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Water Quality Assessment Using Water Quality Index and Principal Component Analysis: A Case Study of Historically Important Lakes of Guwahati City, North-East India

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Abstract This study evaluates the water quality of ten ancient lakes of Guwahati city, located in North east India, using water quality index (WQI) and multivariate statistical methods.The surface water samples were subjected to comprehensive physico-chemical analysis involving important physical parameters (pH, EC, TDS, alkalinity, total hardness, DO, BOD, COD, turbidity); major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), and major anions (HCO_3^-, Cl^-, SO_4^{2-}, NO_3^-, F^-, PO_4^{3}). Principal component analysis (PCA) has been used to assess the factors which influence the quality of water. The results revealed that water quality variations are mostly affected by dissolved mineral salts along with anthropogenic activities in the areas contiguous to the lakes. The present study points out that pH, DO and BOD played a central role in affecting the WQI of these lakes. The WQI values range from 74.78 to 178.55, indicating that majority of the lakes fall in "very poor" and "unsuitable" category. It also reveals an alarming fact that none of the water tanks fall under good category. Hence, the water is not fit for drinking, and is also becoming toxic for the aquatic fauna. The analysis of hydro chemical facies of the pond water shows that most of the water samples belong to Ca-Mg-HCO_3 type of water. These findings will be useful for decisions making regarding water quality management and can also be applied in water modelling for better environmental management and planning perspective.

Keywords: *Surface Water quality, Water Quality Index, PCA, Hydro chemical facies, Guwahati city*

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1. Introduction

Lakes are an integral part of our environment and are very significant as they are important from the ecological and economical point of view, beneficial for the society, and are very helpful in the management of flood hazards mainly in the city areas. They can be useful in maintaining the ecological balance of the environment as they can sustain a variety of flora and fauna. They also enhance the scenic beauty and can be utilized as tourist attraction places. These lakes assume a considerable role in keeping up the hydrological, biological and natural adjust of the area [1]. They are also a reflection of their watershed since the watershed landscape viz the topography, soil, geology and vegetation determine the kinds of materials entering them which in turn reflects their water quality [2]. Lakes are known to be ecological barometers of the health of a city as they regulate the micro-climate of any urban center [3], thereby influencing the life of the people in their vicinity. They are thus an important part of our urban ecosystem, as they perform several environmental, social and economic functions, viz. as a source of drinking water, recharging groundwater, acting as sponges to control flooding, supporting biodiversity and providing livelihoods [4]. Developmental pressures and increasing human population have made these water bodies vulnerable to sewage inflow, solid waste dumping, etc., in turn exerting pressure on the percolation and infiltration processes responsible for the groundwater recharge [5]. In recent decades, population growth, agricultural practices and sewage runoff from urban areas have increased nutrient inputs many times higher than the level of their natural occurrence, resulting in accelerated eutrophication [6,7]. Many urban and rural lakes have vanished under this pressure, raising worldwide environmental concerns [8,9]. Understanding urbanization and its impact on water quality is important to sustain water bodies as community resources, particularly in the case of developing countries [10,11]. Land-use changes often affect the water quality over a long historical period [12], and future land-use changes will exacerbate the water quality problems [13].

Guwahati is a large city and is considered as the gateway to Northeastern states of India. The increased load of immigrants in search of employment or better education and other purposes from the other places to Guwahati leads to huge population growth in the city. Increase in population has been causing scarcity of water in the cities of India, and Guwahati is facing the same since a couple of decades. This issue can be solved to a large extent by proper management of the lakes in the urban areas. The city of Guwahati, in spite of being located on the bank of the mighty Brahmaputra, has been facing the problem of scarcity of water, especially during the lean season [14]. The aquifers are not uniformly developed in Guwahati and often during dry season the handpumps and deep tube wells go dry leading to acute scarcity of groundwater [15]. Although, there were no well-planned public water supply systems in Guwahati in the historic past, a few big lakes :Digholipukhuri, Zorpukhuri, Nakkotapukhuri existed in Guwahati along with a few others in other parts of Assam, which reflected the aspiration of Ahom rulers for ensuring the availability of drinking water for the then resident community of the area [16]. But it is observed that the water quality of these lakes are being degraded by anthropogenic activities, which are very harmful to the environment and to the human society as a whole. Due to the domestic, industrial and municipal wastes discharge the physicochemical characteristics of the lake water has been greatly affected. While, the water scarcity in the city can be mitigated to some extent by these lakes, it has to be ensured that the water should be less polluted and should be free from contamination.

Various assessment tools have been utilized to quantify the water chemistry and status of water quality. Water quality index (WQI) is one such very effective tool to obtain a comprehensive picture of the water quality. It is a mathematical instrument used to transform large quantities of water characterization data into a single number that expresses overall water quality at a certain location and time [17,18,19]. WQI has done an imperative work in management of water resources [20,21]. It has been used by numerous researchers all over the world to get an insight into the overall water quality of the ground water and surface water [22,23,24,25,26].

Multivariate statistical approaches are the most apposite and extensively used methods for processing and examining the data obtained over time. Statistical approaches like PCA are used for classifying the sampling sites and identifying the underlying pollution source [27,28,29,30]. In water quality assessment it helps to identify the potential water contamination sources [31,32,33,34,35,36]. It also help to explain the correlation among large number of variants and also to reduce the number of variables into small number of factors without the loss of essential information [37]. WQI and statistical methods are very useful and efficient for assessing the quality of water and for communicating the information on overall quality of water [38,39,40,41]. So far only a few studies on WQI from the northeast India, have been reported [42,43,44,45]. No studies on the WQI of these lakes have been reported so far.

Lakes have been studied in different parts of the world as well as in different parts of India. However, no adequate studies have been conducted in this part of the country which is today becoming a major economic hub for the entire Northeast. This study mainly aims to analyze the 17 water quality parameters of ten historically important lakes in the heart of Guwahati city and to assess the Water Quality Index (WQI) of these lakes. Moreover, of the ten lakes under study, six are considered as sacred lakes which are located in the premises of temples and attract large number of pilgrims and tourists from different areas. Hence the water here is considered sacred and also consumed as a part of religious rituals. This study will help to understand the water quality situation and determine the main factors which contribute to the water quality degradation in these urban lakes. It will also help the concerned citizens and policy makers in formulating policies and taking necessary action towards proper management and conservation of these lakes.

2. Study Area

Guwahati is one of the largest and fastest growing cities in North east India. It covers an area about 328 km^2 at an altitude of 55.5 m from mean sea level (MSL). It is located at a latitude of 26°10’45’’N and longitude of 91°45’0’’E. The city is surrounded by eighteen hills. It is situated on an undulating plain with varying altitude of 49.5-55.5 m above mean sea level. Situated on the southern bank of the river Brahmaputra, the southern and the eastern sides of the city are bounded by rows of hills which are extensions of the Khasi Hills of Meghalaya [46]. Geologically, Guwahati rests upon the typical precambrian rock units which are overlain by young and recent alluvium. The river Bharalu dissects the main city for a length of about 9 kms [47].

The city experiences humid subtropical climate, characterized by the peak summer temperature rising up to 38°C, while in winter, it falls to as low as 10°C. The average annual rainfall here is 1746.5mm of which 90 % occurs between April to September, the most rainy months being May, June, July and August.

This study is conducted in 10 historical lakes of the city, namely Dighalipukhuri, Jorpukhuri (East), Jorpukhuri (West), Silpukhuri, Nakkata Pukhuri, Padum Pukhuri, Saubhagyakunda, Amritkund, Rinmusonkund and Kaso Pukhuri. In local language ‘Pukhuri’ means ‘Lakes’. The lakes have been categorized as recreational lakes, storage tanks and temple lakes. The map of the study area is given in Figure 1.

2.1. Brief Description of the Lakes with Their Historical Significance

Dighalipukhuri (SS-1) is one of the most ancient lakes of Guwahati, situated at the heart of the city.It was built by Bhagadatta (son of Narakasura), the king of Pragjyotishpura during 7th Century AD . The lake was connected to the Brahmaputra in the north and to Solabeel wetland in the south. In historical times, it was built and used by the Ahoms as a naval dock yard. Its access channel to the Brahmaputra was eventually cut off, and during colonial times, the channel was further earth filled on which the Circuit House and Gauhati High Court were subsequently constructed.

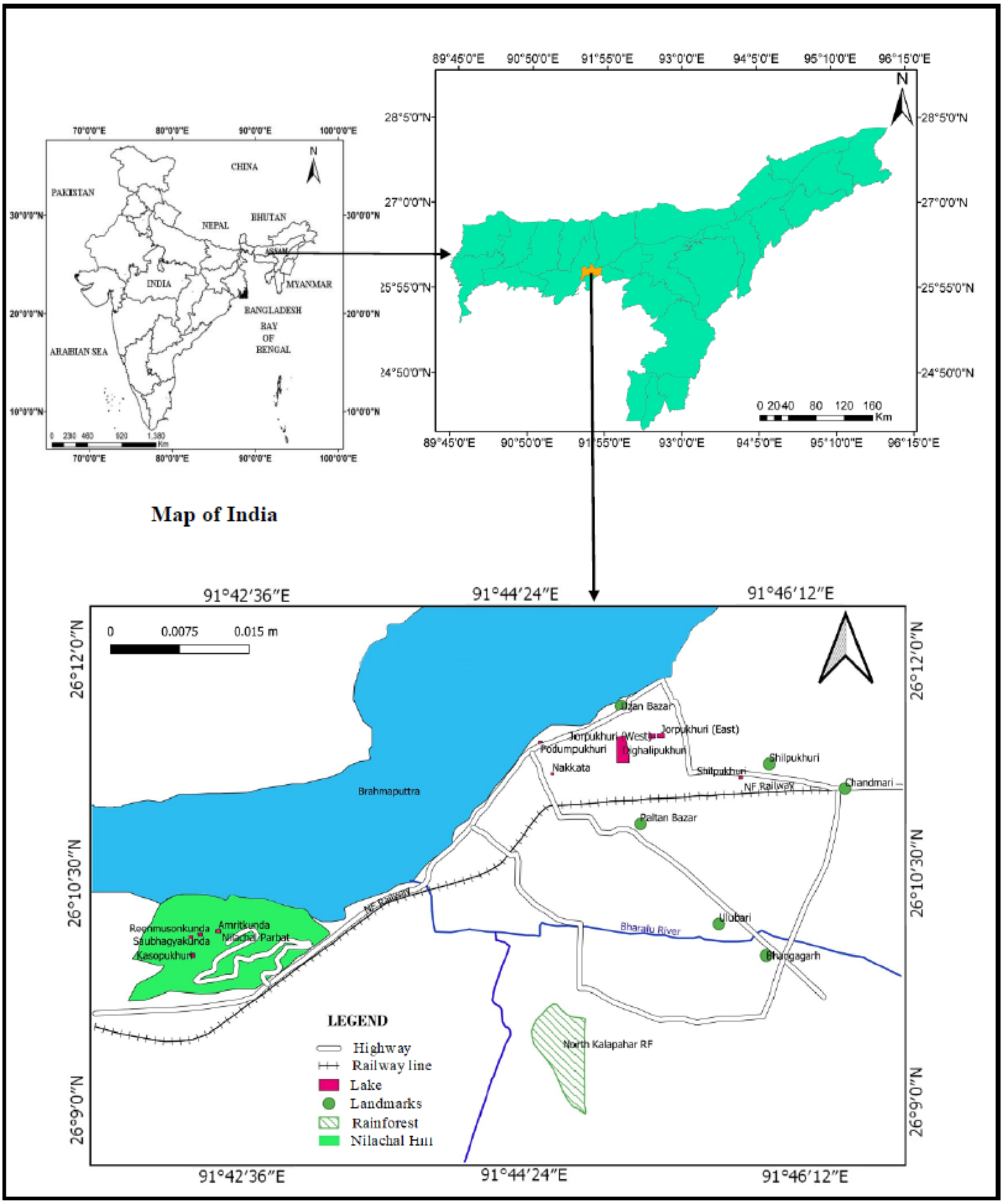

Figure 1. Location map of the study area showing the Lakes

Jorpukhuri (East and West, S2 and S3 respectively) located at Uzan bazaar area was originally only one lake named as “UgrataraPukhuri”, as it was adjacent to the Ugratara Temple, built by Ahom king “Swargadeo Siva Singha” in Saka 1657 (1725 AD). From the stone inscription in the temple it is known that the pond was dug under the order of queen Phuleswari in Saka 1660. The pond was connected with the Brahmaputra and in ancient time king Rudra Singha used to visit the temple through this channel. But later, during British rule this lake was divided into two by construction of a road of about 5 m width running in between.

The Silpukhuri (S-4) was earlier known as Nau-Kunia-Pukhuri (Nau means nine) due to its nonagonal shape. According to a stone script, the pond was dug during the reign of King Rajeshwar Singha by Tarun Duwara Phukan in 1753. The Nabagraha Temple is located at the top of an adjacent hill and is visible from this lake. Legends mentioned that the water of the lake was used to bathe the nine grahas (nine planets of Indian mythology) in the Nabagraha Temple. Hence the lake is also known as *Nabagraha Pushkarani*. However, today this lake is surrounded by a very busy market place with dense habitat all around. Nakkata Pukhuri(S-5) and Podum Pukhuri

(S-6) are two lakes in the Pan Bazar area of Guwahati, which were constructed for water storage. Today, these lakes are surrounded by residential building, business houses, restaurant, and offices.

Saubhagyakunda Pukhuri (Suabhagya meaning “Good luck”) (S-7) is located very near to the famous Kamkhya temple. Legends have it that the lake was dug out by Narakasur for Goddess Ma Kamakhya. There is also a belief that the pond was dug by Indradev-the Hindu king of Gods. As the name suggest, the lake it is considered as a lake of good luck by the pilgrims, which is why it is a custom to bath or wash one’s hands and feet at the lake for good luck or emancipation from sin. Amritkunda Pukhuri (S-8) is another such pond situated at the Kamakhya hill top, very close to Saubhagyakunda (S-7). Rinmusonkunda(S-9) is another lake near the Kamakhya temple at the Nilachal hill. One important lake under this study is the Kasopukhuri (S-10) which is located on the hill top of Nilachal Hill. As per historic records this tank was made during the reign of king Bhagadatta. As the name suggest, the pond is a habitat of tortoise (in local language Kaso refers to tortoise) which are here for hundreds of years. The pond is surrounded by stones and a concrete wall has been newly built in its surrounding. The rainwater from the hill side enters the pond and if it overflows then the excess water goes down the hill. The pond is mainly used for rituals, as the devotees make offerings here to Goddess Bhairabi, which they throw to the pond for the tortoise to feed on.

3. Methodology

3.1. Analysis of Water Quality Parameters

Water samples were collected from the 10 lakes of Guwahati city, during the months of March to May in the year 2019. The coordinates of each study area pond were measured by using ETREX, Garmin Series GPS device and recorded. The dimension of the ten lakes were measured by using measuring tape and recorded. The coordinates, type, length, breadth and area are given in Table 1. The water samples were kept in 1 litre polyethylene plastic bottles that were prior cleaned with metal-free soap, rinsed repeatedly with distilled water, then soaked in 10% nitric acid for 24 hrs and finally rinsed with ultrapure water. Samples were determined for a wide range of water quality parameters appropriate for determination of water quality index (WQI), following the standard methods specified in APHA [48]. The 17 parameters for water quality assessment were; pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), total hardness (TH), dissolved oxygen (DO), 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), chloride (Cl^{-}), fluoride (F^{-}), nitrate (NO_3^{-})and sulphate (SO_4^{2-}). Electrical conductivity, pH, turbidity and total dissolved solids were analysed with the help of Systronics Water Analyser 371. Titration methods were used for the determination of- DO (Azide modified Winkler Method), BOD (5 day BOD test), COD (Closed Reflux method), HCO_3^{-} and total hardness. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, $SO_4^{2-}Cl^{-}$ and F^{-} were determined in Ion Chromatography, while spectrophotometry was employed for NO_3^{-} and SO_4^{2-} (Systronics PC Based Double Beam Spectrophotometer 2206). All statistical analyses were performed using the SPSS statistical software (Version 25).

3.2. WQI Calculation

The calculation of WQI was carried out by following the ‘Weighted Arithmetic Index Method’ [49] using the equation:

$$WQI = \sum QnWn / \sum Wn$$

where,
Qn is the quality rating of nth water quality parameter,
Wn is the unit weight of nth water quality parameter.

The quality rating (Qn) is calculated using the equation

$$Qn = 100\left[\left(V_n - V_i\right)/\left(V_s - V_i\right)\right]$$

where
Vn is the actual amount of nth parameter present,
Vi is the ideal value of the parameter [Vi = 0, except for pH (Vi = 7) and DO (Vi = 14.6 mg/l)],
Vs is the standard permissible value for the nth water quality parameter.

The Unit weight (Wn) is calculated using the formula

$$Wn = k / Vs$$

where
k is the constant of proportionality and it is calculated using the equation

$$k = \left[1/\sum 1/Vs = 1, 2, \ldots n\right].$$

The water quality status (WQS) according to WQI is shown in Table 2.

Table 1. Description of the lakes

Lakes	Code no	Latitude	Longitude	Type	Area (m2)
Dighalipukhuri	S-1	26°11’19.0”N	91°45’02.0”E	Recreational	43785.56
Jorpukhuri (East)	S-2	26°11’16.0”N	91°45’10.0”E	Temple pond	6347.25
Jorpukhuri (West)	S-3	26°11’16.0”N	91°45’10.0”E	Temple pond	6262
Silpukhuri	S-4	26°11’18.0”N	91°45’36.0”E	Recreational	ND
Nakkata Pukhuri	S-5	26°11’09.0”N	91°44’38.0”E	Water storage	2610
Podum Pukhuri	S-6	26°11’19.0”N	91°44’39.0”E	Water storage	1400
Saubhagyakunda Pukhuri	S-7	26°10’00.5”N	91°42’20.8”E	Temple pond	756
Amritkunda Pukhuri	S-8	26°10’01.7”N	91°42’21.4”E	Temple pond	546
Rinmusonkunda Pukhuri	S-9	26°10’01.2”N	91°42’13.3”E	Temple pond	135.8
Kaso Pukhuri	S-10	26°09’56.2”N	91°42’13.1”E	Temple pond	1517

Table 2. The water quality status

WQI	Water Quality Status	Possible usage
0-25	Excellent	Drinking, Irrigation, Industry
26-50	Good	Drinking, Irrigation, Industry
51-75	Poor	Irrigation and Industry
76-100	Very Poor	Irrigation
Above 100	Unsuitable for drinking and fish culture	Proper treatment required before use

4. Results and Discussions

4.1. Physico chemical Parameters

The analysis of result of physical and chemical parameters of water provides a considerable insight of water quality of the lakes in the city. The obtained physicochemical parameters were compared with the Bureau of Indian Standard. The descriptive statistics showing minimum, maximum, mean and standard deviation are given in Table 3.

The pH in the lakes varies between 6.52 to 8.65 with a mean value of 7.54. pH of 6.52 is seen in S-2 and the maximum of 8.65 is found in S-8. The variation of pH might be due to the presence of dissolved gases like carbon dioxide, hydrogen sulphide, ammonia etc.pH range between 6.0 and 8.5 indicates productive nature of water body, which agrees with our findings, as we can see that some form of aquatic life exist in all the lakes.

Electrical Conductivity (EC) is a measure of the presence of inorganic dissolved solids such as chloride, nitrate, sulphate, phosphate, sodium, magnesium, calcium etc. EC in the lakes ranges from 158.1 µS/cm to 596.6 µS/cm, with a mean of 136.12 µS/cm. The standard BIS limit is 300 µS/cm. The maximum value is found in S-10 and minimum in S-6. High EC recorded in some lakes can be attributed to the high degree of anthropogenic activities such as waste disposal and runoff from the nearby areas [50]. The lake is mainly used for religious rituals, as the devotees throw offerings to Goddess Bhairabi, into it on which the tortoise feed. The EC is considered as a direct function of the TDS present and is used to represent the overall concentration of soluble salts in water [51,52]. Total dissolved solids (TDS) mainly comprises of inorganic salts (sodium, calcium, magnesium, potassium, bicarbonates, chlorides and sulphates) and some amounts of organic matter which are dissolved in water. The TDS value in our sampling sites ranges from 157 mg/L to 598 mg/L, with a mean value of 374.5 mg/L. The lowest TDS value found in S-6, where as highest value reported from S-10. The maximum permissible limit of TDS in surface water as per BIS is 500 mg/L. Only one pond S-10 was found above the permissible limit. Total hardness of the water is the property attributed to the presence of alkaline earth metals. It is the property of water by which it prevents the lather formation with soap and increases the boiling point of water. Water can be classified into soft (75 mg/L), moderately hard (75-150 mg/L), hard (150-300 mg/L) and very hard (300 mg/L) based on hardness [53]. Total Hardness was found in the range between 86 mg/L to 226 mg/L, with a mean of 152 mg/L. The minimum was observed in S-1 and the maximum in S-2. These values are well within the limits of BIS standards which is 300 mg/L. 50% of the lakes (S1, S4, S6, S8 and S9) has moderately hard water, whereas the other 50% (S2, S3, S5, S7 and S10) are hard water.

DO is the most important indicator of the health of water bodies and its capacity to support a balanced aquatic ecosystem of flora and fauna. The amount of oxygen dissolved in a reservoir is affected by temperature of water, salinity, altitude, water inflow and photosynthetic activity of algae and plants [54,55]. WHO guideline values for DO in aquatic water body is 4-6 mg/L. A concentration below 5 mg/L disturbs the equilibrium in a freshwater ecosystem which affects biological communities. The DO concentration in the study area varies between 2.66 mg/L to 5.85 mg/L with a mean of 4.82 mg/L. Maximum DO is found in S-4 (DO 5.85 mg/L) and minimum in S-6 (DO 2.66). At this minimum value of DO; it will be very tough to sustain aquatic organisms and fish. DO is very important parameter as maximum physicochemical and biological processes are involved in its variation [56]. The low DO may be due to the presence of dissolve and suspended solids. Moreover, it is observed that this pond is covered with water hyacinth which prevent direct entry of sunlight and obstructs photosynthesis inside the water body. DO level in lakes vary according to the lake trophic levels, and depletion of DO in water probably is the most immediate result of water pollution [57]. BOD and COD are important parameters that indicate contamination with organic wastes [58]. In our sampling points BOD varies between 1.25 mg/L to 4.08 mg/L, with a mean of 3.42. The minimum was observed in S-6, and the maximum in S10. The BOD was found to be low in our study area. High COD is always acssociated with increased anthropogenic activity in the water bodies [59,60]. COD in the lakes varies between 64 mg/L to 224 mg/L, with a mean of 134.4 mg/L. The minimum was observed in S-9, and the maximum in S-10. This high value of COD in these lakes indicates contamination by organic waste due to increased antropogenic activities.

The turbidity in the lakes varies from 2 NTU to 15 NTU, with a mean of 6.9 NTU. The turbidity is found minimum in S-5, and maximum in S-2. Turbidity is a factor of presence of pollutant in water body. Presence of organic matter and the sewage dumps near the S-2 pond may have caused the high value of turbidity. High turbidity may cause problems to the aquatic organisms. Higher turbidity values may be due to increase in water level resulting from increased precipitation, increased soil detachment and increased transportation of detached soil particles. Increased turbidity has a significant effect on aquatic ecosystems, as the most obvious effect is a reduction in the light available for photosynthesis. This reduces the amount of the plant growth and in turn limits the number of aquatic organisms that feed on these plants and finally fish community that rely on aquatic organisms as a food source are affected [61]. Turbidity more than 10 NTU may cause problems in the aquatic ecosystems. In this study 3 lakes (S-2, S-6 and S-10) were found to have turbidity more than 10 NTU.

Table 3. Descriptive statistics of the water quality parameters

Parameters	Minimum	Maximum	Mean	Std. Deviation	BIS Standards
pH	6.52	8.65	7.541	0.76	6.5-8.5
EC (μS/cm)	158.1	596.6	373.6	136.12	300
TDS (mg/L)	157	598	374.5	136.78	500
TH (mg/L)	86	226	152	47.40	200
DO (mg/L)	2.66	5.85	4.822	0.90	5
BOD (mg/L)	1.25	4.08	3.424	0.85	5
COD (mg/L)	64	224	134.4	53.96	5
Turbidity (NTU)	2	15	6.9	4.28	10
Ca^{2+} (mg/L)	25.65	65.73	46.972	12.77	75
Mg^{2+} (mg/L)	1.31	32.96	13.84	10.36	30
Na^{+} (mg/L)	0.807	2.33	1.47	0.564	-
K^{+} (mg/L)	0.075	3.066	1.3	0.875	-
HCO_3^- (mg/L)	120	350	221	74.75	200
NO_3^- (mg/L)	1.93	40.61	12.111	15.45	75
SO_4^{2-} (mg/L)	0	1.96	0.652	0.74	200
Cl^- (mg/L)	0.07	3.02	1.393	1.08	250
F^-(mg/L)	0.007	0.146	0.0243	0.040	1.5

All units in mg/L, EC in (μS/cm), Turbidity in NTU. Here, N=10.

4.2. Major Ion Chemistry

In the lakes of Guwahati, the predominant cation trend was in the order of $Ca^{2+}>Mg^{2+}>Na^{+}>K^{+}$ with Ca^{2+} being the dominant cation. The predominant anion trend was in the order of $HCO_3^->NO_3^->Cl^->SO_4^{2-}>F^-$ with HCO_3^-being the dominant anion. Ca^{2+}concentration in the study area ranges from 25.65 mg/L to 65.73 mg/L, with a mean of 46.97 mg/L. Maximum concentration of 65.73 mg/L was found in S-8 and the minimum concentration was observed in S-10. The Mg^{2+}concentration of the study area ranges from 1.31 mg/L to 31.26 mg/L, with a mean of 13.83 mg/L. The minimum is found in S-7 and the maximum in S-10. Ca^{2+} mostly occurs in all natural water, as its major source is weathering of rocks, from which it leaches out [62]. Na^+ in the lakes varies between 0.807 mg/L to 2.33 mg/l, with a mean of 1.47 mg/L. The minimum is observed in S-8 and the maximum in S-10. K^+ concentartion in the pond varies beween 0.075mg/L to 3.066 mg/L, with a mean of 1.3 mg/L. Minimum is observed in S6 and maximum in S10. [63] reports that higher content of Na^+ and K^+ in freshwaters is due to domestic sewage contamination. In S10 which is s temple pond, there is a regular ritual of feeding the tortoise with the offerings made to the Goddess, this might have resulted in a higher vale of these chemicals in the water body.

HCO_3^- in surface water is primarily a function of carbonate, hydroxide content and also includes the contributions from borates, phosphates, silicates and other bases [42,64]. It could be released from the dissolution of carbonate minerals via biodegradation of organic matter [65]. HCO_3^- in the lakes varies between 120 mg/L to 350 mg/L with a mean of 221 mg/L. The lowest is observed in S-6 and the maximum in S-2. The BIS limit of HCO_3^- in water is 200 mg/L. In our study four lakes (S-2, S-3, S-5 and S-10) exceeds the permissible limit. The high values of HCO_3^- may be due to the liberation of CO_2 during the decomposition of organic matter. Moreover, the core of the city is surrounded by hillocks of varying altitude between 100 to 300 meters [16]. It is observed that the city of Guwahati experiences an average annual rainfall of around 162 cm with about 110 - 115 rainy days per year [14]. Hence the combination of geological factors and climatic condition, might have resulted in soil erosion from the nearby highlands. Cl^- concentration of the lakes varies between 0.066 mg/L to 3.016 mg/L, with a mean of 1.39 mg/L. Lowest concentration is observed in S6 while the highest was detected in S10. The most important source of Cl^- are domestic sewage, waste water discharge, food waste etc. It increases the degree of eutrophication [66], controls the salinity of water and creates osmotic stress on biotic communities [67]. Generally Cl^- is present in several minerals in common rocks and hence slowly release into the water. The F^- concentration ranges from 0.007 mg/L to 0.146 mg/L, with a mean of 0.24 mg/L. The minimum was observed in S8, and maximum in S-9. However, it is too low to show any adverse effect. Geological formations of this zone consist of F^-containing minerals, which could be a major source of F in its groundwater sources [68]. The F^-may also come in contact to water from the weathering of phosphate rocks. NO_3^- in the study area varies between 1.93 mg/L to 40.61 mg/L with a mean value of 12.11 mg/L. The minimum was observed in S-3 and maximum in S-5. The high value of nitrate in S-5 can be attributed to the fact that it is surrounded by residential area on all sides. And the drains at times open to this water body, bringing in domestic sewage and waste water to the water body. SO_4^{3-} concentration in the lakes varies between BDL to 1.957, with a mean of 0.65 mg/L. The minimum was observed in S-1 and S -3, and maximum in S-10. SO_4^{3-} may be contributed by the nearby commercial settlements.

4.3. Hydrochemical Facies

The hydrochemical facies of river water can be obtained through Piper trilinear diagram [69]. This diagram effectively classifies the water quality by the distribution of major cations like Na^+, K^+, Ca^{2+} and Mg^{2+} and some major anions like Cl^-, SO_4^{2-}, CO_3^{2-} and HCO_3^-.

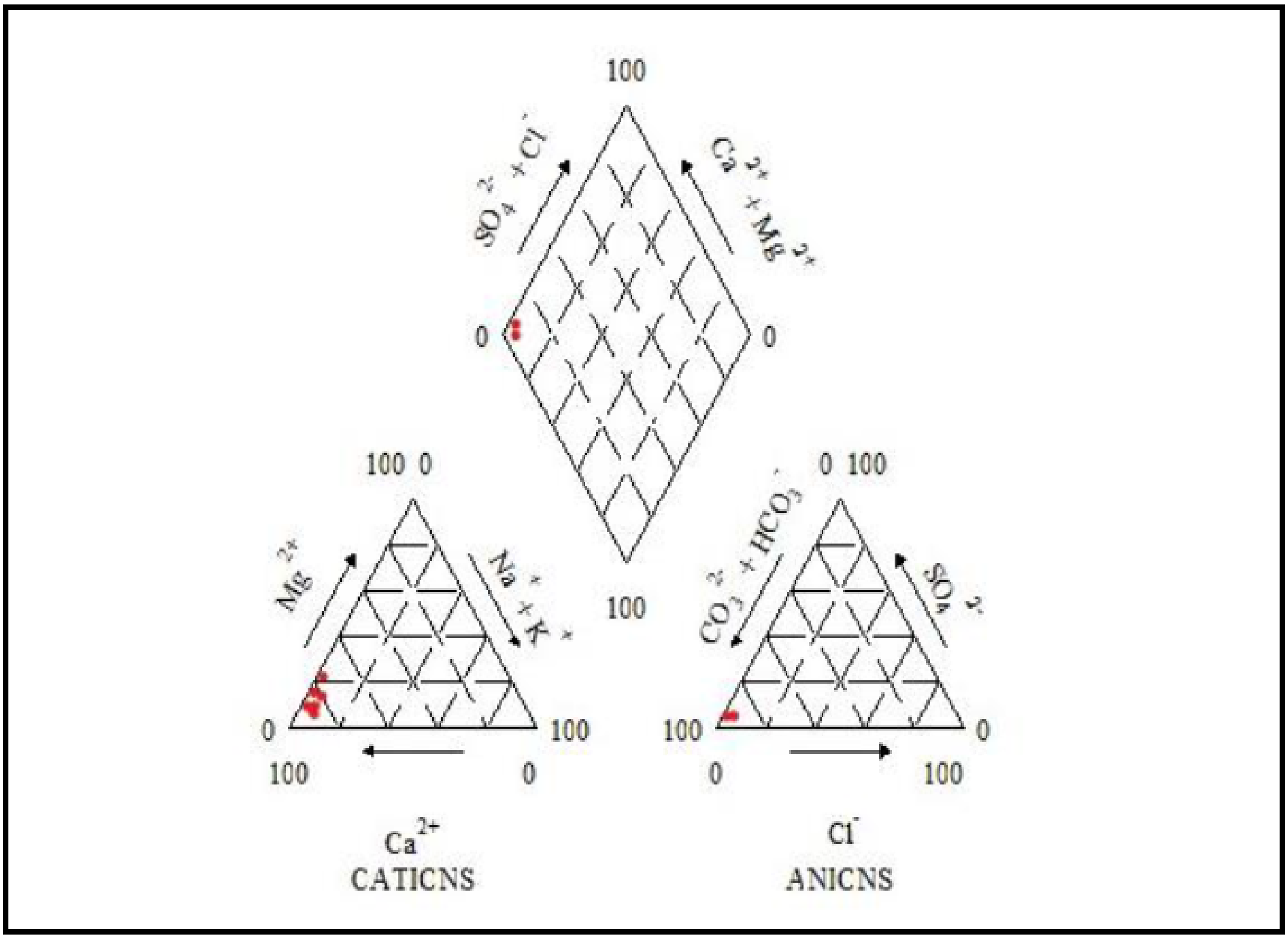

Figure 2. Piper trilinear diagram for major ion analysis of surface water samples

This diagram represents the cations and anions composition of samples on a single graph in which major groupings or trends in the data can be distinguish visually [70]. In the present attempt, piper diagrams of water of all the lakes of Guwahati city is presented in Figure 2. The major ion chemistry results show that calcium is the dominant cation and bicarbonate is the major anion in all the lakes. The plots from the results revealed that in all the water, alkali earth metal elements (Ca^{2+} + Mg^{2+}) are higher than alkali elements (Na^+ + K^+) and weak acids (CO_3^{2-} + HCO_3^-) are higher than strong acids (Cl^- + SO_4^{2-}). It showed that all the pond water samples during the study fall in the field Ca-Mg-HCO^3 type.

4.4. Principal Component Analysis

PCA extracts correlations and reduces the number of data into components that explain a portion of the total variance between chemical parameter. It indicates that the first three principal components together account for 77.45% of the total variance in the data set, in which the first principal component is 38.92%, second principal component is 21.02%, and the third principal component is 17.49% of the total variance. The concentration of EC, TDS, HCO_3^-, Ca^{2+}, $Cl^-$and TH shows high positive loading (0.827-0.971), whereas concentration of BOD, COD and NO_3^- shows moderate loading (0.613-0.678). High positive loading of EC, TDS, HCO_3^-, Ca^{2+}, Cl^- and TH is associated with the combination of hydro chemical processes in the study area. It represents the lake's catchment geology which are linked to the parent rock materials in the catchment area [71,72]. Moreover, it a high rainfall area, where the runoff from the nearby hills also plays a major role. The positive loading of BOD, COD and NO3- indicated inorganic pollution from anthropogenic sources. [73] correlated positive loading on BOD and COD with organic pollution due to waste disposal activities. In the second principal component DO shows high positive loading, with moderate loading of pH. High loading of pH and DO reflects biological activity in the water bodies [74]. For the third principal component, the concentration of SO_4^{2-} and K^+ shows positive loading. The presence of such contaminants is indicative of organic as well as inorganic pollution from anthropogenic sources, such as domestic waste water, untreated municipal sewage discharge, release from industrial effluents and water treatment plants [75]. The surface water quality depends on natural processes such as precipitation inputs, erosion, and weathering of crustal material, as well as on anthropogenic influences (urban, industrial, and agricultural activities) [76]. It has been estimated that in Guwahati, about 70-90% of the total consumption of water is discharged as waste water. Most of the city's waste water is in the form of sanitary sewerage and domestic sewerage together with liquid waste from commercial establishments like hotel/restaurant, hospital/health care units [77].

Table 4. Rotated component matrix obtained from PCA

Parameters	PC 1	PC 2	PC 3
pH	-0.345	0.776	-0.226
EC	0.941	0.131	-0.235
TDS	0.942	0.128	0.232
TH	0.971	-0.016	0.038
DO	0.233	0.898	0.057
BOD	0.613	0.423	0.363
COD	0.678	-0.241	0.262
HCO_3^-	0.984	0.026	-0.134
Cl^-	0.873	0.098	0.36
SO_4^{2-}	0.029	-0.007	0.746
NO_3^-	0.619	0.439	0.458
Ca	0.827	0.159	0.168
Mg^{2+}	-0.026	0.143	-0.822
Na^+	0.305	0.638	0.56
K^+	0.382	0.404	0.81
Turbidity	0.425	-0.944	0.005
Variance (%)	38.92	21.02	17.49
Cumulative % of variance	39.92	59.95	77.45

Extraction method: principal component analysis.
Rotation method: Varimax with Kaiser Normalization.

4.5. Water Quality Index

To determine the WQI initially by using the 'Weighted Arithmetic Index' method the estimation of 'Unit Weight' assigned to each physico-chemical parameter which are considered for the calculation. In this step all the concerned parameters of different units and dimensions are transformed to a common scale [78]. Table 5 shows the drinking water quality standards and the unit weights assigned to each parameter considered for calculating the WQI. The first step in calculation of WQI following 'weighted arithmetic index' method involves the estimation of 'unit weight' assigned to each physico-chemical parameter considered for the calculation. By assigning unit-weights, all the concerned parameters of different units and dimensions are transformed to a common scale. The summary of WQI values of the water samples from all the 10 water bodies are presented in Table 6 given below. Maximum weight i.e 0.4226 is assigned to fluoride, next weight is to DO and BOD with the value 0.12678, thus suggesting the key significance of this parameter in water quality assessment and their considerable impact on the index.The water quality index signifies as scale of water quality. WQI between 0 to 25 means "Excellent" quality of water; 25 to 50 means "Good" quality of water; 51 to 75 means "Poor" quality ofwater; 76 to 100 means "Very poor" quality of water; and >100 means the water is "Unsuitable" for drinking [79]. The computed WQI value ranged between 94 to 178.55, which reflects the poor status of the water quality of the lakes. Out of the 10 lakes taken under this study, it is observed that 5 of them (S-1,S-2, S-3, S-4 and S-10) falls under the unsuitable water category (WQI>100). Four of the lakes (S5-, S-6, S-7 and S-8) falls under the very poor category water (75<WQI<100) and only one S-9 falls under the poor category (51<WQI<75). In this study 2 of them (S-1 and S-4) were used for recreational purpose, 2 of them (S-5 and S-6) were tanks meant for water storage and the rest 6 are temple lakes (S-2, S-3, S-7, S-8, S-9 and S-10). It is observed that the high WQI value in S-1, S-4, S-5, S-6 and S-4 were contributed by various anthropogenic activities like the inflow of direct sewerage from residential and commercial establishments, lack of proper sanitation system and runoff from the nearby road side. However in the temple lakes S-2, S-3, S-7, S-8, S-9 and S-10 the depletion of DO can be related to the human interference in the form of religious rituals performed in the temples.

Table 5. Relative weight of parameters under WQI determination

Parameter	BIS Standard (Vs)	Unit weight (Wn)
pH	6.5-9.2	0.07458
EC	500	0.00211
TDS	500	0.00127
TH	200	0.00317
Turbidity	10	0.06339
DO	5	0.12678
BOD	5	0.12678
COD	10	0.06339
Ca^{2+}	75	0.00845
Mg^{2+}	50	0.02113
K^+	12	0.06339
HCO_3^-	500	0.00317
Cl^-	250	0.00254
SO_4^{2-}	250	0.00317
NO_3^{2-}	45	0.01409
F^-	1.5	0.4226
$\sum W_n=$		1

All parameters are given in mg/L except pH, and EC.

The six out of the ten lakes under the study are situated at the centre of the city and rest four lakes are at the hill top of Nilachal hill, where thousands of pilgrims visit every day. The place is highly commercialised with hotels, restaurantsand other eating joints which caters to the needs of the pilgrims.

Table 6. WQI of the respective lakes

Sl no	Samples Source	Sample Code	WQI	Status
1	Dighalipukhuri	S-1	158.42	Unsuitable
2	Jorpukhuri (East)	S-2	154.09	Unsuitable
3	Jorpukhuri (West)	S-3	114.28	Unsuitable
4	Silpukhuri	S-4	133.45	Unsuitable
5	Nakkatapukhuri	S-5	98.55	Very Poor
6	Podumpukhuri	S-6	88.99	Very Poor
7	SaubhagyakundaPukhuri	S-7	91.74	Very Poor
8	Amritkundapukhuri	S-8	95.51	Very Poor
9	Rinmusonkundapukhuri	S-9	74.78	Poor
10	Kasopukhuri	S-10	178.55	Unsuitable

5. Conclusion

Water quality index technique used to assess the quality of surface water of the lakes reveals that the quality ranges from poor to very poor to unsuitable category. The high WQI values of the water bodies were mainly due to the presence of higher concentration of total dissolved solids, electrical conductivity, COD, HCO_3, turbidity and total hardness and low DO. The low DO creates anoxic condition for the survival of aquatic species, and till date these lakes are considered to be living because of the fauna they sustain. In order to maintain this water bodies, the DO should be improved. Moreover, the high COD value indicated pollution from waste water. According to principal component analysis (PCA) results, the water quality is influenced by mineral components of the catchment area as well as anthropogenic sources. Piper diagram revealed that all the lake water samples are of Ca-Mg-HCO_3 type. Most of the water quality parameters of the selected lakes from the results indicates that the lakes are not in a hygienic condition at all and were found to be lacking in maintenance and management. While Guwahati city faces an acute solid waste management problem, the authorities seem less concerned about the dumps of waste near these lakes. The waste remains open for several days and ultimately finds its way to the nearby lakes with the stormwater runoff. The lakes also get polluted by various factors like domestic sewage, discharge of large volume of effluent, urbanisation, industrialisation, construction works adjacent to the lakes, unplanned drainage system etc.By bringing to light the actual condition of these water bodies, this study would be a meaningful tool in the hands of planners and policy makers for deciding the future course of action for making Guwahati clean and green. A planned management of water quality of these lakes, their reclamation and conservation of their ecosystems will assume a very significant role in sustainable and environment friendly growth of Guwahati city.

Conflict of Interest

Authors declare no conflict of interest

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