EVALUATION OF PREDOMINANT PHYSICO-CHEMICAL PARAMETERS DETERMINING THE WATER QUALITY STATUS OF ROPAR WETLAND (RAMSAR SITE), PUNJAB (INDIA)

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Abstract

During present study, the water quality of Ropar wetland, Punjab (India) has been determined using water quality index (WQI). The water samples were collected from eight (RW1-RW8) selected sampling sites during monthly visits (2018-2020). A total of 17 physicochemical (WT pH, EC, TDS, CO_3, HCO_3, TA, Ca, Mg, TH, PO_4, NO_3, SO_4, NH_4, Na and K) parameters were analyzed using standard methods, out of which, twelve parameters were taken for calculating the WQI. The recorded results of WQI ranged from 23.89 (RW5) in July–67.76 (RW8) in February during present study, demonstrated that the overall water quality of Ropar wetland lied in the 'poor' category as per the given standards of different organizations for drinking water. PCA helped to find out the majorly affected sampling sites with pollutants and distinguished into two groups (Group1 includes RW6, RW7 and RW8 and Group II exhibits RW1, RW2 and RW3) having distinct spatio-temporal water quality patterns during overall study period. The results indicated that, the maximum loading of nutrients was at sites RW1, RW2, RW7 and RW8, due to different pollution sources, which in turn affects the whole water quality of Ropar wetland. Furthermore, Pearson's correlation analysis revealed that water quality showed significant positive correlation with predominant physicochemical parameters such as pH, TDS, EC, PO_4, Na and Cl of Ropar wetland. In present study, the overall water quality status of Ropar wetland is poor, which depicts the necessity to implement proper management strategies and conservation efforts for developing better water quality programs.

Keywords: Ramsar, Wetland, Physico-chemical, Water quality

Introduction

Wetlands are one of the most productive aquatic ecosystems, where water is primary element controlling the surrounding environment along with flora and fauna (Joshi et al. 2020; Singh et al. 2022). Wetlands also impart various eco-services (water storage, biochemical cycling etc.) and help to maintain biodiversity (Papatheodorou et al. 2006; Chaudhary et al. 2018). These are also fulfilling the human needs in the form of water, wood products and food. Moreover, in this period of climatic alterations, wetlands play quite challenging role in carbon cycle due to which its crucial role cannot be ignored (Joshi et al. 2020). In last few decades, rapid advancement in urbanization (Chassiot et al. 2019), industrialization (Taufiq et al. 2019), agricultural runoff and domestic wastes (AijazBhat et al., 2014) creating problems of water pollution which has reached to an alarming stage (Kishor et al. 1998; Jindal and Sharma, 2011; Singh et al. 2020). These are very delicate ecosystems, where even a minor change leads to solemn variations in both biotic as well as abiotic components of the wetlands (Akhter and Brraich 2020). The evaluation of water quality comprises its physical, chemical and biological components. Therefore, water quality is an indispensable element for the survival, sustenance and well-being of all aquatic life (Odulate et al. 2017).

Various methods have been developed in recent years for assessing water quality (Chabukdhara et al. 2017; Sotomayor et al. 2018; Adimalla et al. 2019; Adimalla and Taloor 2020). Water quality index (WQI), is one of that methods which is most effective way to integrate the different water quality parameters into single value and to describe the status of water quality. It represents the data in a shortened, basic and logical form (Semiromi et al. 2011). WQI is an advantageous technique in evaluating water quality of the water body. It helps to understand the overall water quality status of individual sampling site at a certain time (Yogendra and Puttaiah 2008; Lkr et al. 2020). Water quality of any water body can be measured by analyzing the physicochemical parameters of water, if the values of WQI will be more than the well-defined limits (BIS 2012), then it is regarded as unfit for human consumption, agricultural practices and unfit for different usage. In proper management of water quality, the consideration of every water quality variable is significant to find out the collective data on water quality, as it can provide concise information on every aspect of different environmental conditions (Chen et al. 2007). Several studies have been reported on water quality assessment along with its physicochemical parameters for monitoring water quality of various lakes, rivers and wetlands across the world viz. (Kazi et al. 2008; Naubi et al. 2016; Sim and Tai, 2018; Wu et al. 2018).

In past few years, various investigations have been made by different workers from India also, which have focused on different rivers and lakes for their water quality assessment like Chandrabhaga river (Sharma et al. 2007); Ravikumar et al. (2013) analyzed the water quality of Mallathalli lake, Bangalore; Jhelum river in Jammu and Kashmir was analyzed by Hafiz et al. (2014); Joshi et al. (2016) evaluated the physico-chemical parameters from five Himalayan lakes, from Kumaun region in Uttarakhand; Sutlej river (Sharma et al. 2017); Bora and Goswami (2017) evaluated the water quality of Kolong River; Tiwari and Sharma (2018) studied the Nachiketa Tal of Garhwal Himalaya; Singh et al. (2018) studied the relationship between the phytoplankton community and physico-chemical characteristics of Parshuram and Renuka Lake, Himachal Pradesh; Kumar and Sharma (2019) assessed the health status of Neel Tal; Lkr et al. (2020) estimated the water quality of Doyang River of Wokha district, Nagaland; Sharma and Kansal (2020), studied the Yamuna river for its water quality.

In Punjab state of India, the water quality status of many wetlands and other water bodies are known through some workers (Brraich and Saini 2015; Kaur et al. 2017; Akhter and Brraich 2020; Singh et al. 2020; Kumar and Singh 2020; Singh et al. 2022), that are degrading rapidly at a fast rate. The degrading quality of water not only affects the mankind, but also affects the biota of that ecosystem. The evaluation of water quality has become a serious issue in past few years particularly due to worries that fresh water availability will be a big threat for all living beings (Simeonov et al. 2003; Singh et al. 2004; Qadir et al. 2007; Singh et al. 2020).

If the pollutant load-bearing capacity of an ecosystem exceeds, then it causes deterioration of water quality, which results in reduced aquatic biodiversity. Therefore, it is crucial to evaluate the water quality of wetland and to find out the causes of water quality deterioration to improve water quality. Not only great efforts are needed for maintaining the health of Ropar wetland but also further information is needed for the proper management of the wetland. The major aim of this paper was to study the current water quality status of Ropar wetland and how different pollutants are altering the water quality of Ropar. Therefore, continuous monitoring at regular period of time becomes necessary.

Materials and Methods

Study Area

Ropar wetland is a manmade wetland which came into existence in 1952 with the impoundment of water by raising barrage on river Sutlej near Ropar town, for storage and utilization of water for several purposes like industrial, irrigation through canals and water supply for drinking (Ladhar, 2002). It is located at 31°01'N latitude and 76°30' E longitude in the laps of Shivalik foothills of lower Himalayas on river Sutlej. Total area covered by this wetland is 13.65 sq. km (Figure 1). This region of Punjab falls under semi-arid zone and comparatively considered less warm region as compare to another region of Punjab. The mean annual rainfall of this region is 1518 mm (Brraich and Akhter, 2019). It is an important ecosystem, considered as Ramsar site and recognized internationally. It helps to maintain the survival chain of a number of vulnerable and endangered species. Ropar wetland is known for its ecological, economic and social heritage. It acts as substantial staging and dormant ground for water fowls and migratory birds. Weed invasion by *Parthenium* and *Lantana* are the major threats for this wetland, besides this the major sources of pollution are siltation, water pollution through anthropogenic activities and grazing, agricultural runoff etc. are also the threatening factor (Ladhar 2005). The present study was carried out for a period of 2 years (March 2018 to February 2020) from 8 different sampling sites with an objective to analyze the physico-chemical parameters for water quality assessment of Ropar wetland.

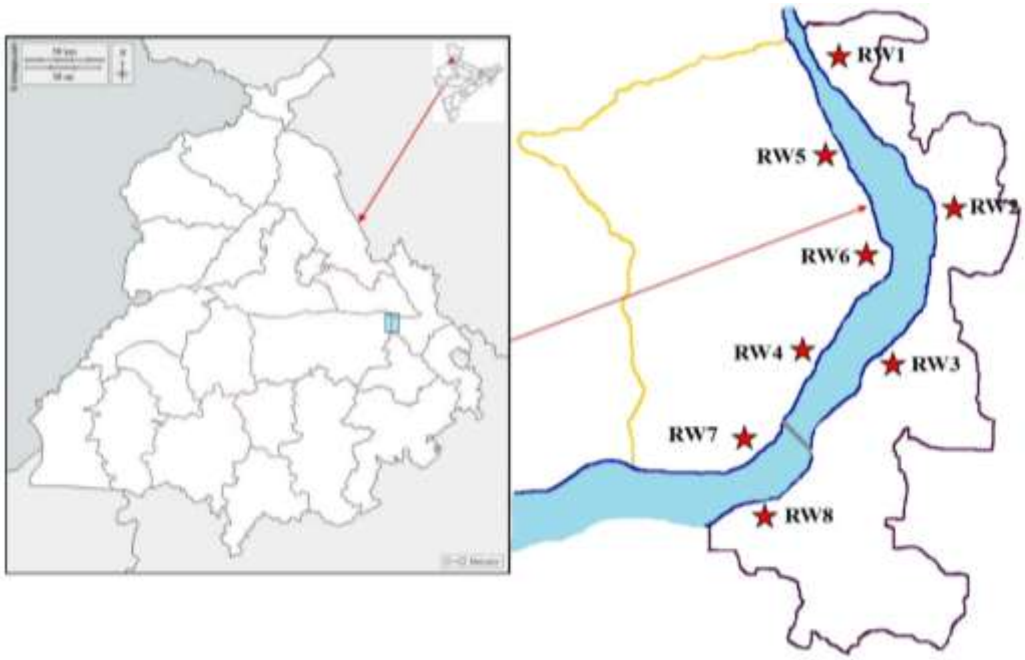

Figure 1: Map showing different sampling sites of Ropar Wetland of Punjab, India.

Water sampling and physico-chemical characterization

Water samples were collected from selected sampling sites (RW1-RW8) of Ropar wetland Punjab, in clean and sterilized two litre plastic bottles during monthly visits (2018-20) (Table 1.).

Sites	Name of the locality	Sources of pollution
RW1	The first sampling site was marked near the Chhan Baba Kuma maski Ji which is located at 31.056508N and 76.542853E	Siltation and Industrial effluents.
RW2	The second sampling sites was near the Dera Baba Sarvan Das ji which is situated at 31.004700 N and 76.538936E	Effluents of agrochemical residues run off.
RW3	Katli is at a distance of 3km away from Rupnagar and located at 30.9950719N and 76.5350947E	Anthropogenic pressure
RW4	The fourth sampling site was selected opp. to 3rd site (Bhinder Nagar) is situated at 31.000527N and 76.532134E	-
RW5	Tibba Tapprian is village in the Nurpur Bedi (Rupnagar) and located at 31.062237N and 76.542189E	-
RW6	Near Gurudwara Sahib, Garh Bagga is situated at 31.010314N and 76.537238E	Domestic waste.
RW7	Shaheed Bhagat Singh Nagar is a locality in Rupnagar which is located at 30.988202N and 76.512684E	Fishing point, agricultural runoff.
RW8	The last and 8th sampling point in the study was Canal Colony that is situated at 30.983568N and 76.517900E	Domestic waste, industrial run off and fishing.

Table 1. Geographical locations, description of sites and major sources of pollution of Ropar wetland.

Total seventeen parameters of water, were analyzed to study the physico-chemical properties of this wetland. These parameters were water temperature (WT,°C), pH, electrical conductivity (EC, µS/cm), total dissolve salts (TDS, mg L^{-1}), carbonate (CO_3, mg L^{-1}), bicarbonate (HCO_3, mg L^{-1}), total alkalinity (TA, mg L^{-1}), total hardness (TH, mg L^{-1}), calcium (Ca, mg L^{-1}), magnesium (Mg, mg L^{-1}), chloride (Cl, mg L^{-1}), phosphate (PO_4, µg L^{-1}), ammonium (NH_4, µg L^{-1}), sulphate (SO_4, µg L^{-1}), nitrate (NO_3, µg L^{-1}), sodium (Na, mg L^{-1}) and potassium (K, mg L^{-1}). Some of the parameters like water temperature by thermometer (Perfit), pH with pH meter (Hanna Instruments, India), TDS and EC with digital EC (Hanna Instruments, India) and TDS meters (HM digital, Inc., CA, USA) were noted down on the spot during sampling period by different instruments. The collected samples were brought to laboratory, immediately analyzed for the remaining parameters with the prepared reagents by following APHA (2012). All the reagents were made in double distilled water and all the chemicals and reagents used for this analysis were of analytical grade (Hi Media).

Water Quality Index Computation

For the computation of WQI a total of twelve physico-chemical parameters were taken into consideration (Jindal and Sharma 2011; Singh et al. 2013b).

Water quality index (WQI) = qiwi,

where qi is (water quality rating) 100 × (Va - Vi)/Vs - Vi

where Va is the actual value of water sample,

Vi represents the ideal value (0 for all the parameters except pH is 8.5),

Vs is the standard value for each parameter, Wi represents (unit weight) = K/Sn,

Where K is constant = $1/1/Vs_1$ $1/Vs_2$…+ 1/VSn

Sn represents the standard permissible value for n^{th} parameter (Table 2).

Table 2. Unit weights (Wi) of different parameters and their standards used for WQI determination.

Parameters	**Sn**	**Wi**
pH	8.5	0.01964
Electrical Conductivity (µS/cm)	300	0.00333
TDS (mg/L)	500	0.0002
Total Alkanity (mg/L)	200.00	0.005
Hardness (mg/L)	200.00	0.005
Calcium (mg/L)	75.00	0.0033
Magnesium (mg/L)	30.00	0.0333
Chloride (mg/L)	250.00	0.004
Phosphate (mg/L)	0.300	0.56077
Ammonium (mg/L)	0.500	0.33646
Sulphate (mg/L)	200.000	0.005
Nitrate (mg/L)	45.000	0.00222
∑Wi = 0.97827		

The water quality index with a range of: 0–24 is 'excellent', 25–49 is 'good', 50–74 is 'poor' and 100 is 'unfit for human consumption'.

Statistical analysis

Prior to statistical analysis the whole data was log transformed (log x+1). To find out the variation in each parameter, the mean and standard deviations (SD) were calculated. Software used for calculations was Microsoft Office Excel-2007 (mean, and standard deviation), excel stat version 2020.5 (PCA) and PAST 4.03 (correlation).

Results and Discussions

Physicochemical analysis of water

The results of the present study revealed that, the water quality parameters can vary with the passage of different months. In present study, a total of 17 physicochemical parameters of water were analyzed. Variations in mean, standard deviation and range of various physicochemical parameters at different sampling sites during studied months are presented in Figure 2 & 3. Most of the physicochemical parameters showed deviation with respect to different sites due to many environmental variables and pollutions (Bhat and Pandit, 2011; Singh et al. 2020).

The water temperature of Ropar wetland during first year (2018-19), was varied from 13 °C at sites RW4-RW6 in February to 28 °C at sites RW3, RW7 & RW8 in July. Whereas, in second year (2019-20), it ranged from 14.5 °C at site RW7 (January) to 28 °C at sites RW7 (July, August) & RW8 (August) (Figure 2 a). The main reason for this range of variation in water temperature was increased length of day, and greater exposure of solar radiations in the Northern part of India during dry climatic conditions (Venkatesharaju et al. 2010; Sharma et al., 2017). Higher temperature of water body accelerates the chemical reactions in water, which reduces the solubility of gases (Bhateria and Jain 2016). The pH is a degree of acidic or basic nature of water and considered as an important indicator of water quality. In the first year, the pH of Ropar wetland was found within the range between 7.4 (at site RW5) in July to 8.3 (at site RW8) in February. While, in the next year, it was almost similar that the water was alkaline, the minimum value of pH was observed at site RW1 as 7.5 in July and maximum value was found as 8.91 at site RW8 in the month of February (Figure 2 b). Similar range of pH was observed (by Ghimire et al. 2013) from lakes of Nepal. The value of pH was maximum during January and February, was due to the addition of industrial waste into the wetland (Mathivanan et al. 2005). On the other hand, low values were recorded in July during the study period. It could be due to low photosynthetic activity and addition of heavy rain water (Wetzel 2001; Sharma and Bhardwaj 2011).

Electrical conductivity is the ability of water to carry electric current. It is an indirect approach to measure the total dissolved salts in water. The greater the content of dissolved salts in the water, more current the water can carry and higher will be its conductivity (Rusydi 2018). The maximum electrical conductivity in the first year, was observed at site RW8 as 340 µS cm $^{-1}$ in December and minimum value was found as 140 µS cm $^{-1}$ at site RW1 in July and August. Whereas, in the second year, Similar type of observations were recorded with slight variations in the values of EC (Figure 2 c).

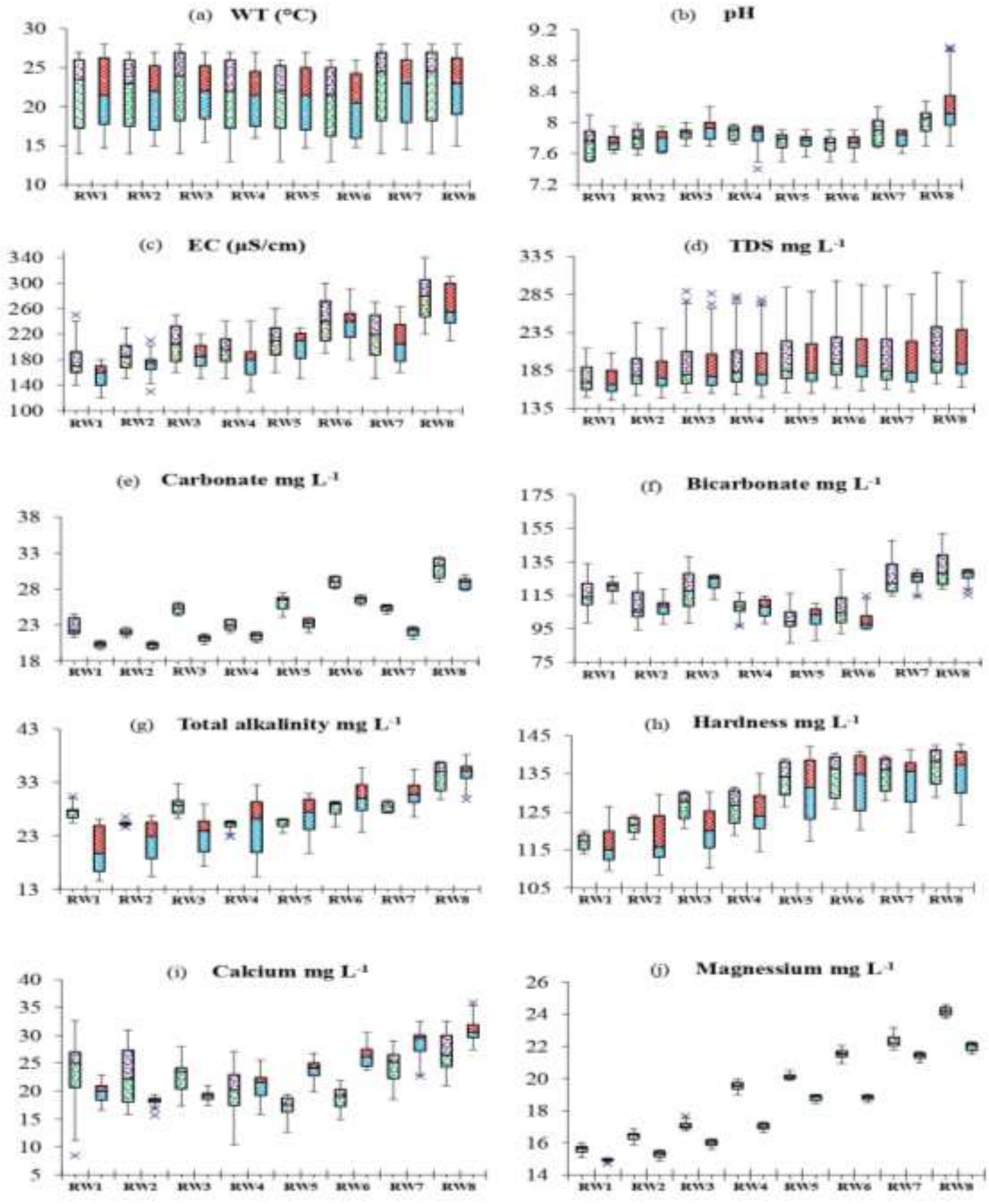

Figure 2: Trends of temperature, pH, electrical conductivity, total dissolved salts, carbonate bicarbonate, total alkanity, total hardness, calcium and magnesium during study period at different sampling sites.

The reasons for the maximum values of EC during winter months could be the addition of pollutants through the industrial effluents, agricultural runoffs and various anthropogenic activities into the wetland (Mathivanan et al. 2005; Singh et al. 2017). Total dissolved salts (TDS) is the measure of amount of dissolved organic and inorganic substances in the water. Their higher concentration limits the suitability of water as a drinking source and irrigation purpose. In the first year, the maximum value of TDS was observed as 314 mg L^{-1} at site RW8 in

February and minimum value was recorded as 150 mg L^{-1} at site RW1 in June. Whereas, in the second year, the values of TDS were ranged from 146 mg L^{-1} at site RW1 in June to 310 mg L^{-1} at site RW8 in February (Figure 2 d). TDS in water directly depends on electrical conductivity (Sallam and Elsayed 2018; Singh et al. 2022). The values of carbonate for the first year, was observed in between the range of 21.25 mg L^{-1} at site RW2 (October) to 32.44 mg L^{-1} at site RW8 in May. Whereas, the maximum value of carbonate in the second year, was recorded at RW8 as 29.94 mg L^{-1} in December and minimum value was observed as 19.54 mg L^{-1} at site RW2 in August (Figure 2 e).

However, the values of bicarbonate during the period of 2018-19, were observed in the range of 86.16 mg L^{-1} at site RW5 in November to 152 mg L^{-1} at site RW8 in April. While, in the second year, the maximum value of bicarbonate (130.46 mg L^{-1}) was recorded at site RW8 in May and minimum value (88 mg L^{-1}) at site RW5 in August (Figure 2 f). Total alkalinity of the Ropar wetland for the first year, was in the range of 22.95 mg L^{-1} at site RW4 (July) to 36.92 mg L^{-1} at RW8 site (May). Whereas, in the second year, the maximum value of total alkalinity was observed as 38.28 mg L^{-1} at RW8 site and minimum value was recorded as 14.54 mg L^{-1} at site RW1 in August (Figure 2 g). The alkalinity of water usually indicates the presence of carbonates, bicarbonates and hydroxyl ions. Alkalinity is not a pollutant, rather it is a degree of substances in water which neutralizes the acid. The maximum value of total hardness during the first year, was observed at site RW8 as 142.49 mg L^{-1} in December and minimum value was found as 113.97 mg L^{-1} at site RW2 in July. While, in the second year, the values of total hardness were in between the range of 108.57 mg L^{-1} at site RW3 in August to 142.85 mg L^{-1} at site RW8 in December (Figure 2 h).

The highest value of calcium in the first year (2018-19), was found as 32.68 mg L^{-1} at site RW5 in April and lowest value was found as 8.40 mg L^{-1} at site RW5 in August. Whereas, in the second year, maximum value of calcium was observed at site RW8, as 35.78 mg L^{-1} and minimum value was recorded as 15.64 mg L^{-1} at site RW6 in April (Figure 2 i). Calcium determines the hardness of water and its concentration in water depends upon the surrounding rocks near the water body (Deep et al. 2020). The range of the magnesium thru first year of study, was 15.05 mg L^{-1} at site RW3 in August to 24.58 mg L^{-1} at site RW8 in the months of September and December. However, with slight differences in the values in the second year, the maximum value was observed as 22.27 mg L^{-1} at site RW8 in December and minimum value was 14.7 mg L^{-1} at site RW3 in August (Figure 2 j). The values of chloride in the first year, were determined in between the range of 15.38 mg L^{-1} at site RW5 in March to 29.14 mg L^{-1} in December at site RW8. On the other hand, these values were ranged from 19.12 mg L^{-1} at site RW4 in March to 37.78 mg L^{-1} at site RW8 in the second year of January (Figure 3 a). Lowest value of chloride was observed at site RW5 which reflects less discharge of municipal and industrial wastes into that site of wetland (Gurumayum et al. 2001) whereas, higher values at site RW8 may be due to release of municipal sewage and industrial wastes (Dwvedi and Odi 2003; Sanap et al. 2006). The maximum value of phosphate in the first year was observed at site RW8 as 0.23 mg L^{-1} in the months of November and February while, minimum value was found as 0.05 mg L^{-1} at site RW5 in July and August. Whereas, these values of phosphate in the second year, were ranged from 0.05 mg L^{-1} at site RW5 in July and August - 0.19 mg L^{-1} at site RW8 in the months of October, November and February (Figure 3 b). Phosphate is one of the other key factors for eutrophic status of any water body which determines the pollution level, and also responsible for the productivity of water body (Dunea et al. 2020). In present study, the higher concentration of phosphate was not observed during the winter months as seen in other nutrient concentrations, because phytoplankton utilizes phosphate and nitrate from water and decreases pollution load (Jindal et al. 2014; Jindal et al. 2015).

In the first year, the highest value of ammonium was found as 0.40 mg L^{-1} at site RW8 during the months of August, November and February while lowest value was observed as 0.17 mg L^{-1} at site RW5 in March. However, in the second year, the values of ammonium were varied from 0.16 mg L^{-1} at site RW5 in August to 0.41 mg L^{-1} at site RW8 in October (Figure 3 c). The values of sulphate were in between the range of 0.56 mg L^{-1} at site RW5 in March to 0.95 mg L^{-1} at site RW8 in the months of May, August, November and February in the first year. Whereas, in the second year, the maximum value of sulphate was recorded as 0.95 mg L^{-1} at site RW8 in October and November while, minimum value was found as 0.56 mg L^{-1} at site RW5 in December (Figure 3 d).

In the first year, the maximum value of nitrate was observed at site RW8 as 0.43 mg L-1 in the month of November and minimum value was observed as 0.16 mg L-1 at site RW5 in August. On the other hand, values of were ranged from 0.12 mg L-1 at site RW5 in August to 0.47 mg L-1 at site RW8 in February (Figure 3 e). Minimum value of nitrate in the August is also observed by Akhter and Brraich (2020). Maximum values of nitrates were recorded during October and November during whole period due to the addition of industrial wastes (Sharma and Singh 2014).

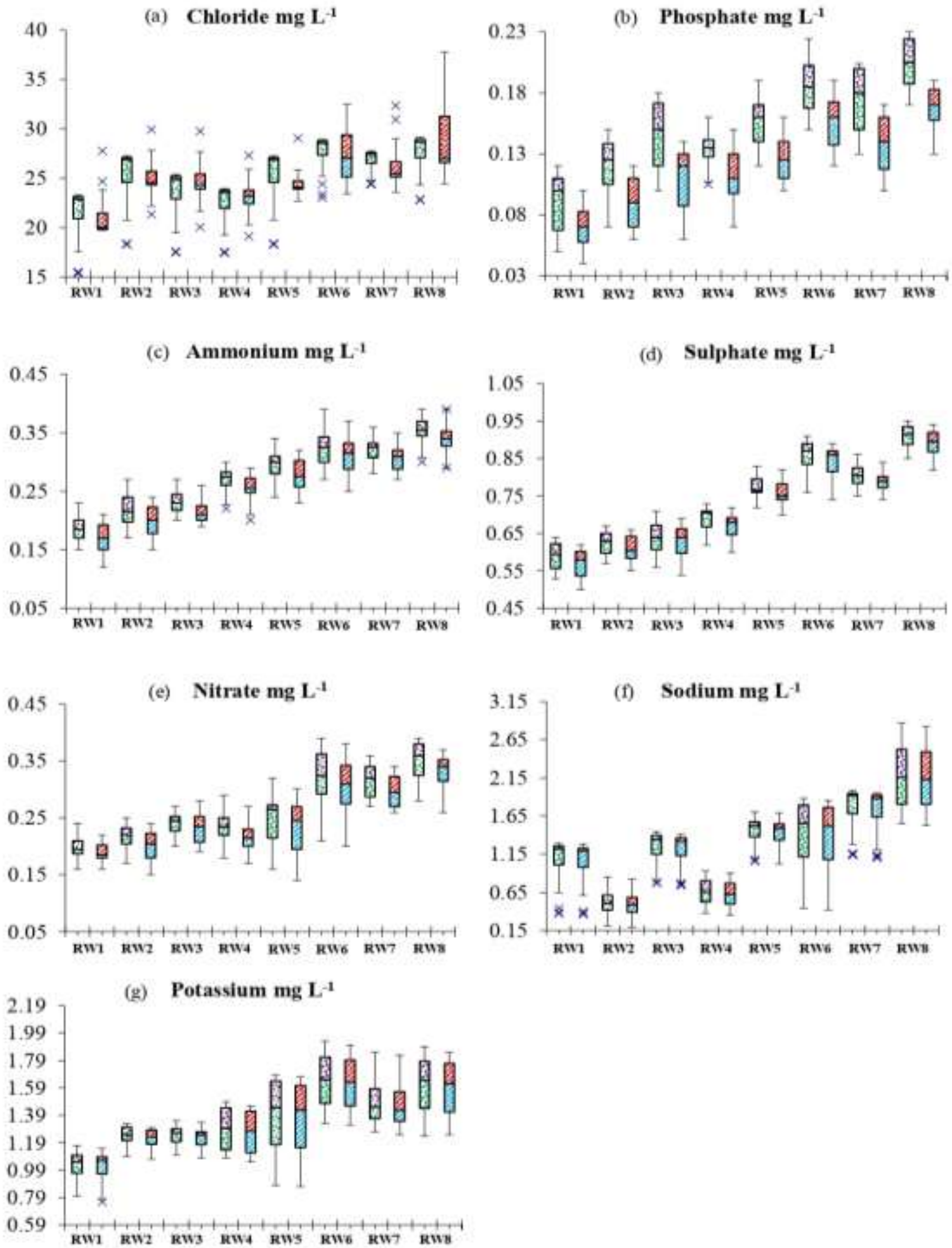

Figure 3. Trends of chloride, phosphate, ammonium, sulphate, nitrate, sodium and potassium during study period at different sampling sites.

The range of the sodium in the first year, was observed from 0.35 mg L^{-1} at RW8 site in August to 2.94 mg L^{-1} at site RW3 in December. Whereas, in the second year, the maximum value of sodium was determined as 2.85 mg L^{-1} at site RW3 during January and minimum value was found as 0.24 mg L^{-1} at site RW8 in August Figure 3 (f). The values of sodium are directly influenced by the concentration of TDS (Leblebiei et al. 2011). The values of potassium in the first year, were ranged from 0.75 mg L^{-1} at site RW3 in July to 2.3 mg L^{-1} at site

RW1 and RW8 in May and August. Whereas, in the second year, the maximum value of potassium was observed as 2.76 mg L^{-1} at site RW6 in December and minimum value was found as 0.84 mg L^{-1} at site RW8 in June (Figure 3 g). Loading of the nutrients from various sources like sewage, industrial influent and fertilizers from agricultural domains are responsible for the diminishing of water quality of wetland. At the same time, wetlands are fetching for the domestic, agricultural and industrial waste which directly enters the wetlands through inflowing streams and rivers (Singh et al. 2020a; Singh et al. 2022). The extreme rise in the concentration of various nutrients have seen in recent study as compared with the previous studies (Akhter and Brraich 2020). The concentration of most of the nutrients were higher during the winter months and less concentrations were recorded during the months of monsoon and summer. The reason for higher values of nutrients during winter months could be due to the accumulation of industrial wastes and sewage effluents from the nearby cities, including agricultural lands from different parts of Punjab which directly or indirectly reached to the wetland (Brraich and Saini 2015; Kumar et al 2016; Kaur et al 2015; Singh et al 2017; Kaur et al 2020; Singh et al 2020a, b), which gets settle down and less concentration during monsoonal months, were due to dilutions after heavy rainfall (Sharma and Bhardwaj 2011).

Principal Component Analysis

Principal component analysis (PCA) is a statistical measure, used to reduce the complexity of large datasets into smaller datasets for better interpretations. It also represents the leading components that have a well interpretation of variables (Bhattrai et al. 2017). PCA can be used to find out classify the sampling sites and to detect the pollution sources (Sharma and Bora 2020). In present study (2018-19), the first two principal components (PCs) explained more than 85.36% of the variance (Figure 4, a). PC1 showed highly positive correlation with EC (0.97), NO_3 (0.95), CO_3 (0.94), PO_4 (0.94), Cl (0.92), Mg (0.90), SO_4 (0.90), TDS (0.88), TA (0.83), NH_4 (0.78), whereas, only Na (-0.01) had negative correlation. However, PC2 had highly positive correlation with WT (0.88), pH (0.83), Ca (0.93), TH (0.87) and HCO_3 (0.77) whereas, EC (-0.11), TDS (-0.36), CO_3 (-0.19), Cl (-0.26), PO_4 (-0.24), NH_4 (-0.45), SO_4 (-0.34) and NO_3 (-0.14) showed negative correlation. In the first year, based on individual parameters, PCA identified two groups, group I involved three sites, RW6, RW7 and RW8 with nearly similar values of Ca, WT, TH, pH, HCO_3, TA and Mg. Group II include site RW1, RW2 and RW3 notably distinguished from other sites by having maximum values of EC, NO_3, CO_3, PO_4, Cl, SO_4, TDS, NH_4, K. Whereas, rest of the sites (RW5 and RW6) were independent due to lower values of nutrients.

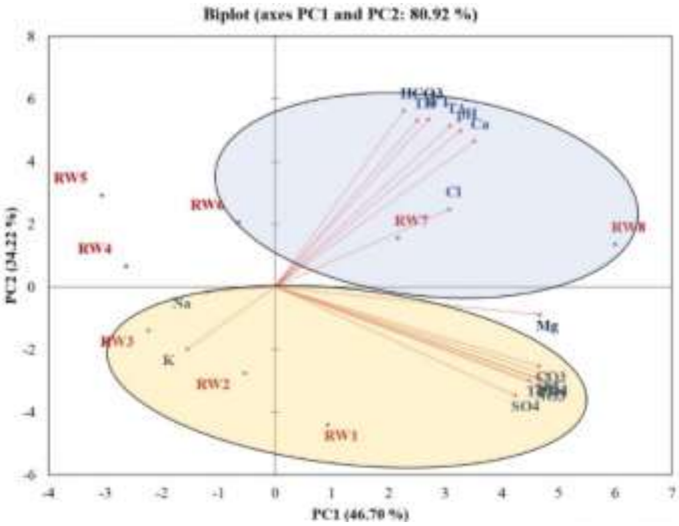

Figure 4. (b) PCA biplot showing relationship between different sampling sites and physico-chemical properties during 2019-20.

During second year (2019-20) of study, the first two PCs explained more than 75.29% (Figure 4, b) of the variance. PC1 had highly positive correlation with variables viz. were EC (0.88), PO_4 (0.86), NH_4 (0.85), CO_3 (0.85), Mg (0.85), NO_3 (0.85), TDS (0.82), SO_4 (0.77) whereas, Na (-0.22) and K (-0.22) showed negative correlation. However, on PC2, the highly positively correlated parameters were WT (0.84), pH (0.78), HCO_3 (0.88), TA (0.80), TH (0.83), Ca (0.73) while EC (-0.44), TDS (-0.46), CO_3 (-0.39), PO_4 (-0.47), NH_4 (-0.46), SO_4 (-0.54), NO_3 (-0.49), Na (-0.02) and Mg (-0.14) had negative correlation on same PC (Fig). Similarly, as in the previous year, the PCA identified two similar type of groups. The major leading sources of pollutants to these sites were mainly through industrial effluents, siltation, agricultural runoff containing fertilizers, and anthropogenic pressures from the encroachment areas into the wetland (Singh et al. 2020; Singh et al. 2022). The extent of pollutants and anthropogenic activities to these sampling sites greatly vary that may be the cause for their water quality range. PCA is found to be useful technique that can be used to extract significant factors (PCs), to evaluate the relationship between the undertaken variables (Hamzah et al. 2016).

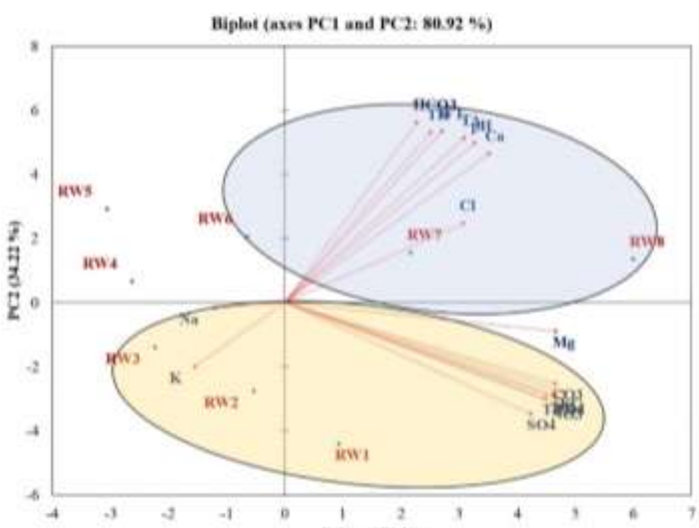

Figure 4. (b) PCA biplot showing relationship between different sampling sites and physico-chemical properties during 2019-20.

Determination of water quality status of Ropar wetland

The foremost purpose of applying WQI was to modify the complex data of water quality parameters into simplest form. It considers various physical and chemical variables and their magnitude in a single value which represents the water quality of Ropar wetland. It was calculated from the computed data for all the twelve water quality parameters (pH, EC, TDS, total alkalinity, total hardness, calcium, magnesium, chloride, phosphate, ammonia, sulphate and nitrate) for each sampling site during sampling period (Balan et al. 2012; Sharma and Kumar, 2017; Deep et al. 2020). The permissible limits according to World Health Organization were employed for the calculation of WQI (WHO, 2011). In the first year (2018-19) of study, the average values of water quality index lied in the range of 23.89 (RW5) -67.76 (RW8).

However, in the second year (2019-20), the overall mean values of water quality were ranged from 24.52 (RW5)- 64.01 (RW8), shown in Table 3. The water quality of sites RW8, RW7, RW1 and RW2 were mostly degraded due to various pollutant sources whereas, sampling sites RW4-RW6 showed less water quality degradation. The monthly mean values of WQI during the study period is represented in Figure 5. The present values indicated that water quality of Ropar wetland falls in the category of 'excellent to poor'. The water quality was mostly deteriorated during December to February whereas, less deteriorated during July and August. Increased water quality during winter months could be attributed to the deposition of nutrients into the wetland after monsoonal effect, results in increased nutrient level in winter months. Furthermore, the water level in the wetland gets reduced due to ice covered glaciers in the Himalayas, leading to maximum concentration of nutrients. The reasons for increasing the values of water quality index day by day are the urbanization, agricultural run offs, anthropogenic activities and industrialization (Jindal and Sharma, 2011; Kumar et al. 2016; Kumar and Singh 2020). Sharma et al. (2017) also assessed the water quality of Sutlej river, which showed poor water quality indicating high pollution level in the river Sutlej, which also affects the water quality of Ropar wetland.

Table 3. Monthly variations in water quality index values during study period (2018-20) in Ropar wetland.

Months	RW1		RW2		RW3		RW4		RW5		RW6		RW7		RW8	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
March	58.34	54.58	53.60	51.85	46.98	45.37	38.60	34.70	28.33	25.74	30.28	37.18	54.58	47.05	58.42	56.48
April	59.28	54.57	54.54	53.72	48.87	47.92	40.48	37.76	30.22	28.28	34.02	40.42	55.51	48.75	61.23	57.44
May	61.16	56.45	55.46	52.62	50.74	46.96	41.43	39.49	33.03	30.17	35.90	39.60	58.32	49.84	62.16	58.39
June	54.59	52.70	52.64	50.73	47.89	45.08	41.35	39.48	30.17	26.41	34.00	39.58	52.66	50.80	56.51	54.64
July	47.08	52.68	45.14	46.98	41.33	41.32	32.00	35.72	**23.90**	24.52	33.98	35.82	47.07	45.18	53.70	52.74
August	45.20	48.93	43.27	43.23	38.51	37.58	30.13	31.98	24.51	24.53	30.24	33.95	42.38	41.44	50.90	50.87
September	62.08	58.32	50.79	53.19	50.07	47.89	42.34	40.43	34.87	31.10	36.84	41.45	59.24	50.61	63.09	59.32
October	60.21	59.25	57.33	54.80	51.66	48.83	43.25	41.36	35.79	32.97	37.76	45.19	60.17	52.81	63.46	60.25
November	65.81	60.19	59.19	53.49	52.07	50.70	45.11	42.30	36.71	33.90	38.68	43.31	60.15	54.48	64.01	61.18
December	58.35	58.31	56.41	52.60	47.93	45.08	41.41	40.41	30.21	28.30	42.44	39.59	50.84	49.48	64.05	62.11
January	67.70	63.93	63.88	56.32	54.47	47.89	43.26	43.24	35.80	32.04	48.06	43.34	56.45	56.44	65.91	60.26
February	63.94	60.19	60.14	55.06	55.83	45.09	40.46	43.24	34.87	33.93	48.04	47.07	58.31	57.83	**67.76**	64.01

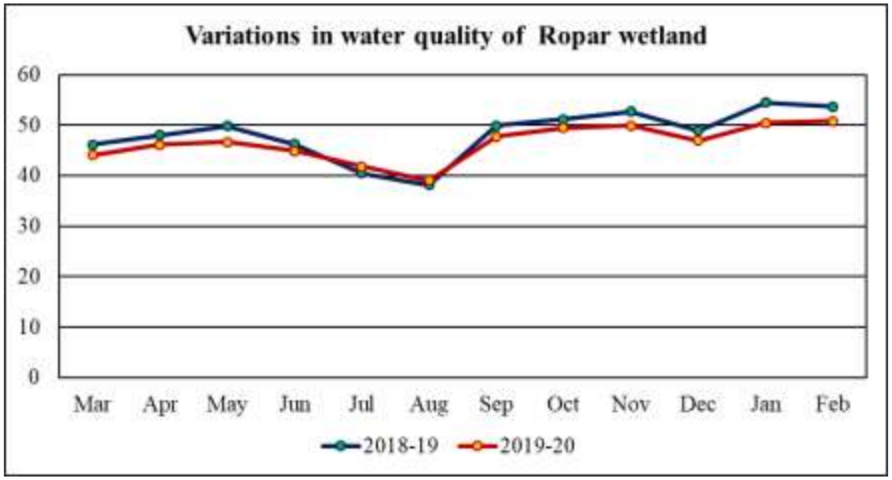

Figure 5. Water Quality Index values during study period showing a varied pattern (2018-20).

Predominant factors influencing the water quality of Ropar wetland

During present study, the Pearson correlation analysis was determined amongst the 17 parameters and water quality index to measure the relationship between them. Pearson's correlation assesses the extent of closeness which exists between two variables, one as independent and another variable as dependent. A Pearson correlation is a number between -1 and +1 that indicates to which extent two variables are linearly related.

During present study (2018-20), Pearson correlation analysis revealed WQ showed positive correlation with pH (0.74 in the first year and 0.38, in the second year), EC (0.74 in 2018-19 and 0.94 in 2019-20), PO_4 (0.89 in 2018-19 and 0.90, in 2019-20), NO_3 (0.81 in 2018-19 and 0.77 in 2019-20). Water quality also had positive correlation with Na (0.63 in the first year and 0.80, in the second year) while with TDS, it showed not strong correlation in the first year but had slightly strong correlation in the second year (0.41, 0.65). In present study, EC showed positive correlation with TDS (0.72 in 2018-19 and 0.74 in 2019-20). Because conductivity of water is directly related to TDS, which corresponded to dissolve impurities such as salts, ions, industrial runoff, municipal discharge etc. (Tubonimi et al. 2010; Amin et al. 2012; Kaur et al. 2020). Similarly, TDS also had positive correlation with Na (0.75 for 2018-19 and 0.95 for 2019-20) study period. Increased salinity means increasing high concentration of sodium and chloride ions in water, due to which TDS has positive correlation with Na and Cl ions (Leblebiei et al. 2011). The unit weight values attained during the study period were maximum for pH (0.019) PO_4 (0.56) and NH_4 (0.33). The overall predominant physico-chemical parameters of water viz. pH, TDS, EC, Na, NO_3, PO_4 had positive correlation with water quality, suggesting that these parameters have significant influence on the water quality of Ropar wetland during present study. As a result, controlling these factors should be prioritized in order to control the water quality of Ropar wetland. The water quality patterns and identification of their primary contributing factors is the present study's unique feature. Furthermore, this research will be helpful for our understanding of water quality pattern and status of Ropar wetland. Various policy makers and management authorities would benefit from this study, to make conservation strategies to protect this wetland from further deterioration.

Conclusions and Recommendations

It can be concluded that, the present study depicts the overall water quality status of Ropar wetland is deteriorating day by day due to various sources of pollutants. The recorded values of nutrients were maximum during winter months whereas minimum during July and August. PCA differentiated the studied sampling sites into two major groups on the basis of their similar nutrient values: (i) RW6, RW7 and RW8; (ii) RW1, RW2 and RW3 by having nearly similar water chemistry, pollution sources and water quality patterns. The water quality was mostly degraded during winter months (January and February) whereas, least during July and August. The recorded values of WQI showed nearly similar trends in both the years. These values of nutrients and WQI showed monthly as well as overall fluctuations in the Ropar wetland. Results of WQI, are helpful in determining the overall water quality of Ropar wetland. On the basis of these observations, Pearson's correlation was employed which suggested that, the water quality showed strong positive correlation with some physico-chemical parameters viz. pH, TDS, EC, Na and PO_4, which had greatly influenced the water quality of Ropar wetland during the present study. The present study revealed that, PCA and the WQI are one of the significant tools to summarize complex data into simplest form, to interpret their results in easiest way for assessing water quality whereas, correlation analysis determined the predominant key parameters majorly responsible for the overall water quality of Ropar wetland. Present study recommends, that the strategies and monitoring programs should be planned and implemented by keeping in mind these pollutant sources to control the further degradation of the Ropar wetland at different stretches. It is endorsed that the continuous water monitoring program must be sustained at regular intervals which will be further helpful in executing the water quality upgrading programme.

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