



Assessment of physicochemical parameters and metal contents of Mansagar lake of Jaipur

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Abstract

The state of Rajasthan of India is predominantly classified as a dry state and therefore its freshwater and agricultural resources are the prime concern for the people and the state agencies. This article presents the analytical study of physicochemical parameters of Mansagar lake Jaipur, India. Our prime objective was to find the quantity and effects of effluents mixing with the water of Jalmahal Lake (officially known as Mansagar lake). Standard approaches were applied to calculate the water quality index (WQI) for the assessment of its surface water for two consecutive years. The values of physicochemical parameters have been calculated before and after the rainy season and the study has been presented in a detailed form. The variation of parameters like COD with heavy metals like lead and zinc have been analyzed and it is found that due to the increase in metal content the COD increased as high as 500 mg/l in rainy while it is as low as 200 before the rainy season. The values of various physiochemical parameters like BOD, COD, conductivity, and turbidity were also observed throughout the year at the various front of the lake and it has been observed that pollutants presence increases in peak summer and late winters. It's noticeable that turbidity and conductivity were normally high in June–July thereby increased pollution concentration in the remaining water levels.

Keywords Physicochemical parameters · Pollution · Mansagar lake · Trend analysis

Introduction

Organic wastes produced by animals and humans begin to break down when dumped into lakes. Such wastes require oxygen to decompose therefore can deprive the aquatic life of the oxygen it needs to survive. Faecal matter, crop debris, yard clippings, food wastes, rubber, plastic, wood, and disposable diapers are categorized as organic wastes. Clean, safe, and adequate water is vital to the survival of all living organisms. India's rivers, lakes and groundwater receive millions of liters of sewage, industrial and agricultural wastes. Water pollution has become one of the most important environmental issues in the present era. The state of Rajasthan in India is predominantly classified as a dry state and therefore its freshwater and agricultural resources are the prime concern for the people and the state agencies (Roberts et al. 2008).

The Mansagar lake was constructed by Raja Man Singh-I and further rulers of Amer (the old capital city of the Jaipur regime) for agriculture and recreation. The lake is surrounded by hills on three (western, north, and east) sides. Post-independence era (after 1947), the lake is no longer utilized for any activities and therefore nearly losing its importance since then. Over the years, the lake water quality has been ruined because of the constant dumping of untreated sewage and toxic chemicals from nearby factories and residential areas. This has resulted in its reduced storage capacity. Due to the easy reach of human activities, the lake is vulnerable to possible organic pollution contents. Nearby located industries, agricultural waste, and city municipal sources are the main suppliers of contamination into the lake.

The municipal pollution sources cover different kind of pollutants such as pesticide, herbicide, sewage, littering process, etc. Common types of contaminations are mainly categorized as point sources or nonpoint sources (NPS) of pollution (Adu and Kumarasamy 2018). Point sources responsible for pollution in lakes can easily be trace along with offenders, while non-point sources are difficult to traced

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(Wu and Chen 2013; Rajput and Pandey 2017; Ongley et al. 2010; Brooks 2009; Bhatia and Jain 2016). Pollutants not only degrade the water quality but also affects the aquatic life within the lakes (Brooks 2009; Vallero 2006). In the present era, the sewage and agriculture waste discharge the phosphate and nitrate at higher levels in nearby lakes, resulting in the poor quality of water and adverse effects on the aquatic habitat. These impurities also produce harmful algal bloom and responsible in unmanageable eutrophication of its water (Minnesota Pollution Control Agency 2008). In a bid to put a stop to the steady destruction of the water bodies, regular measures and guidelines had been adopted by Government agencies in past. Most of the ponds and Jalmahal (Mansagar) lake in particular of state capital city (Jaipur) are in deteriorating state. Their storage capacity is also reducing due to silting and dumping of the solid waste and uncontrolled garbage mixing (Minnesota 2008; Sharma et al. 2007; Raina 2007; Pradhan and Chauhan 2016).

The Mansagar lake had been an area of interest for many environmentalists and researchers, for which religious work had been placed to assess its physicochemical parameters and status of its aquatic life (Sharma et al. 2007; Raina 2007; Pradhan and Chauhan 2016). Keeping these facts in consideration, this study has been done to provide a mirror reflection of the current situation. In the first phase of this study, strategic sample collection points were selected near the shoreline (edges) of the lake to perform the quality check and the effluents testing of physical, chemical, biological, light, and heavy metals using the onsite and the laboratory equipment. In the second phase, all processes followed in the first phase were repeated for different environmental conditions such as before the rain and during the peak summer season.

Standard approaches were applied to for assessment of its surface water for 02 consecutive years (2016–2017 and 2017–2018). The first Sect. 1 gives a detailed background of the studied lake and possible pollutants and their adverse effects on its water quality and aquatic life. Section 2 describes our strategies to identifying the sample collection stations and methods to evaluate physicochemical parameters, metal contents and other quality-associated theoretical and experimental studies. Final Sect. 3 outlines the findings observed during the experimental work for our studied lake area. This section also explains the correlation among the evaluated Physicochemical parameters and other pollutants and variation in their levels due to change in environmental conditions.

The Mansagar (Jalmahal) Lake, Jaipur

The water surface of Mansagar lake has an area of 139 ha with an overall catchment area of 23.5 km². More than 40% of the catchment area lies in the urban area causing

deterioration of the lake, while the rest area is covered by denuded hills. The satellite image as shown in Fig. 1 depict effluent entry locations (white arrows), check dam, birds nesting island, and the outlets of the studied lake. The check dams covering about 5-acre area was constructed in 2005 to prohibit the flow of eroded soil from the surrounding hills. Wooden log structures at channel openings are used to avoid mixing floating solid wastes with it.

However, the lake is the recipient of wastewater from two sewerage canals of the city (locally termed as Nagatalai Nalla and Brahmampuri Nalla) and from nearby industries. Nearly two decades, the Government agencies stressing upon treatment, desiltation and catchment treatment to improve its water quality (Spellman 2014). Images shown in Fig. 2a, b depicts some cause for garbage entry and chemical effluents in the lake. During local festivals and events, the idol immersion practices have been increasing the acidity and metal contents in the lake water and thereby poisoned the lake ecosystems such as vanishing the fishes (Fig. 2c) and plants apart from stagnating the natural flow of the water in the lake. As a measure, the state Government declared the Mansagar lake and its surroundings as protected areas since July 2015.

Despite all measures and efforts, the immersion of lord idols and other rituals performance around the lake have been a challenge for the city municipality to maintain its water quality. From time to time, few restoration projects had been launched as part of urban asset management efforts jointly by agencies from state and central governments of India (Moundiotiya and Kulshreshta 2013). Other private sector developers; the Jalmahal Resort Pvt. Ltd. and the project development consultant (PDCOR) were also assigned restoration and cleaning jobs. Figure 4d shows a glimpse of the restoration works done at the lakeside. Different organisation like Jaipur development authority, city municipality offices and forest departments along with private agencies and contractors have been engaged in the development and

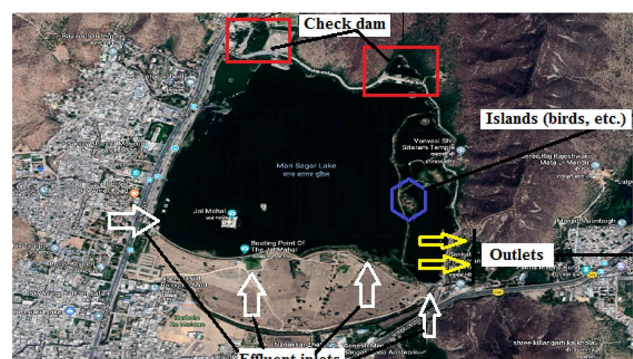


Fig. 1 The satellite image of the studied (Mansagar) lake, Courtesy: Google image

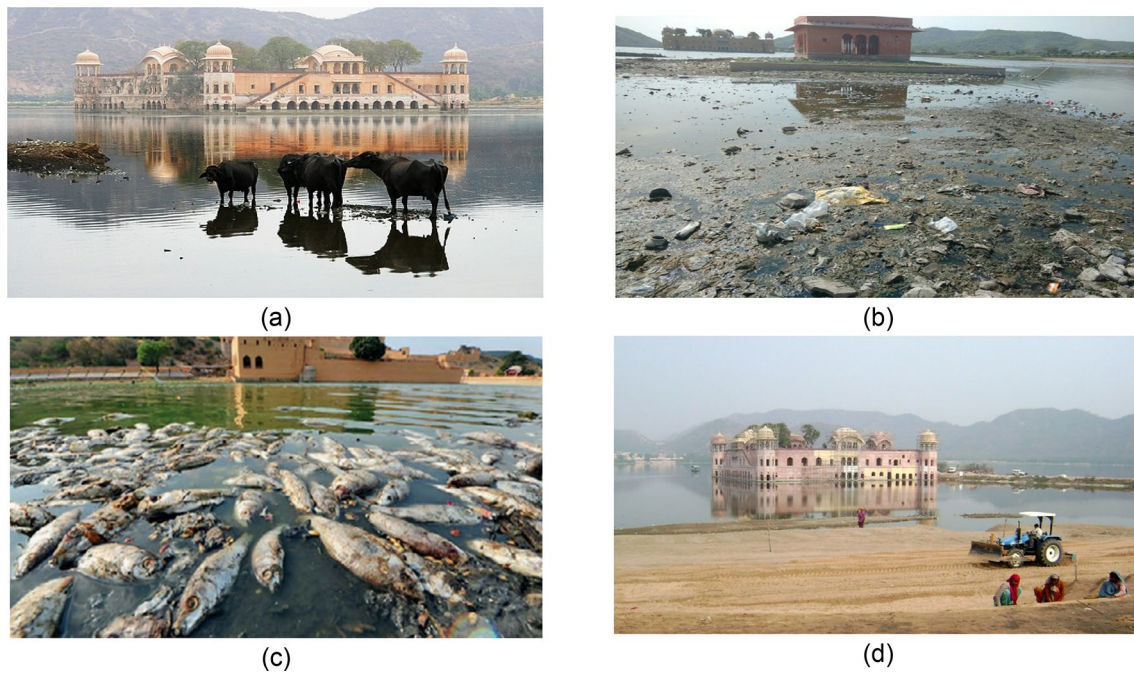


Fig. 2 a, b Images showing the deposition of garbage and chemical effluents, prominent in the lake, ref. Google images. c Image showing dead fishes due to abnormal dissolved oxygen rate, ref. (Times of

India, No. 1, 2017), d Restoration works at the Jal mahal (Mansagar) and nearby locations have done during 2002–2010

management of sewage and tertiary treatment facilities. Additionally, the use of aeration and bioremediation processes and regular monitoring via available baseline data, the water quality of the lake have been improved little. Despite past efforts to improve sewage disposal yet some effluent streams running from Sanjay museum and Gujar Ghati and in front of Jalamahal Haat Bazar adding impurity of Na, K, Cr and Mn and anthropogenic pollution. Even after declaring the lake as a protected area and placing it under the Rajasthan lake development authority (RLDA), conservation efforts have been failed to protect the lake from possible contaminations and environmental damage. Despite such efforts, the lake continues to languish, throttled by pollution, encroachment and heavy silage. Large volumes of sewage waste, pesticides, fertilisers and other pollutants combined with encroachment and damaged recharge channels are now killing the centuries-old lake. The failure in the system management and possible overflow of water during rains had also resulted in an uncontrolled release of untreated sewage water into the lake.

In other words, the apathy of the state government and the municipal body has put this historic lake on the deathbed. Therefore a proper restoration policy for this lake is needed to maintain its physicochemical parameters within admissible limits. Awareness circulation is also must among the nearby residents and visitors to the lake about the ill effects of nutrient level in the lake.

Materials and methods

The quality of the water is defined on some physicochemical and biological standards. It is necessary to check the water quality before using it for many purposes such as drinking, agriculture, domestic or for the industrial purpose. The water contains some impurities either be dissolved or suspended, either bacterial or microbial etc. The quality of any water body can be defined by various physical parameters such as pH, turbidity, TDS, temperature etc., and chemical parameters such as BOD, COD, dissolved oxygen, hardness etc. The waste from agricultural activities pollutes lake estuaries with fertilizers, chemical, livestock waste, bacteria and virus along with washed nutrients (Sany et al. 2019; Sath et al. 2018; Papatheodorou 2006). The wastewater without any treatment and the water after rainfall which carries road waste, chemicals and other waste posing threat to the water bodies. Such contaminations are mixed in the water sources and settle down at the source bed. This pollution particle later absorbs chemicals from the stream and resulted in more pollution. Some time abnormal growth of living aquatic organism also pollute water as more decaying materials leads to the reduction in oxygen levels of water and ultimately lead to the unsuitability of lake water for large organisms (Oliveira et al. 2018).

Weathering of crustal material is a breakdown in subjected crystals of the material by the action of rainwater, extremes temperature, and biological activities. All such

parameters and processes are well known for since long and are actual factors, which forms the environmental condition for any lake system. Therefore maintaining the equilibrium in the environmental status and the presence of surrounding conditions ensure the fragile ecosystem for lakes, which can be prevented via controlling human encroachment and pollution. Although increased population, use of unconventional agricultural practices, and bad drainage systems of the urban areas have been accelerating eutrophication. Since the last century, the environmental concerns, especially within the Indian lakes and reservoirs, have been vanishing due to the pressure from excessive population growth, encroachments, eutrophication and silt, resulting in the sinks for contaminants especially the lakes of the big cities. The situation had worsened in terms of lakes water converting into the non-portable, biodiversity threatened, which resulted in very rare chances for survival of fishes and other living species.

For our study, the present status of social and ecological activities around the lake, the shoreline, and the surroundings have been considered. For a detailed and comparative investigation of lake water quality performance parameters, three main strategic locations shown in Fig. 3, depicted as E1: Jalmahal Haat Bazar, E2: Front of Sanjay Museum, E3: Gujar Ghati were chosen to collect the samples during peak summertime and the just after the rainy season. Various collection points on straight and parallel to the chosen locations (E1, E2 and E3) were selected based on the possibility of maximum and continuous movement of domestic visitors and tourists throughout the year and in all weather conditions. The samples were collected from both; the surface and subsurface (with 1 m depth) to evaluate the average value of various performance parameters. Though in this article, we presented most of the study and outcomes based on the average values of targeted performance parameters. Some parameters such as temperature, dissolved oxygen and free carbon dioxide contents were evaluated at the sites, while other parameters were calculated with the use of equipment

in the laboratory as per APHA 1989 standards (APHA 1999). For evaluation of Biological parameters, a sample in a volume of 500 ml was collected, while the composite samples were centrifuged at 1500 rpm for 20 min. The concentrated samples were finally prepared with a known volume of distilled water and transferred in polyethene bottles for storage. Preservations were also added immediately in each sample with proper concentration mapping on the bottles. Separate 500 ml polyethene plastic bottles were used to identify the cations and anions. The standard procedures for sample collections were followed such as application of metal-free shop cleaning, distilled water rinsing followed by the soaking process with 10% nitric acid upto a sufficient time (20–24 h). Finally, deionized water was used to rinse the sample bottles. Apart from this, site water collected from a depth of 25 cm from the surface of the lake was also used to wash the bottles before filling them.

Out of collected samples, some were acidified with HCl to a $\text{pH} < 2$ for their cationic analysis, while the remaining were kept non-acidified for their anionic analysis. To avoid aeration, the seal was attached with the bottles and insulated ice container were used for storage purposes. All samples were dispatched to the laboratory, while the temperature was maintained upto $4\text{ }^{\circ}\text{C}$ before the start of the analysis procedure (APHA 1999; Huang et al. 2014). To check the anthropogenic impacts on the lake water ecosystem and the surrounding area, we also observed the flow of human traffic within the lake (restricted area) and its surrounding as well. Collected samples were judged based on the various accurate analysis process. During our work, we strictly followed the outlines of BIS (Bureau of Indian Standard) IS-3025/1622 for the sample test as shown in Table 1.

Samples collected were kept and treated separately from each other for the chemical test and microbial analysis with short process intervals. A major part of the experimental analysis for our work has been done with the environmental and public health engineering labs of MNIT Jaipur (An institute of National Importance owned and managed by Government of India). The raw greywater samples were analyzed for Total Kjeldahl Nitrogen (TKN), Ammonical Nitrogen, Phosphorous, Nitrates, pH and Alkalinity. The adaptive monitoring protocols (Grizzle et al. 2014) have been followed for sample collection for long-term analysis. Also, the concept of univariate and multivariate analytical procedures was followed for real-time measurement with possibly low cost and high-efficiency measurement. Multivariate statistical analysis is an efficient method for pollution analysis of lake water and applicable for decision-making in the management of water quality. In our work, conventional multivariate statistical techniques such as cluster analysis and the principal component analysis have been used. All mathematical computations were made using MS office 2010 and Minitab-14. The data matrix obtained during the



Fig. 3 Sample collecting locations (E1: Jalmahal Haat Bazar, E2: Front of Sanjay Museum, E3: Gujar Ghati)

Table 1 Protocol for quality testing of the water samples

No.	Parameter	Methods	Protocol
1	Turbidity	Nephrol metric	2130B
2	Conductivity	Digital meter	2510B
3	pH	Electrometric method	4500 (pH)
4	Chloride	Titration method	4500 (Cl)
5	Hardness	Edta method (titration)	2340 (B)
6	DO	Titrimetric method	4500 -0 (A)
7	BOD	5 days BOD	5210 (B)
8	COD	Close reflux method	5220 (C)
9	Phosphate	Stannous Chloride method	4500-P D
10	Kjel Dahl Nitrogen	Block digester method	4500-N org (B)
11	Ammoniacal Nitrogen	Phenate method	4500-NH3F
12	TDS	Digital meter	2540 (C)
13	Preliminary Treatment of metal Samples	Filtration for dissolved and suspended methods	3030B
14	Cr, Cd, Zn, Fe, Pb, Mn	Atomic absorption spectrophotometry (AAS)	3500 Cr-B, 3500 Cd-B, 3500 Zn-B, 3500 Fe-B, 3500 Pb-B, 3500 Mn-B (APHA)
15	Na, K	Flame photometer method	3500 Na-D, 3500 K-D (APHA) APHA
16	Coliform	Multiple tube technique, single strength test for wastewater	9230-B

study period was subjected to multivariate statistical technique to find the hidden data of similarity between sampling sites, investigation of water quality variables responsible and the influence of possible natural and anthropogenic sources on the water quality parameters.

Results and discussions

The Mansagar (Jalmahal area) lake receives wastewater and runoff water caused by heavy showers, which enters the lake through various influent nallas (Brahampuri and Nagtalai nalla) consist of various pollutants leading to undesirable high level of nutrients. Also, the catchment area of these nallas has many household industries, which also contribute their pollutants load a route. This increases the algal bloom and weeds, which resulted in depletion of turbidity and oxygen affecting the aquatic biota and decreases the sunlight penetration. The locations namely: the front of Jalmahal Haat bazaar (local weekly market) area (E1), Sanjay Museum (E2) and the front yard of Gujar Ghati end (E3) were selected based on the possibility of maximum and continuous movement of domestic visitors and tourist throughout the year and in all weather conditions. The collected samples were assessed to evaluate the levels of targeted physicochemical parameters and other characteristics. In addition to many rounds of chemical tests to evaluate the hardness, DO, COD, BOD, etc., various physical test have also been done to calculate the factors like pH, turbidity, TDS, etc. A comparative analysis of evaluated

parameters was then done at par with the procedure defined by the water act 1974, which defines the possible limits of effluents discharge in surface water under varied environmental conditions (before and after rain) for aquatic water. Descriptive statistics for two main environmental situations; the post rainy season (July–October) and the dry season (January–April) for targeted water quality parameters were examined. Entries in Tables 2, 3, and 4 represent the average values of measured parameters for multiple readings.

The presence of Mn with higher levels can affect DNA and chromosome in fish cells. Also, the availability of Cr within the lake water (especially in the effluent samples collected from nearby areas of the Gujar Ghati), can affect aquatic animals like fish gills and the whole part of their body. A high level of Cr may also affect the whole part of the aquatic plants (root to leaves). The location (E3) was chosen to study the soil erosion effects and mixing of the eroded soils with the lake water and its impact on its water quality. As the erosion of the soils from the nearby hills during rains bring in silt deposit in the lake adding to the turbidity and reduction in the water holding capacity, which is going since several decades. After each rainy season, silt deposits are adding with the lakebed, making it shallow and impacting its water quality severely. The assessed values for Physicochemical and organic parameters shown in Tables 2 and 3 confirm these effects. It was also noticed that low pH value at the surface water was diluted by the lake water with a higher pH value as depth increased. It was observed that the average values of pH for three stations were found to be 7.58, 7.42, and 7.22 before the rainy season while its values

Table 2 Physicochemical characterization at strategic locations: E1, E2 and E3

Location Season/parameters	Haat Bazar Front (E1)		Sanjay Museum (E2)		Gujar Ghati End (E3)	
	Before rain	After rain	Before rain	After rain	Before rain	after rain
pH (pH unit)	7.583	6.92	7.42	6.85	7.22	6.70
Conductivity ($\mu\text{S}/\text{cm}$)	1007	950	1800	1615	1350	1180
Turbidity (NTU)	4.22	6.95	7.42	8.44	12.2	14.4
COD (mg/l)	776	460.5	180.4	270.4	315.4	336
DO (mg/l)	1.6	2.8	3.6	4.9	4.5	4.8
BOD (mg/l)	22	17.64	25.30	24.83	24.40	22.83
TOC (mg/l or ppm)	390.4	405.5	339.5	355.8	416	425.2
Chloride (mg/l)	139.95	129.95	154.95	142.2	179.94	157.95

Table 3 Organic effluents and other pollution characterization at strategic locations: E1, E2 and E3

Location Season/parameters	Haat Bazar front (E1)		Sanjay Museum (E2)		Gujar Ghati End (E3)	
	before rain	After rain	Before rain	After rain	Before rain	After rain
Ammonical Nitrogen	1.20	1.42	1.15	1.70	0.571	0.847
Coliform bacteria	22	23	22	21	23	23
TKN (mg/l)	38.20	31.30	34.20	29.40	36.40	29.40
Nitrate (NO_3) (mg/l)	0.198	0.282	0.185	0.220	0.250	1.274
Phosphate (mg/l)	3.40	7.10	3.70	4.60	4.30	5.08

Table 4 Evaluated heavy metal pollutants in the lake water at strategic locations: E1, E2 and E3

Location Parameters	Haat Bazar Front (E1)		Sanjay Museum (E2)		Gujar Ghati End (E3)	
	Before rain	After rain	Before rain	After rain	Before rain	After rain
Cr (mg/l)	0.30	0.35	BDL	BDL	0.60	0.55
Co (mg/l)	0.010	BDL	0.02	BDL	0.017	BDL
Cd (mg/l)	0.014	BDL	0.014	BDL	BDL	0.016
Cu (mg/l)	AND	AND	BDL	0.040	BDL	0.045
Na (mg/l)	141.0	129	251.6	175.0	173.0	121.0
K (mg/l)	14.2	10.6	60.5	29.8	38.6	24.5
Ca (mg/l)	315.4	155.0	231.0	135.0	207.45	129.8
Fe (mg/l)	BDL	0.09	0.811	0.062	0.37	0.29
Mn (mg/l)	0.05	BDL	0.08	0.07	0.07	0.07
Ni (mg/L)	0.03	0.02	0.05	BDL	0.08	0.06
Pb (mg/l)	BDL	BDL	BDL	0.004	BDL	BDL
Zn (mg/l)	0.92	BDL	0.68	0.138	0.82	BDL

BDL below detection limit, AND analysis not done

decrease slightly (6.92, 6.85, 6.70) after the rainy season. Also, the high pH value indicates that the water quality is more of sub-alkaline to alkaline in nature in all season. Various salts and inorganic compounds produce conductive ions (electrolytes) in the lake water, which makes its water conductive (EPA 2012). When electrolytes are added to water it may increase the conductivity of water but water remains electrically equal (Perlman 2014).

Conductivity generally measured in terms of micro- or millisiemens per centimeter. Since the studied lake is surrounded by the hills, therefore it was expected that the conductivity values of its water shall be in a higher range due

to possible mixing of the clay and the limestone soils from nearby hills, which contribute to an increase in the conductivity. The conductivity values obtained were (1007, 1800, 1350) at three respective stations before the rainy season while after the rainy season their values decreased to lower values (950, 1600, 1180) for respective E1, E2, E3 stations. The values found at higher levels from the samples collected during the peak summer days indicating the presence of more salt due to an increase in the temperature and subsequent evaporation process. Turbidity of the lake and total suspended solids are two important parameters of lake

quality. The increase in the turbidity of the water body is a matter of concern.

In our study, the values of turbidity were obtained 4.22, 7.42 and 12.2 (all in NTU) for three respective stations before the rainy season while its value increased to 6.95, 8.44 and 14.4 (all in NTU) after rainy season for E1, E2, E3 respectively. Since in rainy days, the water flows over the nearby surface and can pick up particles and deposit them within the lake water. Therefore observed an increase in the level of turbidity after the rainy season was mainly from a possible increase in the total suspended solids through runoff caused by the rain. Also, the turbidity was found to more regarding the depth, which agrees with the previous study for the studied lake. The turbidity value was also found to be significantly higher at stations situated at the edge of the lake and adjacent to the Haat bazaar, where visitor's movement was highest in all-season specifically during the rainy and the winter season. Also, the increased value of turbidity at some stations indicate a possible reduction in the photosynthesis process due to blockage of sunlight penetration in the lake water. The reduction in photosynthesis occurs due to a decrease in dissolved oxygen in the water body and it proved to be severe for plants. Total dissolved solids (TDS) quantity in a lake is affected due to various factors like fertilizers, organic matter and dissolved salts which affects the aquatic life of a lake.

The COD determines the amount of oxygen needed to carry out the reaction in the solution. Its value also explains the number of organic compounds and the oxidizable pollutants in water. We have noticed that the values 776, 180.4, and 315.4 (all in mg/l) before the rainy season while its values were 460.5, 270.4, and 336 (all in mg/l) after the rainy season. The higher evaluated levels of COD indicate the addition of organic waste from local and polluted streams. As per our study, the COD levels at most stations exceeded the limit, however, it reduces significantly in the dry season. After the rainy season, the higher values of the COD were mainly due to the illegal discharge of waste by the visitors (especially at two stations E2 and E3) during the winters, garbage dumping, improper sewage, and surface runoff to the lake water. The increase in COD during the rainy season may also be caused by the inflow of organic streams from various sources.

The level of dissolved oxygen (DO) is important for the survival of aquatic plants and animals. The level of DO should not go below 3 mg/l in our duration of study its values at the Mansagar lake were 1.6, 3.6 and 4.5 (all in mg/l) before rainy at three stations while their values increases to 2.8, 4.9, and 4.8 (all in mg/l) at three respective points. To protect aquatic life. In our study, we noticed that the DO was relatively consistent in the surface water of the studied lake, however, it starts decreasing from its surface sample value to the sample taken at the depth of 0.5 m. We also observed

that the DO decreases with the depth in the lake as photosynthesis increases the oxygen level in the surface water, while respiration of bacteria decomposing dead organic matter consumes all the dissolved oxygen in the bottom water column coupled with an insufficient exchange with oxygenated surface water (Zhou et al. 2013). The BOD is a measure of the presence of organic matter in the water and its level needs to be on the lower side i.e. upto 20 mg/l, more than this, the water is considered as highly polluting. The Mansagar lake is now so highly polluted that its values 22, 25.30 and 24.40 (all in mg/l) at three stations before rainy seasons while after rainy it has reduced somewhat 17.64, 24.83 and 22.83 (all in mg/l). As per our study, the elevated BOD concentration in the lake water after post rainy season indicates higher loading and accumulation of organic matter in the lake during the season.

The TOC is used to measure the overall level of organic compounds of water and used as a measurement of water quality. With our serious observation, its values were 390.4, 339.5, and 416 at three stations respectively before the rainy season while its values increased to 405.5, 355.8 and 425.2 after the rainy season. During the site visits and sample collection periods, we conclude that the presence of aquatic plants and stray animals in and around the studied lake is the major contributor for observed TOC contents in its sediments and soils, sufficient to determine the productivity within lake (Lowe and Walker 2015). Chloride is a corrosive agent and its higher value is dangerous for the infrastructures. During dry months, the observed higher values of the chloride (139.95, 154.95, 179.94 mg/l) contents indicate surplus organic pollutants from domestic sources and various polluted streams while it reduced to 129.95, 142.2, 157.95 mg/l for three stations after the rainy season.

It has been also noticed that elevation in the Chloride concentrations was mainly due to road ran off and have increasing trends with passing months in the lake water, which create risk for infrastructure as well as aquatic to ecosystems in coming time. With this work, we also reviewed the total Kjeldahl nitrogen (TKN), Nitrate and Phosphate contents within the lake water quality. The TKN is the parameter utilized to find out organic nitrogen and ammonia. The typical value of TKN of influent water lies 35–60 mg/l. At our observation sites, the values were 38.20, 34.20 and 36.40 (all in mg/l) before rainy season while it was 31.30, 29.40 and 29.40 (all in mg/l) after the rainy season at all three observation stations. The organic nitrogen compounds in wastewater convert from NH_3 to NH_4 . From Table 3, it is clear that observed TKN concentration was within the prescribed limits and depicts the growing trend due to subsequent effects of the rainfall. The coliform bacteria may enter into the lakes through municipal waste, farm waste, animal waste, human waste and other outdoor activities. With the increase in rainfall, the coliform bacteria increases by upto 45%. With this

study, we also conclude that the present status of the coliform bacteria is sufficient to make the lake water more vulnerable to contamination by more harmful microorganisms. It was also observed that, the Phosphorus and Nitrogen concentration increases during the rainy season. The value of phosphorous increase from 3.40, 3.70, 4.30 mg/l to 7.10, 4.60, 5.08 mg/l at all three stations respectively.

The concentration of ammonia is higher than nitrates in water thus the pollution due to Ammonia is more severe than Nitrates. The ammonical nitrogen level was found slightly at higher levels in the effluents of samples taken from nearby locations of Gujar Ghati, which is not suitable for fishes. However, the quantity of the ammoniacal nitrogen was found to be in the permissible limit at the outlets of the sewage treatment plant (between 0.5 to 1.2 before the rainy season while 0.8 to 1.7 after the rainy season). The variations found in the physicochemical, biological, and bacteriological parameters seem to be high indicating the non-uniform nature of the water quality prevailing the Jalmahal (Mansagar) lake.

The parameters also showed that the lake is slightly contaminated especially concerning the higher levels of COD at the lake edges and across its width. While the level of dissolved oxygen (DO) was observed low at some locations and the presence of Phosphate and Kjeldahl relatively at a higher level at the edges of the lake. With study and assessment of samples collected from chosen locations, most of targeted heavy metals concentration were found at low levels at the edges and across the width of the lake. However, the lake water has been found polluted with metal contents such as; Cr (having average value lies between 0.30 to 0.60 mg/l), Mn (present in Mansagar lake with an average content of 0.05–0.08 mg/l), Na, K, which are mainly responsible for the degradation of its water quality. Indeed the presence of Cr, Mn and Na through the lake had been a major cause for the death of fishes in huge numbers especially during the first quarter of 2017. The levels of various metal content at three observation points are shown in Table 3.

Presence of sodium or calcium reaching in excess quantity in the soil leads to accumulation of salts which further deteriorate the permeability of the soil, which affect crops irrigation capacity of the soil. The value for the sodium content (141.0, 251.6, 173.0 before rainy and 129, 175.0, 121.0 mg/l after rainy season) and calcium (315.4, 231.0, 207.45 before rainy season and 155.0, 135.0, 129.8 mg/l) respectively at our three observation stations which were slightly on the higher side. We also observe that the concentration of Na and K were at a sufficient level to affect the aquatic animals and plants severely. On the other hand, even if we apply bio-remediation techniques with the lake water to make it suitable for agricultural purpose, the presence of Na and K in excess shall be harmful for irrigation. As the presence of Na in excess level may affect soil permeability, which will

prevent plants to get water properly caused by subsequent less aggregated soil. However, the observed sodium absorption ratio (SAR) values indicate that the overall water quality of the lake water is at a satisfactory level for agricultural applications, while conductivity values come under medium and higher salinity category depending upon the location for availability of the water. Therefore continuous monitoring and control are needed to ensure prevention of heavy and light metal mixing with the lake water effluents.

Correlation analysis and study of environmental impacts

In our study, we have used two important multivariate statistical techniques such as cluster analysis and principal component analysis to evaluate the lake water quality and possible source identification. All mathematical computations were made using MS office 2010 and MINITAB 14. The chemometric technique approach such as multivariate analysis like cluster analysis (CA), principal component analysis (PCA) and water quality index for analysis of the complex data sets provides a reliable and better understanding of the hydrological processes in the study area. These statistical methods permit the identification of the factors which influence more the water quality of the lake and river system. Such type of analysis techniques has been proved to be a valuable tool for developing effective strategies for the management of the water system as well as provide a quick solution to pollution problems. In addition to this multivariate statistical analysis can also help in verifying spatial variations caused by natural and anthropogenic factors linked with seasonality. Thus major outcomes of our study are based on the results and statics obtained through multivariate statistical analysis and interpretation drawn from different data sets and obviously from the understanding the factors affecting the quality of lake water. Rainwater disposal from roads and polluted streams is one of the most important non-point source of water pollution which reduces the quality of water body such as lake and create severe risk for the ecological system (Todeschini 2016). During rainfall, excess water flowing through various road and polluted streams adds to the water body and pollute them. Although it was very difficult to control particle combined pollutant with water due to randomness of water flow and rain (Bian and Zhu 2009). Therefore it is so important to find out the factor responsible for the accumulation and transfer of pollutants.

To ensure that effective excess water runoff due to torrential rain must be handled with proper planning and understanding. That's why the investigation on the trade-off between pollutant and rainfall is very important. Along with this we also have to calculate the amount of rainfall, non-rainy days, duration of the rainfall and its intensity in

different areas. Therefore this all calculation is required for the planning of storm water mitigation. In our investigation, we have found out the tradeoff between water quality factors in the road runoff and the effect of rainfall. The event mean concentration defined is the concentration of pollutant over the rainfall duration and it can be given as (Qingke et al. 2017):

$$EMC = \frac{\int C_t Q_t dt}{\int Q_t dt}$$

In this C_t is pollutant concentration and Q_t is the flow rate of runoff. The correlation and factor analysis were used to find tradeoff in rainfall condition and pollutants. It is evident from past studies that COD and BOD are the common water quality parameters for measuring various organic compounds in water bodies. COD can be defined as the oxygen needed to oxidize all organic material. While BOD is the amount of oxygen needed to decompose organic matter in water bodies. Therefore BOD content is directly proportional to COD concentration (Allen et al. 2005). Figures 4, 5 and 6 represent the observed correlation analytical outcomes

showing the relationship between the selected metals (Fe, Pb and Zn) and total COD concentrations during the study period (2015–2018). It was found that the concentrations of heavy metal (Fe) increase slightly as COD concentration increased after the rainy season, however, a sharp decrease was observed in the same for samples collected before the rainy season (March–June). While for other metal (Zn), the situation was reverse although in both cases the change was not too much as depicted by Fig. 4a, b. Also, the change in concentration of other important metal (Pb) was not too much and was of the declined nature concerning increased COD concentration in samples collected from seasons as shown in Fig. 5a, b.

On comparing the data obtained during the study period, it was also observed that most of the selected metals had higher concentrations in the water samples collected after the rainy season. This means that the Mansagar lake water might have higher toxicity after rainy season because of the presence of higher level of heavy metals (Zn and Pb). Thus the level of BOD and COD level increases and toxicity of the lake increases which indicates the level of toxicity of the water. Additionally, the higher level of metals in the lake

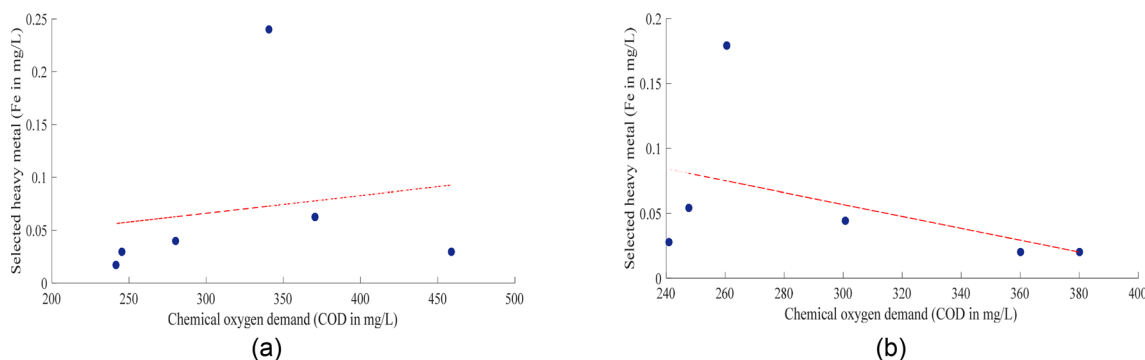


Fig. 4 Correlation analytical representation for chemical oxygen demand (COD) v/s selected heavy metal (Fe) for samples collected a) after the rainy season and b) before the rainy season

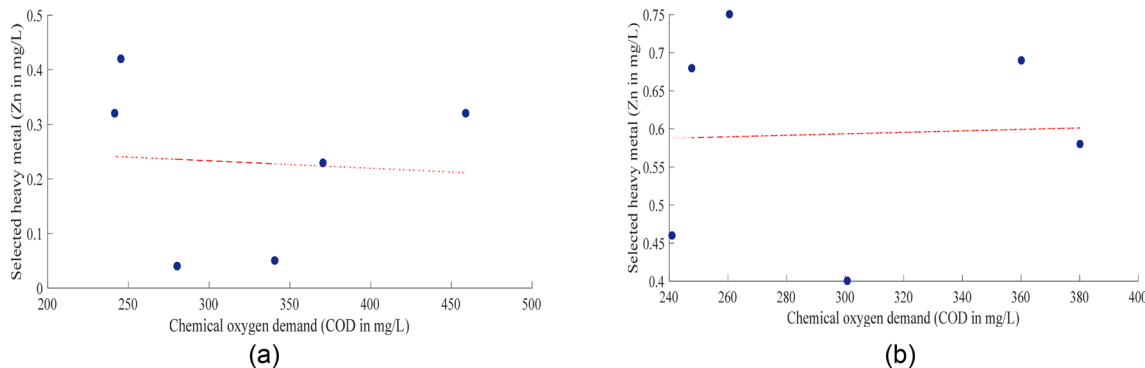


Fig. 5 Correlation analytical representation for chemical oxygen demand (COD) v/s selected heavy metal (Zn) for samples collected a) after the rainy season and b) before the rainy season

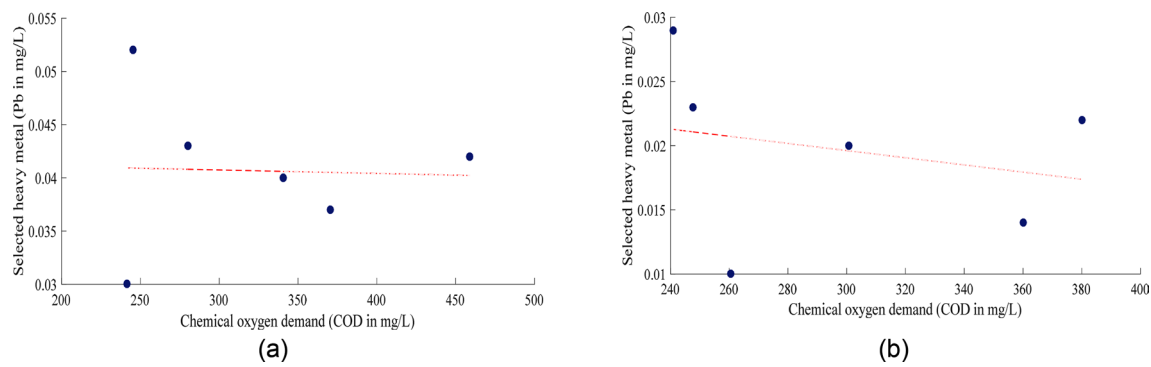


Fig. 6 Correlation analytical representation for chemical oxygen demand (COD) v/s selected heavy metal (Pb) for samples collected **a** after the rainy season and **b** before the rainy season

water after rainy season may be ascribed to the relatively higher amount of wet deposition, resulting from different environmental conditions. To best of our knowledge, the first time a detailed study for the event mean concentration (EMC) of selected metal pollutants (Fe, Zn and Pb) were strongly correlated to rainfall conditions with the Mansagar lake water quality. Although the effect of rainfall conditions on lake water quality can be different from site to site, even then these site-specific relationships can be proved as essential data for lake water management facility monitoring and design. Although the effect of rainfall conditions on lake water quality can be different from site to site, even then these site-specific relationships can be proved as essential data for lake water management facility monitoring and design. We extended our observations to check the environmental effects (temperature and season-based variations) on various physicochemical parameters.

Trends as depicted by Figs. 7 and 8, reveal possible impacts on important physicochemical parameters such as turbidity, BOD, COD and conductivity. It was observed that pollutants presence increases in peak summer and late winters due to discharge of domestic wastes, more acts of domestic cattle and runoff from the agricultural fields and

wasteland. Also as per these trends, it is clear that during or after the winter season, important Physicochemical parameters attains higher values, which may be due to reduced water levels of the lake and increased visitors' movements. It's observed that turbidity and conductivity were normally high in June-July because the rate of vaporisation is higher during these months, thereby increased pollution concentration in the remaining water levels. It is a well-established fact, that the surface water of the lake absorbs more heat from the environment than the water at the bottom and thereby majority responsible for the warming of the lake. With this study, we also observed that turbid water warm more slowly than clear water due to low light penetration. Thermal stratification in the studied lake can be established in early summer and after the winter season. In excessively turbid waters the rapid shutting out of effective light may limit chlorophyll-bearing plants to a very thin surface stratum. We also observed that the conductivity remains high during peak summer due to the presence of much concentrated dissolved solids in its water, while it reduces slightly after the rainy season due to possible dilution TSS possibly by excess water entry during the rainy season. For the excess water caused by the rains runoff from the paved road and

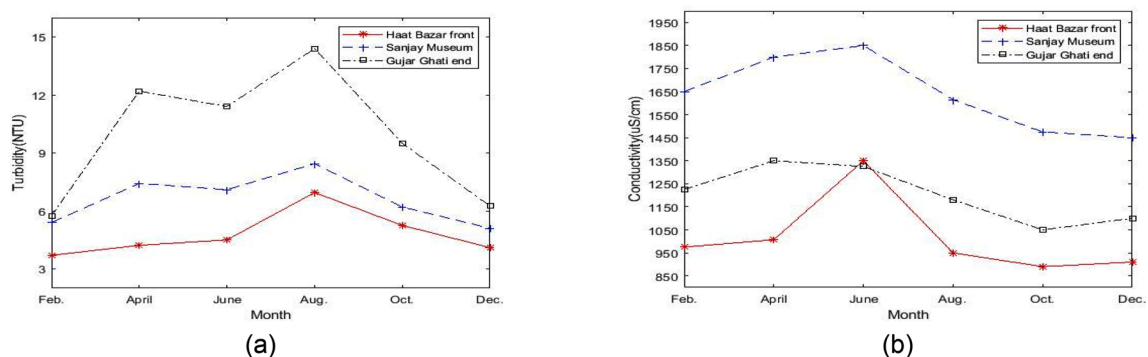


Fig. 7 Correlation analytical representation for variation in the environmental conditions **a** variations in the turbidity (NTU), **b** variations in the conductivity (µS/cm)

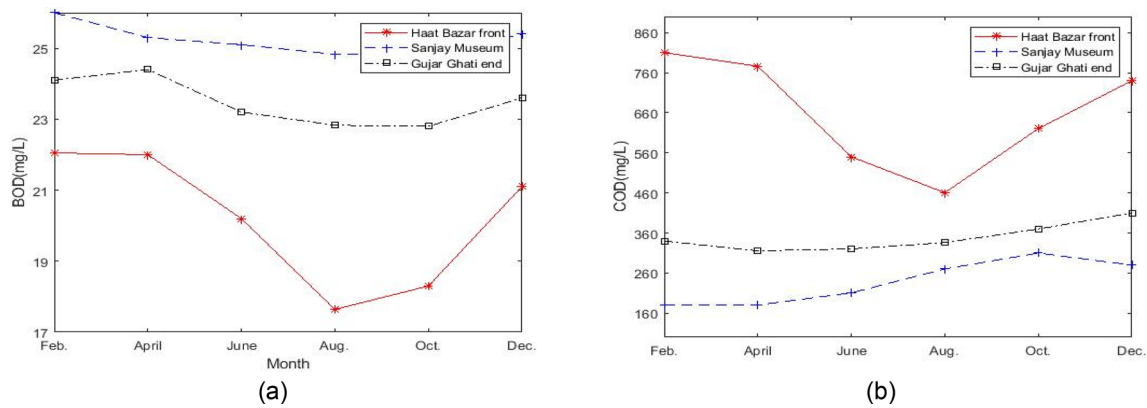


Fig. 8 Correlation analytical representation for variation in the environmental conditions **a** variations in the BOD (mg/l), **b** variations in the COD (mg/l)

nearby areas, in particular, mixing of high levels of heavy metals with the Mansagar lake water poses a potential risk to aquatic microorganisms due to their toxicity (Kayhanian et al. 2008; Singh and Jain 2017, 2018). Although the effect of rainfall conditions on lake water quality can be different from site to site, even then these site-specific relationships can be proved as essential data for lake water management facility monitoring and design. Also impact of rainfall conditions on the lake water quality may vary from site to site, even then these site-specific relationships can be utilized as essential data for lake water management monitoring and design of necessary control units.

Conclusion

With this work, we have presented an experimental work done by us for a 2-year duration and outlined the important findings of the studied lake (the Mansagar lake) to establish its water quality, that should be considered as the ultimate goal for its use and the ecological applications. We observed that due to the increase in metal content the COD increased as high as 500 mg/l in rainy while it is as low as 200 before the rainy season. It has been also observed that pollutants presence increases in peak summer and late winters. It's noticeable that turbidity and conductivity were normally high in June–July thereby increased pollution concentration in the remaining water levels. We have outlined the measured pollutants in the Mansagar lake water and tried our best to establish water quality objectives, that should be considered as the ultimate goal or targeted values indicating a negligible risk of adverse effects on the use of its water and the ecological functions of it. The regular revision in the water quality objectives and compliance techniques should be followed to implement new scientific knowledge for water quality, changes in water use in the catchment area, and to

achieve pollution control from point and non-point sources. No matter what government promises or proposes to do, local people have to invariably involve themselves and be the watchdog to protect Mansagar lake. In recent times, the lake water pollution due to agriculture activities and the resulting risks have made the design of optimal water monitoring networks as one of the important topics of research around the world. Quality monitoring requires the measurement of various parameters in the lakes and requires spending much time and cost, therefore, the design of an optimal network that, can adequately determine the quality of lake systems with minimum cost, would be of great importance.

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