloride (mg/L)	320.24±0.8	328.84±1.12	487.75±0.69	502.28±2.96	303.86±1.19	312.56±1.07	251.18±1.34	262.16±2.02	290.26±0.97	300.84±1.74	271.64±0.96	292.56±2.16	308.76±0.68	334.91±3.65	277.41±1.16	284.75±2.67	292.69±1.57	311.16±1.21	250
Fluoride (mg/L)	0.28±0.02	0.41±0.12	0.29±0.02	0.27±0.00	0.27±0.01	0.25±0.01	1.16±0.04	0.96±0.01	1.04±0.03	0.84±0.01	0.91±0.03	0.75±0.01	1.89±0.03	1.65±0.01	1.75±0.02	1.39±0.01	2.12±0.02	1.92±0.01	1.5
TDS (mg/L)	4.42±0.03	6.48±0.08	4.41±0.01	7.88±0.21	4.39±0.01	8.18±0.25	769.80±1.83	830.00±5.59	795.80±3.12	875.40±6.14	729.60±0.81	859.40±5.24	831.40±0.93	890.60±3.17	808.00±2.10	838.40±9.15	865.40±1.96	917.40±2.23	500

Appendix 2: *Concentrations of heavy metals in the water samples of nine sites around Deepor Beel near the Boragaon Garbage dump during winter (December) and summer (July) season (all values are expressed in Mean ± SEM) (BDL: below detection level).*

	Sample sites																		WHO, 2017
Sample sites	S1		S2		S3		S4		S5		S6		S7		S8		S9		
Parameters	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter	Summer	
Al (mg/L)	6.40±0.13	7.21±0.06	5.35±0.08	6.08±0.02	5.30±0.06	6.10±0.03	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.03±0.00	0.02±0.00	0.03±0.00	0.02±0.00	0.10±0.06	0.1–0.2
As(µg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	9.61±0.03	12.66±0.06	BDL	BDL	17.82±0.02	18.9±0.10	103±0.67	112.03±0.24	123.9±1.50	129.42±0.22	0.01
Be(mg/L)	0.01±0.00	0.01±0.01	0.01±0.00	0.02±0.00	0.02±0.00	0.02±0.00	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.012
Cd(mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.003
Ca(mg/L)	306.9±1.56	320.1±0.44	165.29±1.01	172.4±0.31	15.02±0.09	24.28±0.34	52.66±0.52	50.81±0.35	50.28±1.11	58.54±0.22	56.04±0.71	48.81±0.00	47.23±1.24	53.81±0.35	62.81±1.00	78.76±0.21	62.44±0.43	67.06±0.27	200
Cr(mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.02±0.00	0.02±0.00	0.02±0.00	0.03±0.00	0.02±0.00	0.04±0.00	0.03±0.00	0.06±0.00	0.05
Cu(mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.01±0.00	0.03±0.00	0.01±0.00	0.02±0.00	0.02±0.00	0.04±0.00	0.01±0.00	0.02±0.00	0.02±0.00	0.04±0.00	0.03±0.00	0.05±0.00	2

Fe(mg/L)	43.25±0.50	41.22±0.49	56.23±0.71	52.13±0.70	2.41±0.05	3.61±0.04	1.21±0.01	0.83±0.01	1.80±0.05	1.80±0.05	0.75±0.01	0.83±0.01	1.99±0.02	1.59±0.02	2.94±0.03	2.61±0.03	2.70±0.03	2.54±0.02	0.2–0.3
Mg (mg/L)	51.36±0.36	43.68±0.52	49.80±0.27	44.18±1.15	3.14±0.04	2.32±0.13	26.58±0.27	21.81±0.49	24.75±0.36	22.24±0.24	23.14±0.37	20.74±0.37	24.74±0.38	18.08±0.37	22.82±0.38	22.82±0.38	27.41±0.19	22.78±0.36	150
Mn (mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.58±0.01	0.41±0.01	0.70±0.01	0.66±0.02	0.81±0.00	0.75±0.01	0.86±0.01	0.80±0.01	0.78±0.01	0.70±0.01	0.87±0.01	0.78±0.01	0.08
Ni(mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.09±0.00	0.10±0.00	0.06±0.00	0.08±0.00	-
Pb(mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.02±0.00	0.01±0.00	0.02±0.00	0.01±0.00	0.03±0.00	0.02±0.00	0.03±0.00	0.02±0.00	0.03±0.00	0.03±0.00	0.03±0.00	0.02±0.00	0.01
Zn(mg/L)	BDL	BDL	BDL	BDL	BDL	BDL	0.01±0.00	0.01±0.00	0.03±0.00	0.04±0.00	0.02±0.00	0.02±0.00	0.03±0.00	20.05±0.00	0.04±0.00	0.13±0.09	0.04±0.00	0.05±0.00	0.01-0.05