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S. I. – CEC FRAMEWORK

Hydrogeochemical assessment of wetlands of Gurugram, Haryana, India: implications for natural processes and anthropogenic changes

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Abstract

Surface water samples ($n = 55$) from four wetlands (Lost-W1, Sultanpur-W2, Damdama-W3, and Basai-W4) of Gurugram were studied for their hydrogeochemical characterization, quality assessment and suitability for various purposes. The parameters studied were temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), chemical oxygen demand (COD), biological oxygen demand (BOD), dissolved organic carbon (DOC), major cations, major anions, and trace metals. The results indicate that water samples of all the four wetlands are alkaline. Among studied parameters, pH (8.9), TDS (2233 mg/l), alkalinity (428 mg/l), PO_4^{3-} (7.05 mg/l), F^- (1.88 mg/l), Na^+ (597 mg/l), and K^+ (32 mg/l) are above permissible limits (PL). BOD and COD are above WHO limits in all the wetlands, except W1. Among ions, HCO_3^- and Ca^{2+} are dominant in W1, W2, and W3 which indicate weathering of Ca^{2+} and HCO_3^- minerals (carbonate weathering), whereas Cl^- and Na^+ are dominant in W4, which indicate strong anthropogenic influence. Lower values of the majority of ions in winter as compared to summer indicate the dilution effect. Among metals, Fe (549 mg/l), Cr (90 mg/l), and Ni (117 mg/l) are above PL. Piper diagram revealed the $Ca\text{-}HCO_3$ type of water in W1, W2, and W3 and Na-Cl type in W4. Gibbs plot indicated rock-forming minerals are dominantly affecting the water chemistry of all the wetlands. WQI suggested unsuitability of water from W4 (in both seasons) and W3 (in summer) for drinking, as well as irrigational indices (Wilcox, USSL plots, PI, RSC, KI, and MH) suggest unsuitability of W4 water for irrigation. Also, water from W4 is not suitable for cattle drinking. Water from W1, W2, and W3 is suitable for human consumption, irrigation, and cattle drinking except W3 water in summer which is not suitable for human consumption. Hence, it is concluded that, among studied wetlands, W4 is maximally perturbed, whereas W2 and W3 are disturbed to a lesser extent. All these wetlands need continuous monitoring and timely measures.

Keywords Wetlands · Gurugram · Lost · Sultanpur · Damdama · Basai · Land-use · Hydrogeochemistry · Water quality assessment

Introduction

Urban wetlands (wetlands lying within the city limits) are the most susceptible areas to changes in both water quality (increased levels of inorganic nutrients, metals, and organic pollutants, decreased dissolved oxygen levels, etc.), and quantity (drying and loss) (Ehrenfeld 2000; Prasad et al. 2002; Huang et al. 2014). They are also considered remnants of water bodies in urban settings that once existed in a rural setting. These wetlands play a vital role in recharging aquifers thus keeping the water table high and relatively stable, conserving moisture, mitigating urban floods, replenishing groundwater by trapping suspended solids, doing pollution filtration by trapping attached nutrients, mitigating climate change and recreation and tourism (Mitsch and Gosselink 2000). Enhanced urbanization due to increasing population in urban centers and rising nonagricultural land has severely affected water bodies in cities. Urbanization, land use changes and pollution are reported as the primary reasons for wetlands loss in India (Bassi et al. 2014). Urbanization influences the rate of addition and quantity of influents into the wetlands. This further modifies the hydrological regimes of a wetland thus affecting its functioning and dynamics of nutrients and pollutants. Any change in

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concentration of parameters (biological, major ions or trace metals) may lead to water quality deterioration. Metals are of serious concern due to their non-biodegradable nature and persistent behavior (Manta et al. 2002). Agricultural runoff and wastewater discharges are reported as the main culprits for degradation of majority of Asian wetlands (Prasad et al. 2002; Liu and Diamond 2005). A large percentage of sewage is discharged untreated in these water bodies; hence, lakes in cities are becoming increasingly saprobic and eutrophicated (CGWB 2010). This is the reason Okhla wetland in Delhi was observed to show low DO and high BOD (Manral and Khudsar 2013).

Water quality of urban wetlands is generally characterized by the land-use practices and the extent of development in their vicinity which contributes in the modification of their import sources from natural (i.e., weathering and erosion) to anthropogenic (i.e., sewage, industrial effluents, agricultural runoff, and building materials and road runoff) (Faulkner 2004; Huang et al. 2013; Khatri and Tyagi 2015). Haidary et al. (2013) studied the impact of different land use on water quality and indicated a significant positive relationship of EC, pH, TDS, NO_3^-, NH^{4+}, TN, and DON with % of urban areas within the catchments of the wetlands, and a significant negative relation with % of forest area in these wetlands. A change in quality of water may affect biodiversity, succession and behavior of migratory and resident bird species (Gopal 2009; Kaushik and Gupta 2014; Jangra and Sharma 2015). Deterioration of water quality also makes it unsuitable for drinking, agriculture and other purposes. Water quality index and hydrogeochemical assessment are the most widely used methods to analyze quality of water for different purposes (Naik and Purohit 2001; Khadka and Ramanathan 2013; Tiwari and Singh 2014; Rana et al. 2018; Davraz et al. 2019; Vasistha and Ganguly 2020). Water quality index (WQI) is considered one of the most accurate and effective tools for drinking water quality assessment where a large number of parameters can be represented in a single number (Horton 1965; Mishra and Patel 2001; Ravikumar et al. 2013; Tiwari et al. 2017; Garcia et al. 2018; Chabuk et al. 2020; Sharma et al. 2020).

Gurugram in a millennium city witnessing rapid urbanization and land use changes. Continuously increasing demand for water and depleting groundwater sources in the city develops a need to monitor and manage other available potential water resources. All the smaller wetlands present in the city has potential to serve the purpose. In the previous studies done in the city, the analysis mostly focused on the groundwater prospects (Chaudhary et al. 1996; Toleti et al. 2001; Kumar et al. 2015) and land use land cover (Jain 2002; Chaudhary et al. 2008). Some other studies also focused on water quality limited to diatom communities only (Gautam et al. 2017). Bhandari et al. (2010) analyzed water quality of Gurugram canal which supplies its water to a major part of Gurugram and Sultanpur wetland and observed high BOD and COD. A number of other studies have been also carried but they are limited to avian diversity (Sundar 2005; Urfi et al. 2007; Gupta et al. 2011; Chopra et al. 2012), zooplankton diversity (Tyor et al. 2014), and seasonal variation of phytoplankton's (Chopra et al. 2012). But no systematic work has been done related to the water quality of wetlands in Gurugram. Hence, the present study attempts to characterize surface water of four surviving wetlands of Gurugram, their seasonal variations, and to assess their current pollution status. The ensuing results will be useful to policymakers and local people in managing these water bodies.

Material and methods

Study area

The study sites lay in Gurugram (earlier Gurgaon) city of Haryana, which is a satellite township of the national capital of India, Delhi (Fig. 1). The city is situated between longitudes 76° 40′ and 77° 10′ and between latitudes 27° 37′ and 28° 30′ and falls in the southernmost region of Haryana. The annual temperature ranges between 5 °C and 40 °C, with an average annual rainfall of about 615 mm (CGWB 2010). The winds are generally westerly or north-westerly during most of the time. The district is divided into four blocks: Farrukhnagar, Gurgaon, Pataudi and Sohna (Malik et al. 2010; Dixit et al. 2020).

The presence of both hills and depressions in the city leads to irregular and diverse topography. Gurugram district is surrounded by Ferozpur-Jhirka Delhi ridge in the west and Delhi ridge in the east. Geologically, a large part of this city comprises of Pre-Cambrian metasediments of Delhi Super Group and Quaternary alluvium. Soils are sandy and alkaline. A major part of the district comprises old alluvium, which consists of generally poorly sorted sand, silt, and clay. The overall texture of soils of Gurugram is medium-textured loamy sand (Chaudhary et al. 1996; Mahmood et al. 2012).

Gurugram, a millennium city in Delhi NCR, is witnessing rapid population migration and developmental changes, thus creating a huge pressure on its water resources. Over the past 25 years, Gurugram has undergone rapid construction, which has converted the land-use from agricultural to residential, commercial, industrial, and different other land uses (Narain 2009). In such a city where the primary water source, i.e., groundwater, is facing a rapid depletion of its aquifers, even smaller water bodies such as ponds and other wetlands are precious. The revenue records suggest Gurugram had around 640 waterbodies in 1956. But rapid urbanization, developmental activities, and thus changing land use has resulted in the loss of 251 water bodies. Where other wetlands like Ghata jheel, Sikandarpur pond, and Kadarpur drain have become

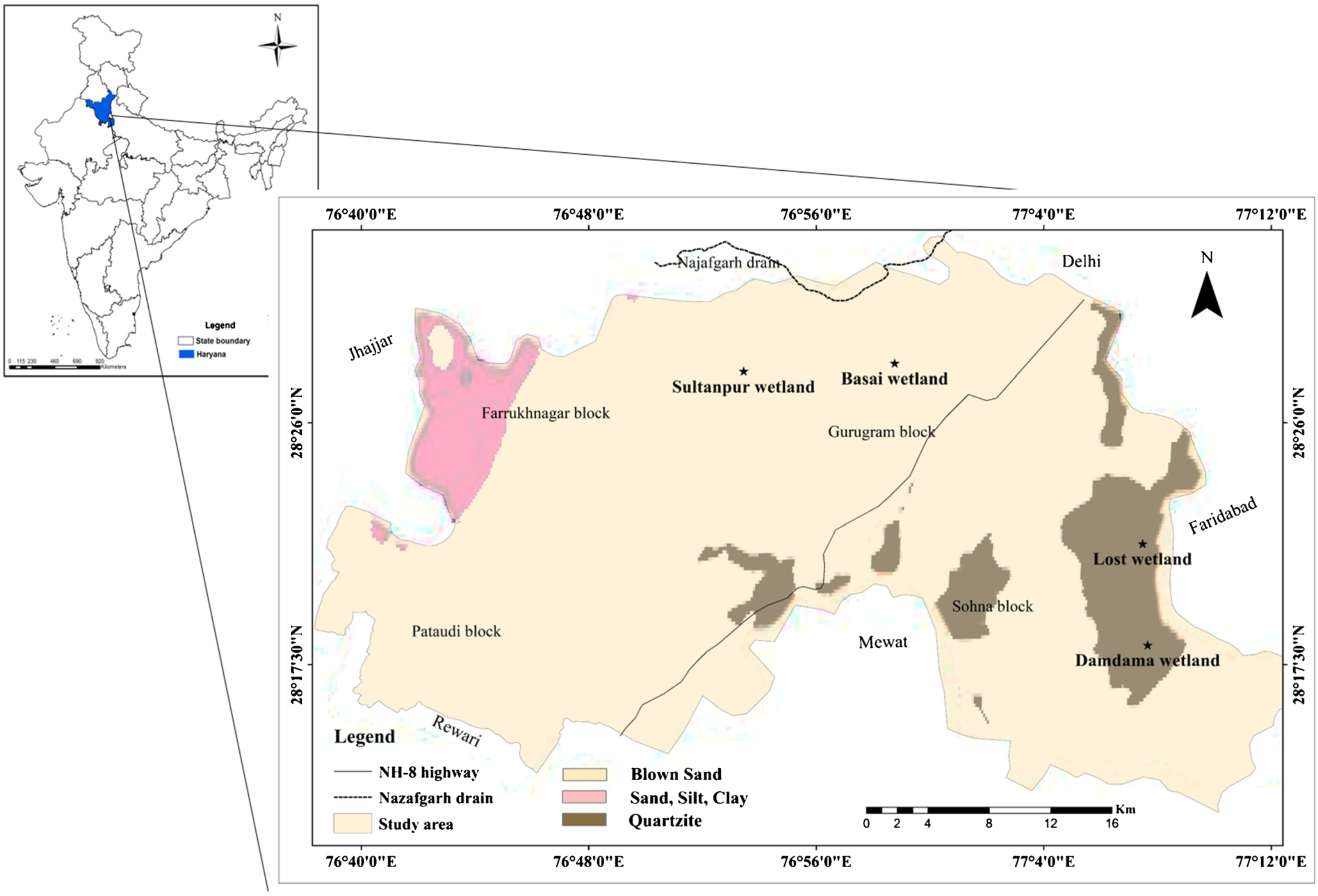

Fig. 1 Location of the studied wetlands over the lithological map of the study area

dried, wetlands—Lost, Sultanpur, Damdama, and Basai—are the only left undried (SANDRP 2018; Arora 2018). The addition of wastewater from treatment plants, sewage, agricultural runoff, and road runoff are the major sources of pollution in these wetlands. For their excellent potential as a wetland, Lost, Sultanpur, Damdama, and Basai wetlands were selected in this study.

Lost wetland lies in Sohna block of the district and is a water body amidst Aravalli forest near Dhauj with negligible human disturbances. Due to its pristine condition, it is chosen as the background site for comparison. Sultanpur wetland lies in Farrukhnagar block and is a shallow lake situated inside Sultanpur national park in an area of 143 ha. The lake is rich in avian fauna. It is fed water from rainfall, irrigation canal, and runoff from agricultural land. Fishes are reared to feed visiting avian fauna. Damdama wetland is an artificial lake in the lap of Aravalli hills. It receives its input from precipitation, surface drainage and runoff from nearby village area (Laroia 2015). It is used for tourism, irrigation, idol immersion and fish farming. Basai wetland is also situated in Farrukhnagar block and is a permanent, shallow, sewage fed, accidental wetland spread in an area of 100 ha in a depressional land. It also possesses rich avian visits like Sultanpur (Solanki and Joshi 2017; SANDRP 2018). A well-stabilized sewage fed aquaculture is prominent at one end of this wetland. The wetland is mainly surrounded by built-up area and agricultural land on one side and receives wastewater input from there. Study area map and locations of wetlands selected for the study are depicted in Fig. 1. The descriptive view of the selected wetlands and their catchment activities are shown in Fig. 2. All the wetlands differ in terms of the disturbances created in the catchment area. A detailed description of the study sites, ongoing activities in their vicinity, and their possible threats are provided in Table 1.

Sampling and analysis

Surface water samples (n = 55) were collected in pre-cleaned polyethylene bottles from four selected wetlands in Gurugram during winter 2017 and summer 2018. Samples were collected in separate bottles for different sets of parameters, preserved according to the requirement, brought to the laboratory, and kept at 4 °C for further analysis (APHA 2005). Samples were analyzed for various physico-chemical parameters such as pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO), (biological oxygen demand (BOD), chemical oxygen demand (COD), major cations (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), major anions (Cl^{-}, F^{-}, SO_4^{2-}, PO_4^{3-}, NO_3^{-}, and HCO_3^{-}) and metals (Cr, Cu, Fe, Mn, Ni, Pb, and Zn). The variables selected in the

Table 1 A detailed description of characteristics of all the four wetlands

Parameters	Lost (W1)	Sultanpur (W2)	Damdama (W3)	Basai (W4)
Lat-Long	28° 28′ N and 76° 53′ E	28° 28′ N and 76° 53′ E	28° 30′ N and 77° 12′ E	28° 47′ N and 76° 98′ E
Type	Square shaped, rain-fed pond located 10–15 km inside a forested area on Aravalli hills located in Rithouj village. Referred in this study as background site.	A low-lying shallow, artificial lake with irregular margins present inside Sultanpur national park, Gurugram designated the status in 1991 (Kalpavriksh 1994, Islam and Rahmani 2004).	An artificial, shallow, elongated lake with irregular margins built in 1947 to harvest rainwater in a hilly terrain of the Aravalli Hills in Sohna district of Gurugram	Permanent shallow freshwaters swamp comprising open water, dominated by Water hyacinth and Typha beds.
Area	2–3 ha	143 ha	1.5 km*0.5 km	100 ha
Depth	7–9 ft. (both summer and winter)	3–6 ft. (winter) and 0.5–2 ft. in (summer)	8–9 ft. (winter) and 3–4 ft. (summer)	4–6 ft. (winter) and 3–4 ft. (summer)
Avian richness	low	Rich	moderate	rich
Catchment area	Forest and hills, not much human interference.	Forest or agricultural land crisscrossed by irrigational canals	Forested land, village and farmhouses, adventurous sports	Large buildings and urban settlements on three sides and Dwarka highway on fourth
Input	Precipitation	Precipitation, surface drainage water from Gurugram canal.	Precipitation, surface drainage, nearby village area.	Precipitation, surface drainage, wastewater from nearby villages, sectors, water treatment plant and storm runoff.
Anthropogenic disturbance	Low	Medium	Medium	High
Aquaculture	No	No, but fishes reared for avian fauna	Yes	Yes
Importance	Still in pristine condition	Harbor rich biodiversity and aesthetic value.	Harbor rich biodiversity and aesthetic value, used for fish farming, water used for irrigation purpose	Supports rich Avian diversity, used for fish farming and water used for irrigation purpose
Threats	Encroachment in near future	Agriculture runoff, excessive water extraction nearby hence drying, addition of polluted canal water	Siltation, water quality deterioration through sewage, drying, sacred idols immersion.	Encroachment by real estate, Agriculture and sewage and road runoff, dumping of waste.

study are the variables mostly used in other studies. The variables selected were those which are routinely measured and widely analyzed worldwide. Also, they were selected based on their toxicity, sensitivity and effect on water quality (Horton 1965; Brown et al. 1970; Hu et al. 2015; Garcia et al. 2018). The pH, EC, and TDS were measured on-site with the help of portable pH meter (Hanna instrument, H196107) and multimeter (Aquapro water tester, model AP-2), respectively. The standard titration methods were used for alkalinity, CO_3^{2-} and HCO_3^- (APHA 2005). Cl^- was analyzed using the argentometric method. SO_4^{2-}, PO_4^{3-} and NO_3^- were estimated by the barium chloride, ascorbic acid method, and spectrophotometer method using TRI solution, respectively, using a UV-VIS spectrophotometer (Lambda-35). Ca^{2+}, Mg^{2+}, Na^+, and K^+ were analyzed using AAS (ThermoScientific, M series). H_4SiO_4 was measured using molybdo-silicate method. Total and dissolved organic carbon was analyzed using a TOC analyzer (Shimadzu TOC-L series). Winkler's method was used for the determination of DO and BOD. COD was analyzed by open reflux method (APHA 2005). A separate slot of 250 ml (preserved with ultrapure nitric acid onsite) was filtered using a 0.45 μm syringe filter (Millipore) and used for metal determination using atomic absorption spectrophotometer. The reagent blanks were analyzed at each step to check the accuracy and precision of the analysis. E-Merck single element standards used in the analysis were serially diluted using Milli-Q to obtain a working standard for preparing the calibration curve. The relative standard deviation for sample replicates was recorded within the range of 5%.

Hydrogeochemical study and water quality index

Piper plot (trilinear diagram) and Gibbs plot

Piper diagram (Fig. 5) is an effective method used in hydrogeochemistry to represent facies of water-based on dominant ions (Piper 1944; Mohammed and Merkel 2006; Madhav et al. 2018). Major cations (Ca^{2+}, Mg^{2+}, Na^+, and K^+) and anions (CO_3^{2-}, HCO_3^-, SO_4^{2-}, Cl^-) are plotted on two triangles, which are then combined to plot the ions on a diamond. The concentration of these ions in milliequivalents is plotted on a graph, and their percentages are considered for representation.

The "Gibbs diagram" (Fig. 6) is used to understand the critical processes involved in controlling surface water chemistry (Gibbs 1970; Marandi and Shand 2018). The three

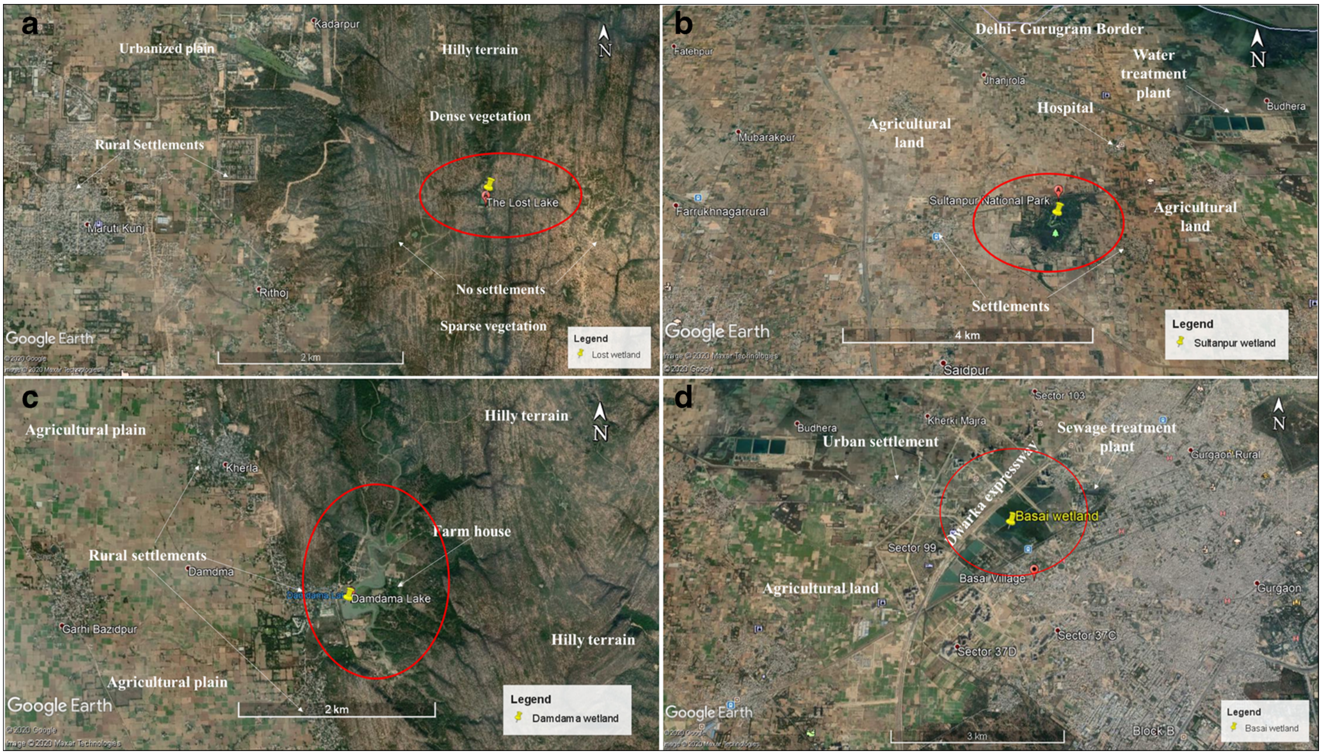

Fig. 2 (a–d) Descriptive view of the studied wetlands and their catchment activities. (a) Lost wetland (W1), (b) Sultanpur wetland, (c) Damdama wetland, and (d) Basai wetland

governing important processes used by Gibbs for the diagram are evaporation, precipitation, and rock–water interaction. The two ratios used for this analysis are 1) cation, which uses Na+K/Na+K+Ca ratio, and 2) anion, which uses $Cl/Cl+HCO_3$ ratio to explain the interaction

Water quality index

WQI is one of the most common methods to characterize water and its suitability for human consumption. It is a ranking method that utilizes the cumulative effect of all water quality parameters to describe the quality of water and, thus, the status of the water body (Singh et al. 2016; Rawat et al. 2017; Madhav et al. 2018). The method described by Vasanthavigar et al. (2010) has been adopted to calculate WQI in this study. The WQI is calculated in the following steps: In the first step, W_i is calculated using the equation given below where all values are in mg/l.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \tag{1}$$

where w_i is the weight of each parameter, W_i is the relative weight, and n is the number of parameters. To calculate this, firstly, each parameter is assigned a value (wi) from 1 to 5 based on their role in determining water quality. The w_i values of each parameter are then used to calculate Wi. There values are given in Supplementary table: Table 1S. In the next step, Q_i is calculated using the equation:

$$Qi = \left(\frac{Ci}{Si}\right) \times 100 \tag{2}$$

where Q_i is the quality rating, Si is the drinking water standard for each chemical parameter in mg/l and Ci is the concentration of each chemical parameter in each water sample in mg/l. In this study, Standards (Si) for human consumption, as suggested by WHO (2011), have been used to establish water quality. In third step, SI is calculated using the equation:

$$SI_i = W_i X\ Qi \tag{3}$$

where SI_i is the sub-index of ith parameter. In the last step, WQI is calculated:

$$WQI = \sum SI_i \tag{4}$$

WQI standards are categorized into the following: (1) excellent (< 50), (2) good (50–100), (3) poor (100–200), (4) very poor (200–300), and (5) unsuitable for drinking (> 300) (Vasanthavigar et al. 2010).

Suitability of agriculture

Wetlands are important surface water resources and are often used for the irrigation of agricultural fields. An inefficient or poor-quality irrigation supply may create agriculture hinders like sodium hazard and salinity hazard. Thus, the assessment of surface water quality for their suitability for agricultural purposes is of paramount importance (Madhav et al. 2018; Joshi et al. 2020a).

Percent sodium (% Na) (Wilcox diagram)

It is one of the primary indicators for evaluating surface water's suitability for irrigation purposes. High % Na content in soil may interfere with soil permeability and thus water infiltration. Also, it can directly affect crops by increasing total salinity content in the soil. % Na is computed using the relative abundance of cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}). It is calculated using the equation given below, where all values are in meq/l.

$$\%Na = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100 \quad (5)$$

Based on % Na and EC, Wilcox (1955) categorized water for irrigational use in the form of a diagram—Wilcox diagram (Fig. 7). In this diagram, water is classified into five different categories based on their suitability for irrigation.

Sodium adsorption ratio and USSL diagram

Sodium adsorption ratio (SAR) is an indicator of sodium hazard, and EC indicates salinity hazard. It is calculated using the equation given below, where all values are in meq/l.

$$SAR = \frac{Na^+}{1/2\sqrt{Ca^{2+} + Mg2+}} \quad (6)$$

USSL (US Salinity Laboratory) diagram (Fig. 8) is a plot of SAR against EC and is used for classifying agricultural water (Richards 1954).

Residual sodium carbonate

Residual sodium carbonate (RSC) is a measure of the effect of CO_3^{2-} and HCO_3^- on the suitability of water for irrigation purposes. The high concentration of HCO_3^- leads to sodium hazard (Richards 1954). It is calculated using the equation given below, where all values are in meq/l.

$$RSC = \left(CO_3^{2-} + HCO_3^-\right) - \left(Ca^{2+} + Mg^{2+}\right) \quad (7)$$

Permeability index

Ca^{2+}, Mg^{2+}, Na^+, and HCO_3^- ions present in water influence the permeability of the soil. Permeability index (PI) is calculated using the equation given below, where all values are in meq/l.

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{\sqrt{\left(Na^+ + Mg^{2+} + Ca^{2+}\right)}} \times 100 \quad (8)$$

Doneen (1964) developed a diagram based on PI to categorize irrigational waters. It classified PI in three categories, such as class I (> 75% permeability), class II (25–75% permeability), and class III (< 75% permeability). A sample falling in class I and class II are good for irrigation while that falling in class III water is unsuitable with 25% of and maximum permeability.

Kelly's index

Kelly's index/Kelly's ratio is another parameter that determines the hazardous effect of sodium and is used to classify water for irrigational uses. The equation calculates it as:

$$KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (9)$$

Kelly's index (KI) value < 1 for water indicates its suitability for irrigation, whereas > 1 indicates unsuitability for irrigation (Kelly 1963; Sappa et al. 2014). All values are in meq/l.

Magnesium hazard

Szabolcs and Darab (1964) suggested a magnesium hazard (MH) value of water for irrigation purposes. MH can be calculated by the given formula:

$$MH = \left(\frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}}\right) \times 100 \quad (10)$$

where, all values are in meq/l. Water having MH of more than 50 is unsuitable for agricultural use according to criteria set by Szabolcs and Darab (1964). Applying such water increases the basic nature of the soil, thus negatively affecting the crop yield (Raju et al. 2011).

Data interpretation

For the interpretation of data Pearson's inter-element correlation and principal component analysis (PCA) is adopted for analysis, the results of which are given in Tables 3 and 4, respectively. Correlation between two variables. The correlation between two variables is the measure of the linear relationship between them (Nettleton 2014). Its values lie between − 1 and + 1. Only values greater than 0.5 are reported in the study. The PCA is a powerful method that helps in identification of different correlated groups having a common origin and similar behavior (Tahri et al. 2005). This multivariate analysis technique segregates the data into different principal components so that it is easier to analyze the variance in a reduced dimensional space thus increasing interpretability (Osei et al. 2010; Jolliffe and Cadima 2016). Varimax rotation with Kaiser normalization is used for the analysis. Only those components having Eigen value greater than 1 is selected in the study (Kaiser 1960).

Results and discussion

Physico-chemical parameters

Figure 3 and Fig. 4 represent the average concentration of the studied parameters, their seasonal variations, and permissible limits. Their results along with WHO limits have been provided in Table 2. Lost, Sultanpur, Damdama, and Basai wetlands are designated as W1, W2, W3, and W4, in Table 2, and discussion henceforth.

pH, EC, DO, H_4SiO_4, DOC, and alkalinity

pH determines the corrosive nature of water (low pH high corrosiveness and vice-versa). It also explains the assimilatory effect of carbon dioxide and photosynthetic activity (higher the pH, lower the photosynthetic activity) (Bhateria and Jain 2016; Joshi et al. 2020b). pH, in general, is found to be alkaline in all the studied wetlands except for W1, which has an average pH of 7.9 and 7.5 in winter and summer, the other three wetlands have average pH above the permissible limit (BIS 2012; WHO 2011) of 8.5. A total of 50% of the samples in W2, 57% in W3, and 69% in W4 have pH above the permissible limit of 8.5. The order of pH follows as: W1 (7.6 mg/l) < W2 (8.5 mg/l) < W3 (8.5 mg/l) < W4 (8.7 mg/l). High pH values of W2, W3, and W4, as compared to W1, are due to the addition of nutrients, salts, and other extraneous materials from wastewater. The variation in electrical conductivity (EC) depends on ionic composition, mobility of ions, the concentration of ions, and the temperature of water (Okbah et al. 2017). Average EC ranges from 91.60 μS/cm (W1) to 2040.11 μS/cm (W4) in winter and 208 μS/cm (W3) to 2817 μS/cm (W4) in summer. Similar results for pH and EC were obtained in studies of Singh and Deepika (2017) and Ayyanar and Thatikonda (2020) as given in Table 5. TDS has a direct correlation with EC and is one of the essential constituents in describing the chemistry of water. It also has a significant contribution to productivity (Dutta et al. 2016). Average TDS in summer in W4 (2233 mg/l) is above the permissible limit of 2000 mg/l (BIS 2012) as reported in Table 2. All other wetlands are observed for TDS below the permissible limit. High TDS in W4 as compared to other wetlands may be due to the mixing of sewerage water and organic matter from nearby residential areas and sewage treatment plants, supporting the earlier studies (Qureshimatva et al. 2015; Dutta et al. 2016).

Average dissolved oxygen (DO) is 7.8, 6.8, 7.0, and 5.9 mg/l in winter and 7.0, 7.0, 5.4, and 5.1 mg/l in summer for W1, W2, W3, and W4, respectively. DO values below 5 mg/l are the permissible limit for inland water (BIS 2012). DO in all the wetlands are above 5 mg/l. Low values of DO in W4 (close to the permissible limit) as compared to other wetlands suggest the addition of some external pollution sources (Srivastava et al. 2009). These external sources may be sewage water, which reduces DO and increases BOD (Belanger 1991) and photosynthetic plants, (abundantly present in W4), which utilizes DO or dead organic matter decomposition (Mnaya et al. 2006; Ravikumar et al. 2013). DO is also reduced by disturbances created by animals visiting the wetland (Mnaya et al. 2006). All the wetlands show high DO in winter as compared to summer, which may be attributed to the high solubility of DO in the water at low temperature (Sajitha and Vijayamma 2016).

H_4SiO_4 is a vital nutrient required by aquatic organisms like diatoms and siliceous sponges for making their skeleton. Natural water consists of an average concentration of H_4SiO_4 between 1.0 and 30.0 ml/L (Davis 1964). Average H_4SiO_4 is 9.46, 1.25, 2.47, and 13.61 mg/l in winter and 9.96, 1.84, 3.55, and 15.05 mg/l in summer in W1, W2, W3, and W4, respectively. High values of H_4SiO_4 in W4 may be attributed to wastewater input from nearby villages and waste treatment plants, in addition to natural sources. H_4SiO_4 primarily enters the water system through diffuse natural sources like weathering. Most of the anthropogenic inputs include point sources like urban runoff (weatherable road materials), domestic sewage (food items like beer and grain products and detergents which use Na^+ metasilicate), and industrial waste (pulp and paper production) (Sferratore et al. 2006).

Alkalinity in water bodies comes from carbonate-rich surrounding soils, rocks, and some plant activities (Matagi 2004). The alkalinity is observed to be 20.99, 86.92, 55.76 and 310.14 in winter and 38.26, 125.73, 82.82 and 428.86 in summer for W1, W2, W3, and W4, respectively. All values in mg/l as CaCO3. The alkalinity of these water bodies is mainly due to the presence of HCO_3^-. 50% of the samples in W4 are above the desirable limit of 300 mg/l, and one sample is above the permissible limit of 600 mg/l (BIS 2012). All the samples from W1, W2, and W3 are below this limit. Water having high alkalinity is unsuitable for irrigation as it negatively impacts the soil health and ultimately reduces crop yields (Sundar and Saseetharan 2008).

Any organic compound that passes through a 0.45 μm size filter is termed as dissolved organic matter (DOM), which often is an essential component of natural waters. DOM greatly influences the functioning of water bodies through its effect on the nutrient supply, acidity, and trace metal transport by

Table 2 Average concentration of parameters (mean ± s.e.), their comparison with standard limits, WQI and average irrigational parameters in the studied wetlands

	Winter								Summer								Range of standards	
	W1 (n=5)		W2 (n =14)		W3 (n =10)		W4 (n =9)		W1 (n =3)		W2 (n =6)		W3 (n =4)		W4 (n=4)		(DL–PL) BIS	Max limit WHO
	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE	Avg	SE		
pH	7.9	0.1	8.5	0.1	8.6	0	8.8	0.2	7.5	0	8.6	0.2	8.6	0.3	8.7	0.3	6.5–8.5	8.5
EC	91.60	0.68	301.07	8.90	167.50	0.27	2040.11	191.12	208.00	3.00	314.67	16.92	439.50	14.61	2817.00	299.28	-	
TDS	83.37	4.51	225.45	6.26	157.26	1.62	1392.83	132.68	140.07	8.06	314.41	22.92	325.51	8.27	2233.21	114.37	500–2000	500
DO	7.9	0.2	6.8	0.6	7.1	0.3	5.9	0.6	7.0	0.1	7.1	0.3	5.4	0.3	5.1	0.3	5	-
Alk	20.99	1.97	86.92	2.77	55.76	0.84	310.14	53.76	38.27	1.09	125.73	12.66	82.82	4.52	428.86	29.8	200–600	-
H_4SiO_4	9.46	0.25	1.26	0.22	2.47	0.25	13.61	1.1	9.97	0.67	1.85	0.77	3.55	1.19	15.05	2.01	-	17
DOC	14.33	1.22	10.21	0.66	11.87	0.24	58.11	18.14	15.63	0.19	7.22	1.26	18.43	0.56	67.92	14.6	-	-
TDC	19.37	0.69	35.05	1.82	28.16	0.25	118.86	28.56	27.43	0.37	37.08	4.38	44.91	0.99	143.05	12.77		-
BOD	5.3	0.1	7.8	0.3	6.7	0.4	55.7	3.8	5.9	0.0	7.1	0.3	9.8	1.0	52.8	5.0	-	6
COD	9.0	0.0	28.3	1.1	32.5	1.6	154.3	21.1	10.0	0.0	40.5	2.5	42.5	4.9	182.5	24.7	-	10
CO_3^{2-}	0	0	4.21	1.13	5.11	0.59	34.97	14.19	0	0	6.56	2.19	6.88	2.47	53.11	20.97	-	-
HCO_3^-	25.60	2.41	96.86	4.56	57.60	1.34	296.00	53.34	45.33	1.33	140.00	19.23	87.00	5.26	415.00	67.06	300–600	600
NO_3^-	2.62	0.31	15.04	0.97	20.11	0.72	21.52	2.22	4.60	0.32	20.37	0.72	27.93	1.96	41.93	7.38	45	50
Cl^-	10.00	0.63	9.43	1.02	6.40	0.87	522.22	55.52	16.67	0.67	8.52	1.43	21.50	0.96	837.50	82.60	250–1000	250
SO_4^{2-}	24.03	1.69	39.79	1.33	23.96	1.26	48.97	4.90	32.80	0.42	55.64	1.71	70.10	4.31	65.45	2.18	200–400	600
PO_4^{3-}	0.04	0.00	0.20	0.01	0.23	0.01	3.24	0.29	0.50	0.04	0.33	0.06	0.24	0.02	7.05	1.10		0/1
F^-	0.35	0.02	0.30	0.02	0.30	0.01	1.01	0.09	0.48	0.02	0.31	0.03	0.36	0.02	1.88	0.19	1–1.5	1.5
Na^+	3.43	0.12	13.86	1.34	12.52	0.55	361.51	35.25	4.37	0.48	13.50	1.22	37.38	3.33	597.50	42.90	-	200
K^+	0.86	0.29	3.91	0.50	3.19	0.31	23.95	2.58	4.38	1.15	6.05	1.28	5.88	0.32	32.10	2.57	10–12	12
Ca^{2+}	18.60	0.93	31.67	1.43	24.75	0.73	59.83	6.06	28.47	0.07	49.82	1.01	43.18	1.70	86.08	5.25	75–200	200
Mg^{2+}	2.45	0.41	10.17	0.89	3.07	0.09	36.14	3.13	3.80	0.48	13.32	1.42	5.07	0.69	46.87	9.84	30–100	150
Cr	1.28	0.40	3.11	0.58	2.40	0.52	15.56	1.44	74.10	8.43	19.72	0.87	47.94	20.94	90.15	23.87	nr	50
Cu	7.70	1.87	4.77	0.98	4.03	0.76	5.39	0.98	26.37	16.56	9.72	0.23	19.92	9.63	35.13	5.45	1500	2000
Fe	2011.98	170.57	90.10	23.54	119.21	51.46	56.30	10.37	1359.37	157.58	345.35	49.18	2799.26	47.35	549.68	162.37	nr	300
Mn	229.76	25.87	55.25	15.23	63.09	4.70	168.43	26.42	135.87	19.94	168.88	29.04	335.66	63.03	342.53	100.49	300	500
Ni	1.54	0.30	0.47	0.09	6.36	1.11	5.96	1.09	60.57	3.93	2.53	0.32	52.56	4.35	117.93	27.20	nr	70
Zn	20.00	6.22	5.64	1.31	3.50	0.91	16.84	8.48	99.50	19.70	47.62	4.95	103.94	33.97	160.03	35.06	15,000	5000
Pb	bdl	-	bdl	-	bdl	-	bdl	-	bdl	-	bdl	-	bdl	-	bdl	-	nr	10
WQI	57.38	4.58	23.59	2.45	28.21	2.62	108.67	13	62.99	2.15	37.77	5.24	103.10	3.93	191.14	6.69	-	-
% Na	13.19	-	22.55	-	29.68	-	72.9	-	14.78	-	17.03	-	40.78	-	76.79	-	-	-
SAR	0.2	-	0.56	-	0.63	-	9.15	-	0.2	-	0.44	-	1.44	-	13.07	-	-	-
RSC	−0.71	-	−0.84	-	−0.55	-	−1.13	-	−0.99	-	−1.3	-	−1.15	-	−1.39	-	-	-
PI	62.12	-	61.6	-	74.74	-	82.13	-	54.58	-	49.67	-	67.11	-	83.92	-	-	-
KI	0.13	-	0.26	-	0.37	-	2.7	-	0.11	-	0.16	-	0.64	-	3.33	-	-	-
MH	17.82	-	34.37	-	17.02	-	50.15	-	17.94	-	30.16	-	16.05	-	45.65	-	-	-

Units: pH, no units; EC, μS/cm; TDS, DO, alkalinity, anions, and cations, mg/l; metals, μg/l; nr, no relaxation; SE, standard error; SAR, PI, KI, MH, no units directly influencing pH (Evans et al. 2005). In natural waters, it comes from the biodegradation of biota (Yu et al. 2015). Dissolved organic carbon (DOC), a component of DOM, is quantified in most of the studies which vary widely, from < 1 to > 50 mg/l in natural waters (Thurman 2012). Although some dissolved organic carbon is naturally present in water bodies through partially decomposed organic materials however studies (Pal et al. 2014; Yu et al. 2015; Daniel et al. 2002) has described sewage and wastewater as one of the major contributors of DOC in polluted water bodies. In natural conditions, 80% of DOC is formed by fulvic and humic acids (Chapman 1996). In the present study, the mean values of DOC are 14.33, 10.20, 11.87, 58.10 mg/l in winter and 15.62, 7.21, 18.43 and 67.92 mg/l in summer in W1, W2, W3, and W4, respectively. W4 has DOC values almost four times the concentration of DOC in W1 (background site) in both the seasons which is due to the addition of sewage from nearby villages. The mean values of total dissolved carbon (TDC) in W1, W2, W3, and W4 are 19.36, 35.04, 28.16, and 118.85 mg/l in winter and 27.43, 37.08, 44.90 and 143.05 mg/l in summer, respectively. High TDC content in any water body is attributed to the high concentration of CO_3^{2-} and HCO_3^- (Yu et al. 2015).

Biological oxygen demand (BOD) or chemical oxygen demand (COD) are routinely monitored in water systems to analyze organic pollutants and hence a very useful parameter to determine pollution index (Ndimele 2012; Lee et al. 2010). Where BOD is equivalent to the amount of oxygen required to degrade organic matter principally consumed by microorganism, COD is a measure of amount of oxygen required to degrade organic matter and inorganic matter which cannot be decomposed biologically (Chandra et al. 2012; Lee et al. 2010). They are also considered a measure of bioavailability of carbon (Hu and Grasso 2005). Majority of Indian lakes are observed for high BOD level. Water is considered polluted when BOD is high due to presence of a large number of microorganism (Martin and Hine 2000). In some studies, TOC is highlighted as an alternative for BOD and COD measurement lakes but its authenticity is established in rivers only not in urban wetlands (Lee et al. 2010). The average BOD is 5.3 and 5.9 mg/l in W1, 7.8 and 7.1 mg/l in W2, 6.7 and 9.8 mg/l, 55.7 and 52.8 mg/l in W4 in winter and summer, respectively. The observed high BOD in W4 indicates high organic load and high activity of heterotrophic organisms for oxygen consumption in this wetland. In surface waters, COD can vary from 20 mg/l in unpolluted waters to 200 mg/l in waters receiving effluents. The same range for BOD is 2 and 10 mg/l, in unpolluted and polluted water, respectively (Chapman 1996). Average COD in summer and winter is 16.0 and 18 mg/l in W1, 28.3 and 40.5 mg/l in W2, 32.5 and 42.5 mg/l and 154.3 and 182.5 mg/l in W4. The main reason for high BOD in W4 is due to the continuous supply of sewage, whereas high COD might be due to addition of nonbiodegradable agricultural inputs along with municipal and industrial wastewater.

Major anions and cations

Average HCO_3^- concentrations are 25.60, 96.85, 57.60 and 296.00 mg/l in winter and 45.33, 140.00, 87.00 and 415.00 mg/l in summer in W1, W2, W3 and W4, respectively. Some HCO_3^- is naturally added in water from weathering of minerals (silicate and carbonate) or rainfall (Mallick 2017), as seen in W1. However, approximately twelve times higher average HCO_3^- concentration in W4 compared to W1 is attributed to anthropogenic additions such as wastewater from treatment plants, sewage, and $NaHCO_3$ along with the natural contribution. $NaHCO_3$ is added in water for remediation purposes of enhancing aquaculture (Tucker and D'Abramo 2008). $CO_3^{2-}$is absent from W1 and found in the highest concentration in W4 compared to W2 and W4. Average Cl^- concentration is 10.00, 9.42, 6.40, and 522.22 mg/l in winter and 16.66, 8.51, 21.50, and 837.50 mg/l in summer in W1, W2, W3, and W4, respectively. SO_4^{2-} in natural water usually comes from the dissolution of gypsum and anhydrite present in sedimentary rocks, oxidation of sulfite ores, rocks containing shale particularly rich in organic compounds (Egbunike 2007; Nwankwoala and Peterside 2019). It can also be introduced to the water bodies from anthropogenic additions like fertilizers used in paddy cultivation, industrial waste, and atmospheric sulfur dioxide (Twort et al. 2000). In arid regions, sulfur salts accumulate in surface layers of around 10–12 ft and reach water bodies with rain (APHA 2005). The observed average concentrations of SO_4^{2-} in the study region considered are 24.03 and 32.80 mg/l in W1, 39.79 and 55.63 mg/l in W2, 23.96, and 70.10 mg/l in W3 and 48.97 and 65.45 mg/l in W4 in summer and winter, respectively. All these locations have a comparatively higher concentration of SO_4^{2-} in W1 but well below the permissible limit of 400 mg/l. High values of SO_4^{2-} in summer in all the wetlands may be attributed to high microbial degradation during this season (Shan et al. 2017). Moreover, a positive correlation of SO_4^{2-} with Ca^{2+}, indicated dissolution of gypsum is also a source of sulphate in water samples (Table 3). PO_4^{3-} and NO_3^- are important water quality parameters in the wetland system. Natural sources of NO_3^- in surface water generally include igneous rocks (Stadler et al. 2012) and nitrification, while sewage disposal and paddy field land drainage (agricultural runoff) are the common anthropogenic sources (Azam et al. 2015, 2018). Phosphorous mainly comes from weathering of phosphorous bearing rocks and decomposed organic matter. Phosphate fertilizers are the most common anthropogenic sources. In surface water, PO_4^{3-} concentration generally ranges from 0.005 and 0.020 mg/l (Ganguly et al. 2015; Chattopadhyay et al. 2005). High inputs of PO_4^{3-} and NO_3^- in lakes may lead to its eutrophication and can have an adverse effect on flora and fauna (Vyas et al.

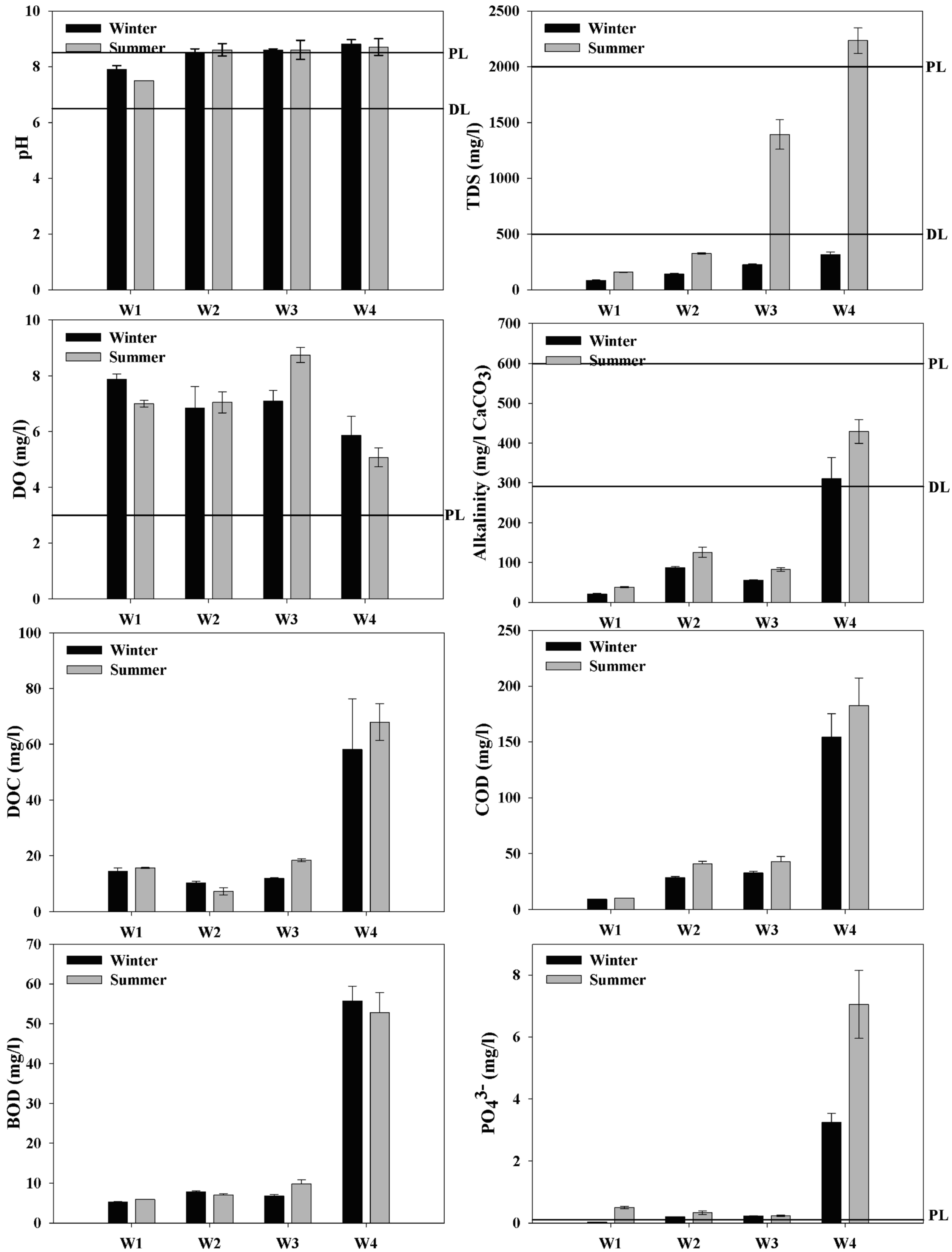

Fig. 3 Bar graphs representing average concentrations of different parameters, their seasonal variations, and their comparison with Permissible limits in the studied wetlands

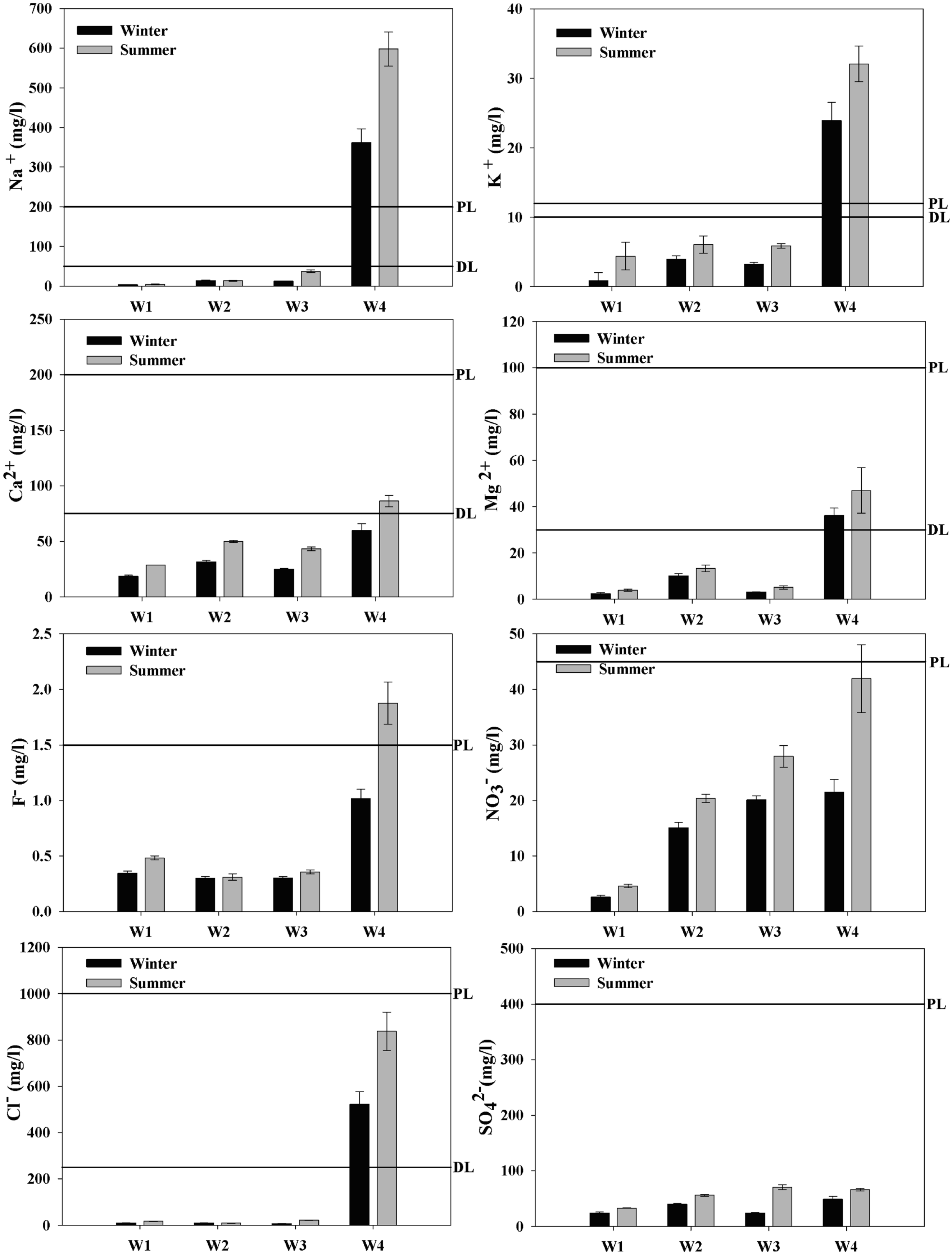

Fig. 3 (continued)

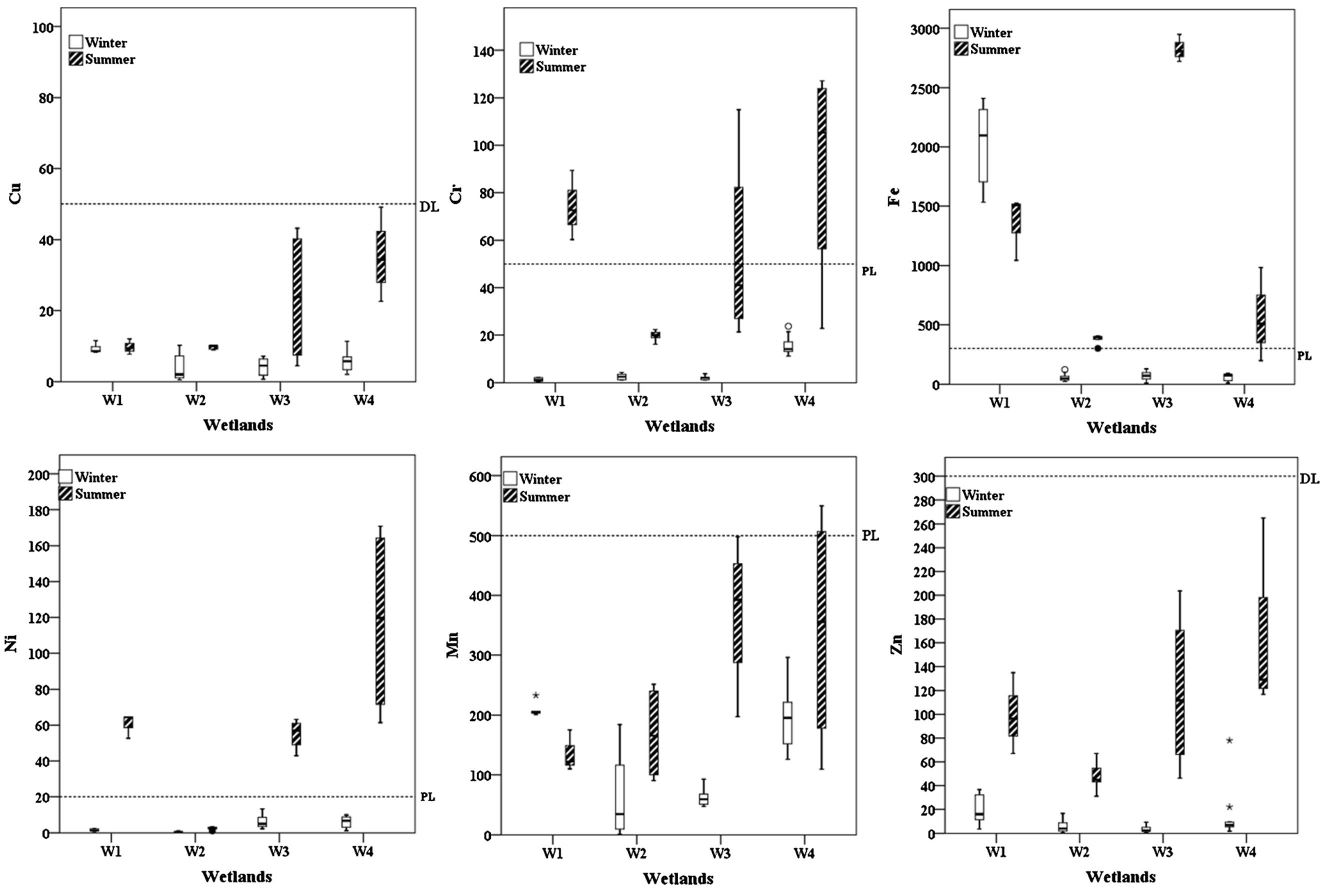

Fig. 4 Box plots representing average concentration of trace metals in surface water of studied wetlands

2006; Madhav et al. 2020). The present study estimated the average concentration of PO_4^{3-}, 0.03, 0.19, 0.22, and 3.24 mg/l, and NO_3^-, 2.62, 15.04, 20.11, and 21.52 mg/l, in W1, W2, W3, and W4, respectively in winter. In summer, the average concentration is 0.5, 0.33, 0.23 and 7.05 mg/l for PO_4^{3-} whereas, 4.60, 20.37, 27.92 and 41.92 mg/l for NO_3^- in W1, W2, W3 and W4, respectively. W4 shows four times higher PO_4^{3-} concentration than other wetlands, indicating its eutrophic nature. Higher NO_3^- concentration in W4 as compared to other wetland may be attributed to runoff from agriculture surrounding the wetland and more plant growth and decay. Although the average concentration of NO_3^- is well below the permissible limits in all wetlands however high nitrates at few sites is above permissible limits in W4 which is due to their proximity to sewage discharge points. The points away from the discharge points have low nitrate concentration. The concentration of Cl^- is below the desirable limit of 250 mg/l in W1, W2, and W3 however, it is above this limit in W4. Low Cl^- concentration in W1, W2, and W3 suggests its sources being natural like weathering of natural salts however in W4 concentration above desirable limit suggests addition from anthropogenic sources such as sewage waste, inorganic fertilizers, leachate from landfills, industrial and irrigation drainage, etc. (Ritter et al. 2002). Table 3 shows a positive correlation of PO_4^{3-} with NO_3^- and Cl^- and this added proof that the local anthropogenic activities are the key sources of these ions in water samples. F^- is essential in trace amounts but causes severe problems if found in the high amount (Prasad and Shukla 2019). The mean concentration of F^- is 0.34, 0.29, 0.30 and 1.01 mg/l in winter and 0.48, 0.31, 0.35 and 1.87 mg/l in summer in W1, W2, W3, and W4, respectively. All samples show F^- concentration below the permissible limit of 1.5 mg/l except in W4 in summer, where its concentration (1.87 mg/l) is above the permissible limit. Additionally, high F in W4$^-$, other than naturally present, may be attributed to the addition of sewage input, phosphate fertilizer (Mukherjee and Singh 2020), or chemical enrofloxacin (a fluoroquinolone), which is extensively used for fish and poultry management (Pradhan et al. 1995).

The mean concentration of Na^+ is 3.43, 13.86, 12.52 and 361.50 mg/l in winter and 4.37, 13.50, 37.37 and 597.50 mg/l in summer in W1, W2, W3, and W4, respectively. All samples show Na^+ concentration below the permissible limit (200 mg/l), except W4 wetland, which shows Na^+ values much beyond this limit. Studies have reported weathering and dissolution of plagioclases and Na- and K-bearing minerals present in rocks as the primary source of Na^+ and K^+ in a water body (Velde and Meunier 2008). Low average Na^+ values in W1, W2, and W3 suggest their natural origin. Such high value in W4 is probably due to its anthropogenic sources in water, which includes municipal sewage effluents, water softeners, detergents, paper, and food waste used in houses (Gautam et al. 2013; Madhav et al. 2018) and $NaHCO_3$ added for fish management. Similarly, the average concentration of K^+ is comparatively higher and suggests similar anthropogenic sources. A positive correlation of Na^+ and K^+ with Cl^-, PO_4^{3-} and NO_3^- (Table 3), suggested that the high concentration of ions in W4 samples due to the local anthropogenic sources. The mean concentration of Ca^{2+} is 18.60, 31.43, 24.75, and 59.83 mg/l in winter and 28.46, 49.81, 43.17, and 86.08 mg/l in W1, W3, W2, and W4, respectively. The permissible limit of Ca^{2+} is 200 mg/l as per standards. Samples from all studied wetlands have Ca^{2+} less than the permissible limit. All wetlands show a high concentration of both Ca^{2+} and Mg^{2+} as compared to W1. In W2, this can be attributed to the addition of canal water from the Najafgarh drain, which supplies water mixed with sewage to the wetland every year (TNN 2015). In W3, these ions are added probably due to the immersion of idols during Durga pooja or Ganesh Chaturthi (Laroia 2015). In W4, the addition of sewage, wastewater, construction material, and fertilizers are the most common source (Gautam et al. 2013; Solanki and Joshi 2017).

Among anions, the major proportion of water samples from W1 is dominated by almost equal percentages of HCO_3^- (41% in winter and 33% in summer) and SO_4^{2-} (38% in winter and 33% in summer) followed by Cl^-, NO_3^-, F^- and PO_4^{3-}. HCO_3^- alone is the major ion in W2 (58% in winter and 60% in summer) and W3 (51% in winter and 41% in summer). While SO_4^{2-} (24% in both summer and winter) is the second major contributor of anionic concentration followed by NO_3^-, Cl^-, CO_3^{2-}, F^-, and PO_4^{3-}. The major proportion of anionic concentration in W4 is covered by Cl^- (56% in winter and 59% in summer) followed by HCO_3^- (32 and 29% in winter and summer, respectively). The rest 30% is covered by SO_4^{2-} (5%), CO_3^{2-} (4%), and NO_3^- (2–3%). F^- and PO_4^{3-} cover < 1% of the total anionic concentration in all the wetlands; however, in W4, F^- concentration is > 1 in approximately 70% of the samples. Among cations, major proportions of W1, W2, and W3 are observed to show the highest concentration for Ca^{2+} (60–70% in W1 and W2, while 50–60% in W3 of the total cation concentration) followed by Na^+, Mg^{2+}, and K^+ which show approximately similar percentages. Dominance of Ca^{2+}, Mg^{2+}, and HCO_3^- suggests leaching of carbonates and presence of carbonate weathering in the area. However, W4 is observed to show Na^+ as the major cation constituting 70% of total cationic concentration followed by Ca^{2+}, Mg^{2+}, and K^+. A well-mixed lake is the one in which samples collected from one site have approximately the same concentration as the sample collected from any other site. A natural shallow lake is supposed to have a well-mixed nature (Clark and Hutchinson 1992). Samples collected from W1 do not show much variation in concentrations of different samples for the same parameter, while W2, W3, and W4 show variations in concentration in different samples. This indicates W1 is a well-mixed type of lake, while W2, W3, and W4 are not. This variation is due to the addition of effluents from the point and non-point sources in W2, W3, and W4. All wetlands belong to the same geographical setting and have rainwater as the only common natural source among the wetlands. Hence the concentration of samples indicates the quality of their catchment.

Trace metals

The trace metal characterization and their seasonal variation in the surface water of the studied wetlands have been

Table 3 Correlation analysis for physico-chemical parameters and trace metals in the studied wetlands (values in bold show significant values, i.e., > 0.5)

	pH	EC	TDS	HCO_3^-	NO_3^-	Cl^-	SO_4^{2-}	PO_4^{3-}	F^-	Na^+	K^+	Ca^{2+}	Mg^{2+}
pH	1.00												
EC	0.29	1.00											
TDS	0.28	0.98	1.00										
HCO_3^-	0.12	0.85	0.88	1.00									
NO_3^-	0.26	0.54	0.62	0.69	1.00								
Cl^-	0.29	0.97	0.98	0.79	0.52	1.00							
SO_4^{2-}	0.22	0.45	0.48	0.39	0.49	0.43	1.00						
PO_4^{3-}	0.13	0.85	0.89	0.85	0.69	0.86	0.43	1.00					
F^-	0.18	0.88	0.91	0.79	0.63	0.90	0.38	0.94	1.00				
Na^+	0.28	0.97	0.99	0.84	0.58	0.99	0.44	0.88	0.90	1.00			
K^+	0.22	0.94	0.94	0.89	0.64	0.90	0.43	0.89	0.90	0.92	1.00		
Ca^{2+}	0.29	0.88	0.89	0.79	0.62	0.85	0.68	0.77	0.78	0.83	0.84	1.00	
Mg^{2+}	0.32	0.95	0.93	0.81	0.48	0.91	0.45	0.79	0.82	0.89	0.88	0.87	1.00

Correlation matrix of $n = 55$

summarized in Table 2 and their representation is shown graphically through box plots in Fig. 4. Weathering and leaching from topsoil are considered one of the major sources of metals entering water bodies (WHO 2011). Other than that, effluents from textile industries, tannery, electroplating, automobiles, and improper disposal of waste also lead to the addition of large amounts of metals in surface waters (Guertin 2004; Tao et al. 2012; Wang et al. 2014). Concentrations of metals in water follow the order: Fe, Mn, Zn, Cu, Ni, Cr, and Pb in winter and Fe, Mn, Zn, Ni, Cr, Cu, and Pb in summer in W1; Fe, Mn, Zn, Cu, Cr, Ni, and Pb in winter and Fe, Mn, Zn, Cr, Cu, Ni, and Pb in summer in W2; Fe, Mn, Ni, Cu, Zn, Cr, and Pb in winter and Fe, Mn, Zn, Ni, Cr, Cu, and Pb in summer in W3; Mn, Fe, Zn, Cr, Cu = Ni in winter and Fe, Mn, Zn, Ni, Cr, Cu, and Pb in summer in W4. The highest concentration was found for Fe, followed by Mn and Zn in all the wetlands. Similar observations have been reported in the wetlands of Varanasi and Gujarat (Table 5). In winter, Surface water samples from all the wetlands have average metal concentration below WHO permissible limits except Fe in W1 (2011.98 μg/l). In summer, the metals above permissible limits are Fe in W1 (1359.37 μg/l), W2 (345.35 μg/l), W3 (2799.26 μg/l) and W4 (549.68 μg/l), Cr in W1 (74.10 μg/l), and W4 (90.15 μg/l) and Ni in W4 (117.93 μg/l). Fe and Cr are abundantly present in soils of Gurugram (Dixit et al. 2020), hence weathering is the main source for high concentration. Additional source of high concentration of Cr in W4 can be the addition of raw sewage, industrial effluents and waste disposal (Arora 2017; Pant 2018; Kanti 2018). All other metals are below permissible limits. Among all the wetlands W4 has the highest concentration for all the studied metals except Fe which is highest in W3 (2799.26 μg/l). Low concentration of metals in winter is due to dilution. Lead is present in concentrations which are below the limits of detection in all the wetlands. In general, the concentrations of metals are low in all the studied wetlands. This suggests strong affinity of these metals with the sediments as compared to other metals. Some studies have also found control of pH and DOC on metals that decides their presence in water phase which also might be the reason.

Hydrogeochemical study

Piper plot (trilinear diagram) and Gibbs plot

The results of the diagram (Fig. 5) reveal that in cationic triangle water samples fall into class A, i.e., Ca-type in both summer and winter in W1 and W2, Ca-type in summer and no dominant type in winter in W3 and Na-K type in both summer and winter in W4. Whereas, in the anionic triangle, water samples fall into class H, i.e., no dominant type in W1, HCO_3^- type in both summer and winter in W2, no dominant type in summer and HCO_3^- type in winter in W3 and Cl- type in both summer and winter in W4. The plot of data on the diamond-shaped central part of the diagram reveals that water samples from W1, W2, and W3 indicate alkaline earth metals exceed alkali metals. At the same time, W4 narrates an entirely different story and indicates the dominance of alkali metals over alkaline earth metals in both the seasons. This part also suggests prevailing HCO_3^- with SO_4^{2-} or Cl^- in W1, i.e., mixed type, Ca-Mg-HCO_3 type in W2, Ca-Mg-HCO_3 type in winter and mixed type in summer in W3 and Na-Cl type in W4. The "Gibbs diagram" suggests that samples from W1, W2, W3, and W4 fall in the rock dominance region, which indicates, rock-forming minerals are dominantly affecting the water chemistry of the studied wetlands.

Principal component analysis

In W1 (forest dominated area), first principal component which explained 74.06% of total variation (Table 4) is characterized by (DOC, TDC, HCO_3^-, NO_3^-, Cl^-, SO4^{2-}, PO4^{3-}, F^-, Na^+, K^+, Ca^{2+}, Cr and Ni). Due to their grouping with Cr, which is abundantly present in soils of Gurugram nutrients are possibly naturally present in water. Minerals abundantly present in Gurugram soils (K-feldspar, muscovite and sodic plagioclases) are natural sources of cations present (Dixit et al. 2020). Ca^{2+} and Mg^{2+} usually come from carbonate mineral which is naturally present in Gurugram soils. In W2, the total variance due to PC1 (COD, HCO_3^-, NO_3^-, SO_4^{2-}, PO_4^{3-}, F-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cr, Cu, Fe, Mn, Ni, and Zn), PC2 (DOC, TDC, Cl^-, and F^-) and PC3 (BOD and Mg^{2+}) was 48.13, 28.04, and 8.33%, respectively. Similar abundance of NO_3^- and PO_4^{3-} in PC1 was also found in forest and agriculture surrounded water body in the studies of Lee et al. (2010). In W2, PC1 reflects towards mixed type of sources, i.e., both natural and anthropogenic. Its relation with Cr and Fe reflects towards natural sources whereas COD, NO_3^- and PO_4^{3-} points to addition of non-biodegradable matter, organic matter and agricultural wastewater (Cicek et al. 1998). For W2, PC1 is characterized by DOC, TDC, BOD, COD, HCO_3^-, NO_3^-, Cl^-, SO_4^{2-}, PO_4^{3-}, F^-, Na^+, K^+, Ca^{2+}, Mg^{2+}, Cr, Cu, Fe, Mn, Ni, and Zn, which explained 67.72% of the total variation and PC2 (12% of the total variance) is characterized by BOD, COD, F-, Cr, Cu, Mn, Ni and Zn. PC1 and non-biodegradable material that may be from livestock and agricultural input. In W4, PC1 is the total variance due to the PC1 (DOC, TDC, BOD, COD, Cl^-, Na^+, K^+, Ca^{2+}, Mg^{2+}) and PC2 (NO_3^-, SO_4^{2-}, PO_4^{3-}, F^-, Ca^{2+}, Fe, Mn, Ni, and Zn) is 42.1 and 30.7%, respectively. PC1 reflects towards high control of organic matter which is the characteristic of high sewage fed and livestock affected water bodies. Similar high concentration of BOD, COD, NO_3^- and PO_4^{3-} was found in residential wastewater in the studies of Lee et al. (2010) which is characteristic of W4. Presence of SO_4^{2-} reflects towards high microbial degradation (Shan et al. 2017) which also supports

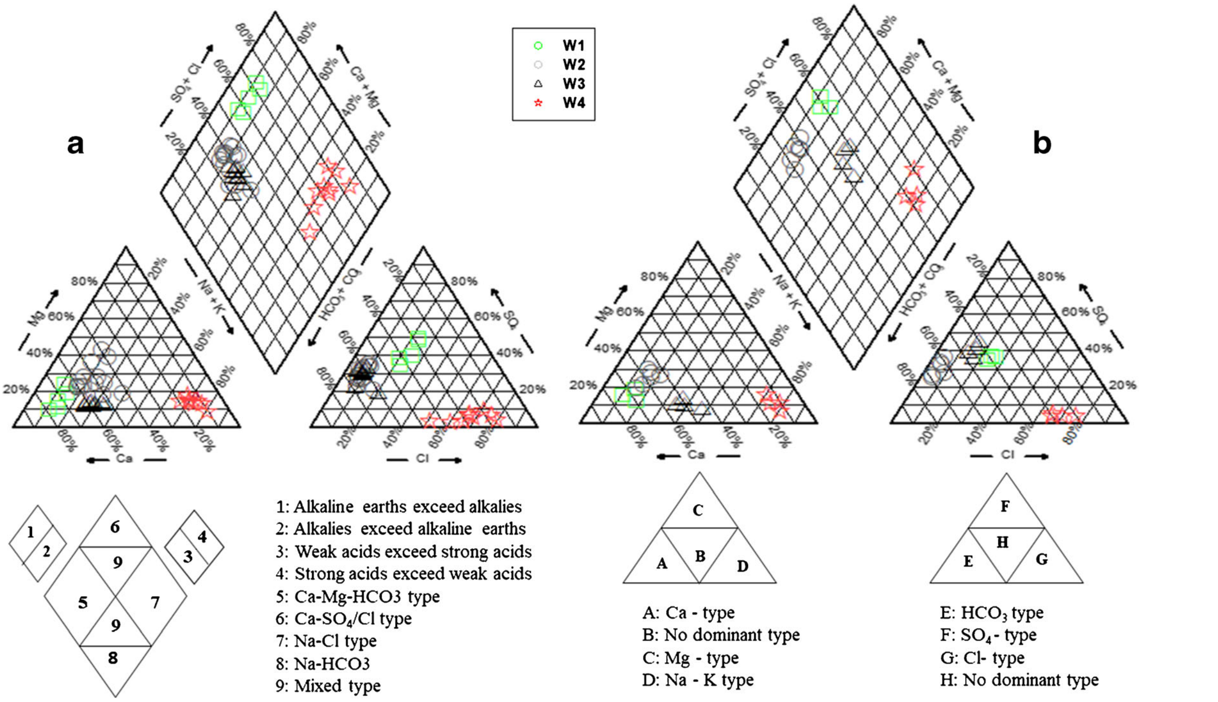

Fig. 5 The relative cation and anion composition of water samples for the studied lakes in winter (a) and summer (b) represented by the Piper diagram. (All values are calculated in meq/l)

high BOD. Other than the natural source (plagioclases) as present in PC1, additional Na^+ and K^+ may come from domestic sources, fertilizers and industrial/residential waste (Bahar et al. 2008).

Suitability for drinking (using WQI)

The results of WQI have been provided in Table 2 and is shown graphically in Fig. 10. Average WQI for W1, W2, W3, and W4, in winter is 57.38, 23.59, 28.21 and 108.7, whereas during summer, it is 62.99, 37.77, 103.10 and 191.14, respectively. It is observed that the WQI values are slightly higher in summer compared to winter. The results of WQI indicate that the average WQI of samples from W1 and W2 fall in the "good" and "excellent" category, respectively during both the seasons according to the criteria set by (Vasanthavigar et al. 2010). Samples from W3 fall in "excellent" category in winter whereas "poor" category in summer. This might be due to the dilution effect, which has improved the quality of water samples in winter, whereas sample from W4 lies in "poor" category in both the seasons. This suggests water from W1, W2, and W3 can be used for drinking whereas, water from W4 shows poor quality for drinking purposes (Singh et al. 2016; Şener et al. 2017).

Suitability of agriculture

Percent sodium (% Na) (Wilcox diagram)

The average % Na in W1, W2, W3, and W4 is 13.19, 22.55, 29.68, and 72.90% in winter and 14.78, 17.03,

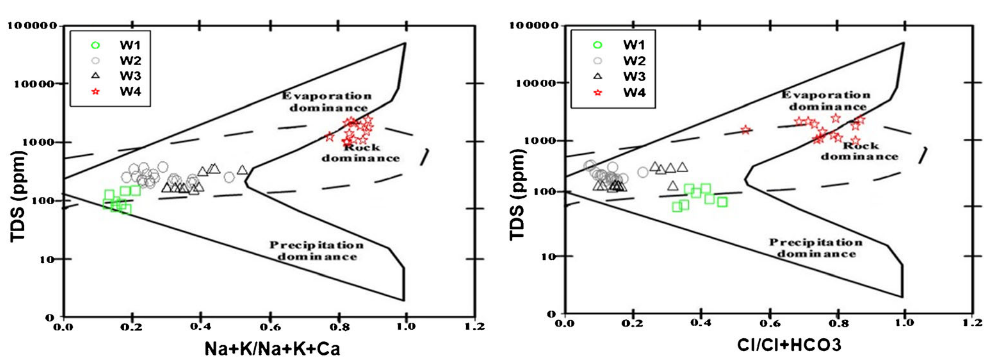

Fig. 6 Gibbs diagram showing mechanism controlling surface water chemistry. (a) Gibbs I. (b) Gibbs II

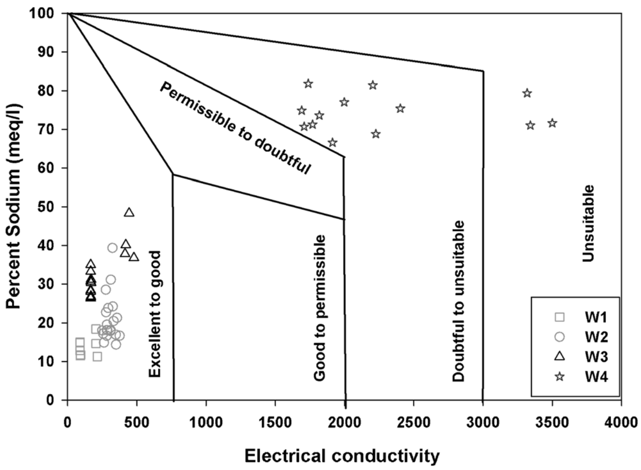

Fig. 7 Wilcox diagram indicating the suitability of water from wetlands for irrigation

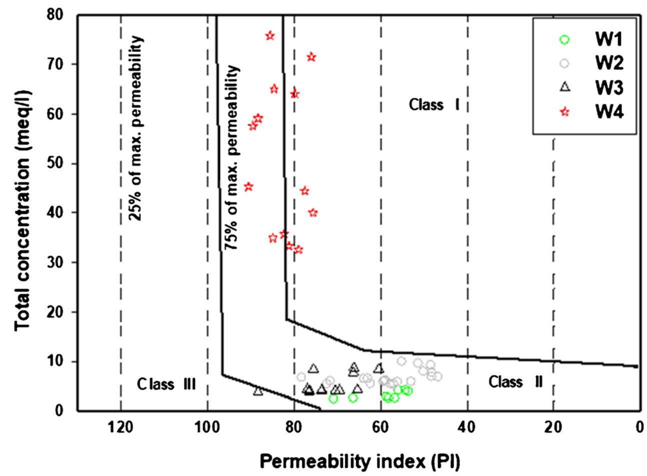

Fig. 9 Suitability of water for agricultural use based on the Doneen permeability index plot (1964)

40.78 and 76.79% in summer (Table 2). The result indicated that water samples from W1, W2, and W3 fall under the "excellent to good" category. As seen in Fig. 7, ten samples from W4 fall in "doubtful to unsuitable" category and three in the "unsuitable" category. This suggests that, in general, water from W1, W2, and W3 is suitable for irrigation while that of W4 is not suitable.

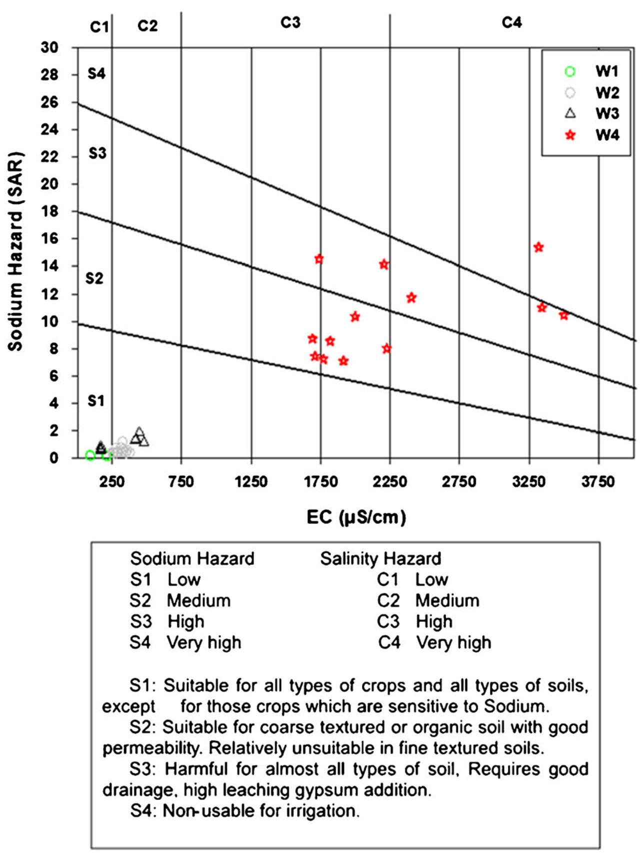

Fig. 8 USSL diagram indicating Sodium and salinity hazard in wetlands and their suitability for irrigation of different types of crops and variety of soils

Sodium adsorption ratio and USSL diagram

Average SAR values are given in Table 2. Water with SAR value < 10 is safe to irrigate the field, while > 10 creates problems of permeability for soil and structural deformation. A total of 46% of the samples in W4 have SAR value > 10, which suggests water here is unsafe while the rest of the wetlands have SAR value < 10 and are safe for irrigation (Saleh et al. 1999; Sappa et al. 2014). The results plotted on the USSL diagram reveal that, samples of W1 and W3 fall in low sodium hazard (S1) and low salinity hazard category. This explains their suitability for all types of crops and all types of soils, except for those crops which are sensitive to Sodium. Water from W2 falls in low sodium hazard (S1) and low to medium salinity hazard (C1 and C2) and is also found to be suitable. Whereas most of the

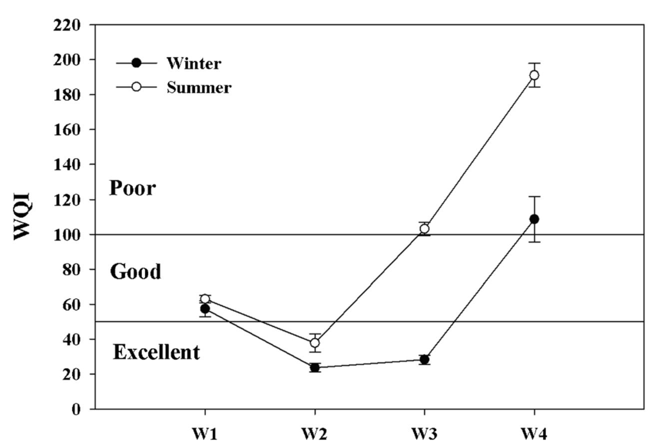

Fig. 10 WQI in samples from studied wetlands in winter and summer

Table 4 The matrix of principal component analysis for physico-chemical parameters and trace metals in the studied wetlands (values in bold show significant values i.e., > 0.5)

	PC*	pH	EC	DOC	BOD	COD	HCO3-	NO3-	Cl⁻	SO42-	PO43-	F-	Na+	K+	Ca2+	Mg2+	Cr	Cu	Fe	Mn	Ni	Zn	1	2	3
W1	PC 1	−0.78	0.77	0.59	0.43	0.78	0.60	0.78	0.90	0.89	0.84	0.95	0.61	0.92	0.85	0.21	0.69	0.20	−0.40	−0.26	0.78	0.49	19.26	74.06	74.06
	PC 2	−0.49	0.45	−0.03	0.58	0.45	0.74	0.35	0.34	0.06	0.38	0.17	0.30	0.08	0.34	0.96	0.47	0.09	−0.31	−0.88	0.39	0.46	2.90	11.15	85.22
	PC 3	−0.12	0.36	0.35	0.39	0.31	0.19	0.48	0.20	0.33	0.21	0.08	−0.37	−0.11	0.30	−0.05	0.49	0.97	−0.68	−0.29	0.38	0.66	2.05	7.87	93.09
	PC 4	0.37	0.28	0.72	0.54	0.30	0.21	0.18	0.16	0.25	0.32	0.14	0.63	0.32	0.24	−0.03	0.23	0.04	−0.53	−0.26	0.28	0.29	1.47	5.65	98.73
W2	PC 1	−0.37	0.51	−0.21	−0.10	0.77	0.87	0.76	0.10	0.78	0.59	0.30	0.18	0.92	0.95	0.78	0.80	0.93	0.87	0.92	0.88	0.89	13.00	48.13	48.13
	PC 2	−0.83	0.82	0.95	0.15	−0.32	0.32	0.13	0.86	−0.54	−0.16	0.86	0.33	0.11	−0.24	0.48	−0.53	−0.25	−0.13	0.16	−0.32	−0.33	7.57	28.04	76.17
	PC 3	−0.04	−0.01	−0.16	0.87	0.08	0.10	−0.32	−0.30	0.12	−0.36	−0.11	0.87	0.14	−0.08	−0.17	0.19	−0.01	−0.03	−0.13	−0.11	0.17	2.25	8.33	84.50
	PC 4	0.35	−0.11	0.06	0.32	−0.22	−0.29	0.52	0.36	0.01	−0.58	0.35	−0.03	−0.27	0.09	0.33	0.07	0.25	0.41	0.01	−0.22	0.05	2.08	7.70	92.20
	PC 5	0.09	−0.14	−0.04	0.12	0.45	−0.17	0.06	0.15	−0.27	0.38	0.16	0.00	0.00	−0.12	−0.05	−0.07	0.07	0.16	0.29	0.21	−0.12	1.23	4.56	96.76
W3	PC 1	−0.05	0.88	0.93	0.37	0.24	0.97	0.94	0.85	0.82	0.07	0.28	0.89	0.81	0.86	0.57	0.42	0.41	0.87	0.69	0.80	0.55	18.29	67.72	67.72
	PC 2	−0.22	0.39	0.23	0.89	0.85	0.20	0.10	0.46	0.36	0.07	0.82	0.36	−0.02	0.29	0.28	0.53	0.59	0.41	0.54	0.54	0.59	3.25	12.03	79.75
	PC 3	0.16	0.23	0.18	0.13	0.39	−0.03	−0.19	0.22	0.44	0.30	0.37	0.10	0.34	0.36	0.73	0.66	0.32	0.23	0.34	0.24	0.50	2.58	9.57	89.32
	PC 4	0.92	−0.11	0.07	−0.21	0.00	−0.08	−0.18	0.06	0.09	−0.87	0.04	0.20	−0.02	0.02	0.19	0.25	0.50	0.03	−0.26	0.01	0.19	1.42	5.25	94.57
W4	PC 1	0.27	0.95	0.93	0.64	0.94	0.26	−0.03	0.77	−0.02	−0.05	0.26	0.63	0.55	0.84	0.87	−0.07	0.21	−0.01	−0.39	0.26	0.35	11.37	42.12	42.12
	PC 2	−0.17	0.06	−0.13	−0.37	−0.09	0.05	0.71	0.36	0.70	0.74	0.87	0.30	0.44	0.51	0.00	0.47	0.46	0.87	0.69	0.81	0.57	8.29	30.70	72.82
	PC 3	−0.92	0.02	0.25	−0.32	0.03	0.94	0.64	−0.08	−0.37	0.43	0.11	0.18	0.60	0.06	−0.17	0.30	0.12	0.08	0.42	0.02	−0.04	3.39	12.54	85.36
	PC 4	−0.11	0.30	−0.16	−0.44	−0.16	0.09	0.17	0.44	0.53	0.24	0.23	0.66	0.06	0.17	0.03	0.82	0.82	0.29	0.36	0.16	0.22	1.28	4.74	90.10
	PC 5	−0.08	0.08	−0.15	0.09	0.06	0.06	0.19	0.25	0.24	0.38	0.10	0.20	−0.07	−0.02	0.40	−0.01	0.20	0.03	0.09	0.47	0.66	1.26	4.67	94.77

*PC**, principal components; *1*, total Eigen value; *2*, % of variance; *3*, cumulative %

Table 5 Comparison of results of the study with other studies from India

Wetland	pH	EC	TDS	DO	BOD	COD	Alk	NO_3^-	Cl	SO_4^{2-}	PO_4^{3-}	References
		µS/cm	mg/l									
Mallathahalli lake, Bangalore (Karnataka)	8.3	385	248.49	6.28	6	22	320	20	112	25	9	Ravikumar et al. (2013)
Okhla wetland, Delhi (Delhi)	8.78	6740	3298	10.17	9.5	216	580	2907	1749	145.72	7.60	Singh and Deepika (2017)
Raipur ponds, Raipur (Chattisgarh)	6.6–8.2	474–1225	1320–2475	6.1–8.1	-	-	380–550	13–60	15–100	13–150	-	Yadav et al. (2016)
Gangasagar, Viramgam (Gujarat)	9	1440	950	7.1	24	56	297	2	302	46	0.43	Kankal et al. (2012)
Hussain sagar, Hyderabad (Telangana)	7.2–7.7	750–2450	-	-	-	-	-	-	-	-	-	Ayyanar and Thatikonda (2020)
Himalayan ponds, Badrinath (Uttrakhand)	8.1	660	470	8.4	-	-	116	0.38	212	-	0.056	Kumar et al. (2012)
Tilyar lake, Rohtak (Haryana)	8.5	310	160	3.5	2.1	-	78	-	21	0.50	0.15	Tanwar and Tyor (2014)
Varanasi ponds, Varanasi (U.P.)	-	-	-	-	-	-	-	-	-	-	-	Azam et al. (2015)
Loktak lake, Bishnupur (Manipur)	7	161	88	6	1.84	32.5	-	14	4.5	0.10	0.003	Kangabam et al. (2017)
Lost wetland, Gurgaon (Haryana)	7.8	135.25	104.63	7.50	5.54	17.00	27.47	3.36	12.50	27.32	0.21	This study
Sultanpur wetland, Gurgaon (Haryana)	8.5	305.15	252.13	6.91	7.54	32.33	98.56	16.64	9.15	44.55	0.24	
Damdama wetland, Gurgaon (Haryana)	8.6	245.21	205.33	6.53	7.77	35.83	63.49	22.34	10.71	37.15	0.23	
Basai wetland, Gurgaon (Haryana)	8.7	2279.15	1651.41	5.55	54.50	164.55	346.67	27.80	619.23	54.04	4.42	
	Ca	**Mg**	**F^-**	**Na^+**	**K^+**	**Cr**	**Cu**	**Fe**	**Mn**	**Ni**	**Zn**	
	mg/l					**µg/l**						
Mallathahalli lake, Bangalore (Karnataka)	16	20	0.5	50	30	-	-	0200	-	-	-	Ravikumar et al. (2013)
Okhla wetland, Delhi (Delhi)	61	11	-	910	-	-	-	228	-	-	-	Singh and Deepika (2017)
Raipur ponds, Raipur (Chattisgarh)	30–65	6–25	0.8–1.6	33–170	15–83	-	-	300–1150	-	-	-	Yadav et al. (2016)
Gangasagar, Viramgam (Gujarat)	-	-	-	305	9	bdl	bdl	1620	200	bdl	bdl	Kankal et al. (2012)
Hussain sagar, Hyderabad (Telangana)	-	-	-	-	-	5–26	3–808	-	133–5365	31–480	3–4880	Ayyanar and Thatikonda (2020)
Himalayan ponds, Badrin ath (Uttrakhand)	44	20	-	-	-	-	-	-	-	-	-	Kumar et al. (2012)
Tilyar lake, Rohtak (Haryana)	25	15	-	-	-	-	-	-	-	-	-	Tanwar and Tyor et al. (2014)
Varanasi ponds, Varanasi (U.P.)	-	-	-	-	-	3	10	733	45.	2	22	Azam et al. (2015)
Loktak lake, Bishnupur (Manipur)	24	6	0.2	6.30	3.82	-	-	-	-	-	-	Kangabam et al. (2017)
Lost wetland, Gurgaon (Haryana)	22.30	2.95	0.40	3.78	2.18	28.59	14.70	1767.25	194.55	23.68	49.81	**This study**
Sultanpur wetland, Gurgaon (Haryana)	37.12	11.12	0.30	13.75	4.55	8.09	6.63	166.68	93.13	1.09	18.24	
Damdama wetland, Gurgaon (Haryana)	30.01	3.64	0.32	19.63	3.96	17.31	9.68	890.61	150.84	20.25	41.78	
Basai wetland, Gurgaon (Haryana)	67.91	39.44	1.28	434.12	26.46	38.51	14.54	208.11	222.00	40.41	64.57	

samples from W4 fall in high salinity (C3) and low to medium sodium hazard (S3 and S4) whereas three samples fall in high salinity hazard zone. The results suggest water from W4 is unsuitable for irrigation purposes. High leaching gypsum addition can be beneficial.

Residual sodium carbonate

In the present study, the average value of residual sodium carbonate in all the wetlands falls below 1.25 (Table 2). This suggests all the wetlands fall under safe category according to criteria set by Richards (1954).

Permeability index

Based on this classification scheme, all the samples from W1, W2, and W3 fell in class II, whereas approximately 50% of the samples from W4 fell in class II and rest in class I (Fig. 9 and Table 2). This suggests that all the samples are suitable for irrigation purposes.

Kelly's index

The average value of Kelly's ratio is 0.13, 0.26, 0.37, and 2.70 in winter, whereas 0.11, 0.16, 0.64, and 3.33 in summer in W1, W2, W3, and W4, respectively. All the samples from W1, W2, and W3 have KI value < 1, which suggests their suitability for irrigational purposes (Table 2). However, W4 has KI value > 1 and thus water is unsuitable for irrigational purposes.

Magnesium hazard

The magnesium hazard in W4 is analyzed as 50.15 and 45.65 in winter and summer, respectively, which suggests its unsuitability for irrigation purposes based on MH. All other wetlands are observed for MH < 50 and are found suitable (Table 2).

Suitability for cattle drinking

Wetlands may serve as water supplies for livestock. Quality determination of cattle consuming water from wetlands is a common sight in Gurugram. Therefore, surface water samples from selected wetlands are also analyzed to check their suitability for cattle drinking purposes. The water quality guidelines for cattle provided by UK Cooperative (Higgins et al. 2008) are used for the assessment. There are no known effects of pH on water intake rates and cattle well-being. However, various studies report pH values ranging from 5 to 9 are safe for cattle drinking. Based on total dissolved solids (TDS), water samples of all wetlands fall under the safe water category (TDS < 1000 mg/l) for cattle drinking, except W4, where TDS values are greater than this limit. F- concentration > 2.0 mg/L is also considered unsafe for cattle. The results of the study indicate samples are below this value and safe for cattle drinking with respect to F^-. Cattles are hit by a laxative effect when consuming water has high SO_4^{2-} concentration (Linn and Raeth-Knight 2010). Permissible SO_4^{2-} levels in water for cattle drinking is < 500 mg/l for calves and < 1000 mg/l for adults whereas, maximum recommended NO_3^- levels in water is between 0 and 44 mg/l (safe for consumption) and 45–132 mg/l (safe with low NO_3^- feeds and balanced diet). Water samples of all wetlands lie in a safe category for both SO_4^{2-} and NO_3^- and are fit for cattle drinking.

Conclusions

In the rapid urbanization process, wetlands of Gurugram are completely neglected. If provided proper management these wetlands have high potential to solve water issues of the city. With this objective in mind a study was conducted for water quality assessment of selected wetlands (Lost-W1, Sultanpur-W2, Damdama-W3, and Basai-W4) in Gurugram. The results of the study indicate that water samples of all the four wetlands are alkaline. pH, TDS, and alkalinity are above the permissible limits in W4. Higher concentration of cations and anions in summer as compared to winter in all four wetlands may be due to the dilution effect in winter. The dominant anion in W1, W2 and W3 are HCO_3^- and SO_4^{2-}, whereas in W4 it is Cl^-. Concentration of all the anions is below the desirable and permissible limits in W1, W2, and W3. In W4, F^- is above the permissible limit, whereas HCO_3^- and Cl^- are present above the desirable limits. In W1, W2 and W3, Ca^{2+} is the dominant cation, whereas in W4, Na^+ is dominant. Concentration of Na^+ in W4 is cause of concern, as it is above the permissible limit, the rest of the cations are below this limit in all the wetlands. Dominance of alkaline earth metals along with HCO_3^- suggests prevailing carbonate weathering in the region. The ionic concentration in W2 and W3 are close to W1 (background site), which suggests dominant sources being geogenic, whereas comparatively higher concentration in W4 suggests anthropogenic as the dominant sources. Results also suggest W1 is a well-mixed type of lake, whereas W2, W3, and W4 are not. This variation is attributed to the addition of effluents from various point and non-point sources. High organic load due to sewage in W4 is also supported with high BOD. Among trace metals, most abundant is Fe followed by Mn and Zn in all the wetlands. Metals above permissible limits and cause of concern are Fe, Ni, and Cr. Their high concentration is attributed mainly to their natural enrichment in soil of Gurugram.

Based on WQI, water in W4 in both the seasons and in W3 in summer is not suitable for human consumption whereas suitable in all other wetlands. Based on some irrigational parameters—Wilcox diagram, USSL plot, RSC, KI and MH—water from W4 is not suitable for irrigation, but for other purposes, whereas that of W1, W2, and W3 is suitable. PI values suggest water is suitable for irrigation purposes in all the wetlands. The analysis of parameters for suitability of water for cattle drinking supports its suitability in W1, W2, and W3, whereas not in W4.

Among the studied wetlands, W4 is observed to be maximally perturbed and exhibit serious pollution conditions and therefore needs continuous monitoring and immediate recovery measures. W2 and W3, although face risk of wetland drying but are in good water quality condition, probably due to the maintenance of a comparatively pristine environment in the catchment area. However, W4 has significantly lost its catchment area to urbanization. Due to a variable degree of disturbances in the studied wetlands, W2 and W3 can be managed with minimal efforts, whereas W4 needs immediate attention. Both W3 and W4 can be designated "protected" status similar to W2 to prevent them from further deterioration. Thus, the present study provides evidence of the deteriorating water quality of urban wetlands in Gurugram and warrants the effective management of these wetlands to reduce the anthropogenic contamination for sustainable wetland ecology.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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