3 STUDY AREA AND MATERIALS AND METHODOLOGY

3.1 Study area

Vadodara District is located in the central-eastern part of the state of Gujarat. The city of Vadodara (Baroda), in the central part of the district, is the administrative headquarter. Vadodara District covers an area of 7,546 km^2, with a population of 41.7 Lakh as per 2011 Census. As of 2011, it is the third most populous districts of Gujarat, after Ahmadabad and Surat. Vadodara district lies between 72^o 51' to 73^o 33' E and 21^o 49' to 22^o 49' N. The district is bounded in the west by Anand, in the east by Chotaudaipur and Panchmahal districts, in the north by Kheda district and in the south by Bharuch and Narmada districts. Vadodara city, the district headquarter, is about 100 km south of Ahmedabad and is well connected to other parts of the state and country by network of highways and railway. The historical city of Baroda was the capital of Baroda Residency and one of the princely states of India under the Bombay Presidency. Vadodara, one of the most cosmopolitan cities in India, is Located on the Vishwamitri Riverbank. The district is known as "Sanskar Nagri" (City of Culture) due to its rich cultural traditions. It is famous for its Palaces, Parks, Temples and Museums. It is also famous as a "Gateway to the Golden Corridor", as all the rail and road arteries that link Delhi, Mumbai and Ahmedabad pass through Vadodara including the Delhi-Mumbai Industrial Corridor (DMIC). Focus industries are Chemicals and Petrochemicals, Pharmaceuticals and Biotechnology. The district has 8 tehsils, 15 towns and 1,548 villages, of which the major towns are Vadodara (District Headquarter), Savli, Waghodiya, Padra, Dabhoi, Karjan and Shinor (VMC).

The year in this region may broadly be divided into four seasons:

- Winter season: December to February
- Pre-monsoon season: March to May
- Monsoon season: June to September
- Post-monsoon season: October to November

The summer season comprises of March, April, May, and mid-June months. The mean daily maximum temperature during the season remains between 36.6 to 44.7 °C while the mean daily minimum temperature remains between 16.6 to 26.1 °C. May is the hottest month of the season with the highest maximum temperature ever recorded at 46.7 °C. Temperature remains normal during monsoon and post-monsoon. It ranges mean maximum between 32.6 to 37.2 °C and mean minimum temperature between 24.1 to 27.1 °C. The winter season comprises of December, January, and February months. The season's average maximum temperature ranges from 30.1 to 32.4 °C, while the average low temperature ranges from 10.8 to 12.7 °C. Five year rainfall data is shown in Table 6.

Table 6 Five year rainfall data for Vadodara in mm

Month	2017	2018	2019	2020	2021
January	0.0	0.0	0.0	0.0	0.0
February	0.0	0.0	0.0	0.0	0.0
March	0.0	0.0	0.0	1.0	0.0
April	0.0	0.0	0.0	0.0	0.0
May	0.0	0.0	0.0	0.0	43.4
June	91.4	74.2	88.6	95.4	125.5
July	320.1	283.6	172.6	140.1	150.2
August	118.2	138.4	599.2	467.4	54.1
September	39.7	42.3	210.1	89.7	344.2
October	1.0	0.0	55.1	1.6	38.0
November	0.0	0.0	8.9	0.0	2.1
December	6.5	0.0	2.6	10.2	18.5

Source: District Survey report of Vadodara District

Drainage pattern:

The Narmada and the Mahi are the chief rivers of the district, flowing along the northwestern and southern boundaries respectively while the independent small river system of the Dhadhar with its numerous tributaries flows in the south-central part of the district. Broadly, the entire district, as a River Basin is divided into these three basins, namely the Narmada, the Mahi Basin and the Dhadhar. The Mesari, the Goma and the Karad are the small rivers flowing northwest part of the district, are tributaries of the Mahi River, and are part of the Mahi Basin. The Jambuva, the Surya, the Vishwamitri and the Dhadhar, which flow through the central part of the district and empty into the Gulf of Khambat, are part of the Dhadhar Basin. The eastern and southern part of the district, drained by the Narmada River and its tributaries, like the Unch, the Heran, the Dev, the Orsang, the Karjan, the Aswan and the Bhukhi, constitutes the Narmada basin. Figure 7 shows the study area in Map prepared in Arc GIS and individual study area map are prepared in QGIS.

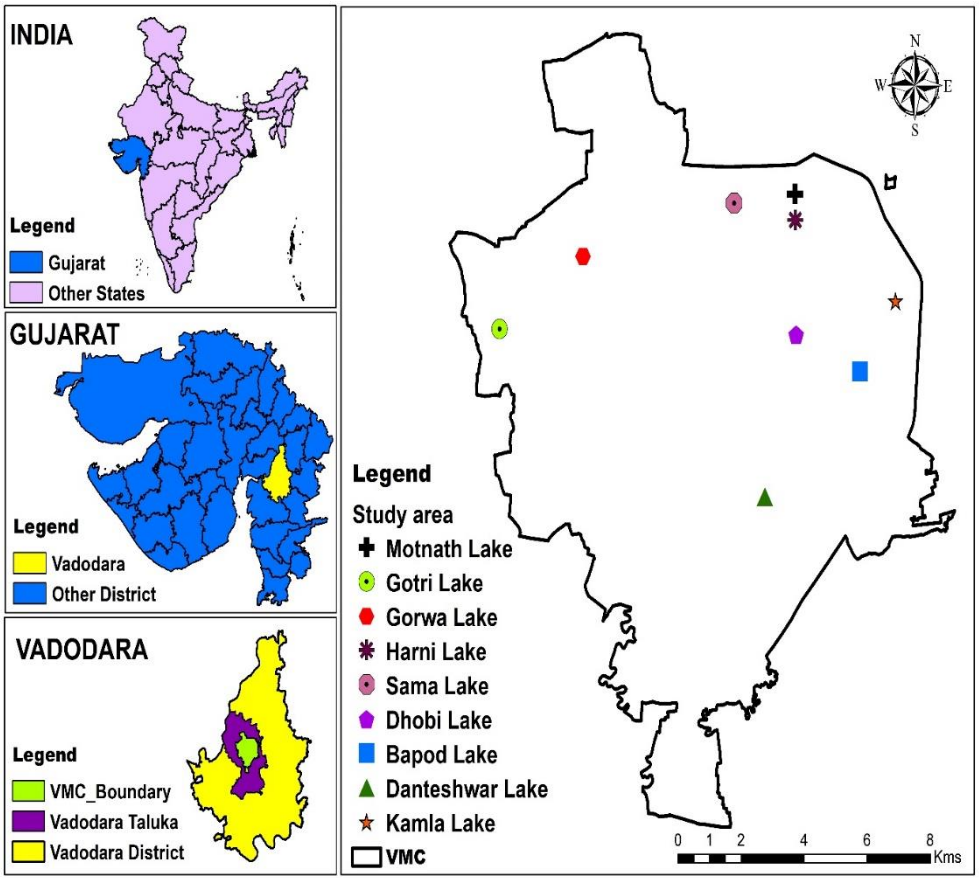

Figure 7 Study area map

The following section describes each lake in terms of its location and surrounding, along with its location map/google earth map.

Sama Lake

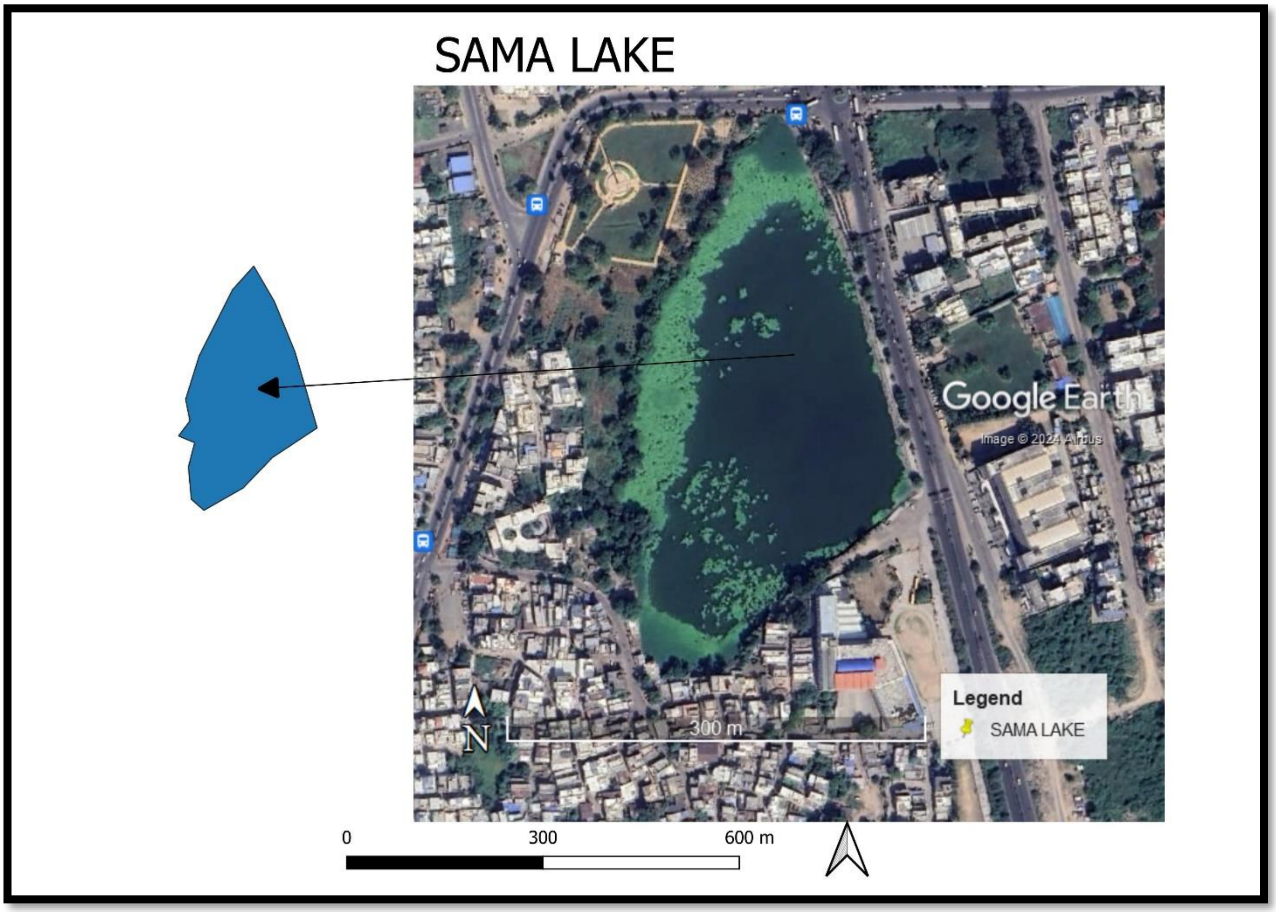

Figure 8 Sama lake boundary

Sama lake is located at 22°20'32.50"N Latitude and 73°12'7.21"E Longitude (Figure 8). The south side of the lake is surrounded by slum houses which extend to the west side of the lake and the backside of Urmi School. The northwest side of the lake is surrounded by the garden adjacent to the lake boundary. Roads and commercial plus residential areas surround the East side of the lake boundary. The primary source of contamination is the dumping of garbage from the surrounding slums and schools. Sewage discharge outlet opens into the lake directly increasing the pollution load of the water body. Secondary source of contamination is the dumping of waste which includes plastics, flowers, photo frames and sculptures by the nearby passers. Idol immersion during festive season was also one of the major activities seen in these 4 years of study which adds to the deterioration of the water body. Eutrophication with cover for Eichhornia was seen 2 times in 4 years for 2 months followed by cleaning of lake conducted by VMSS using lake cleaning machine.

Gotri Lake

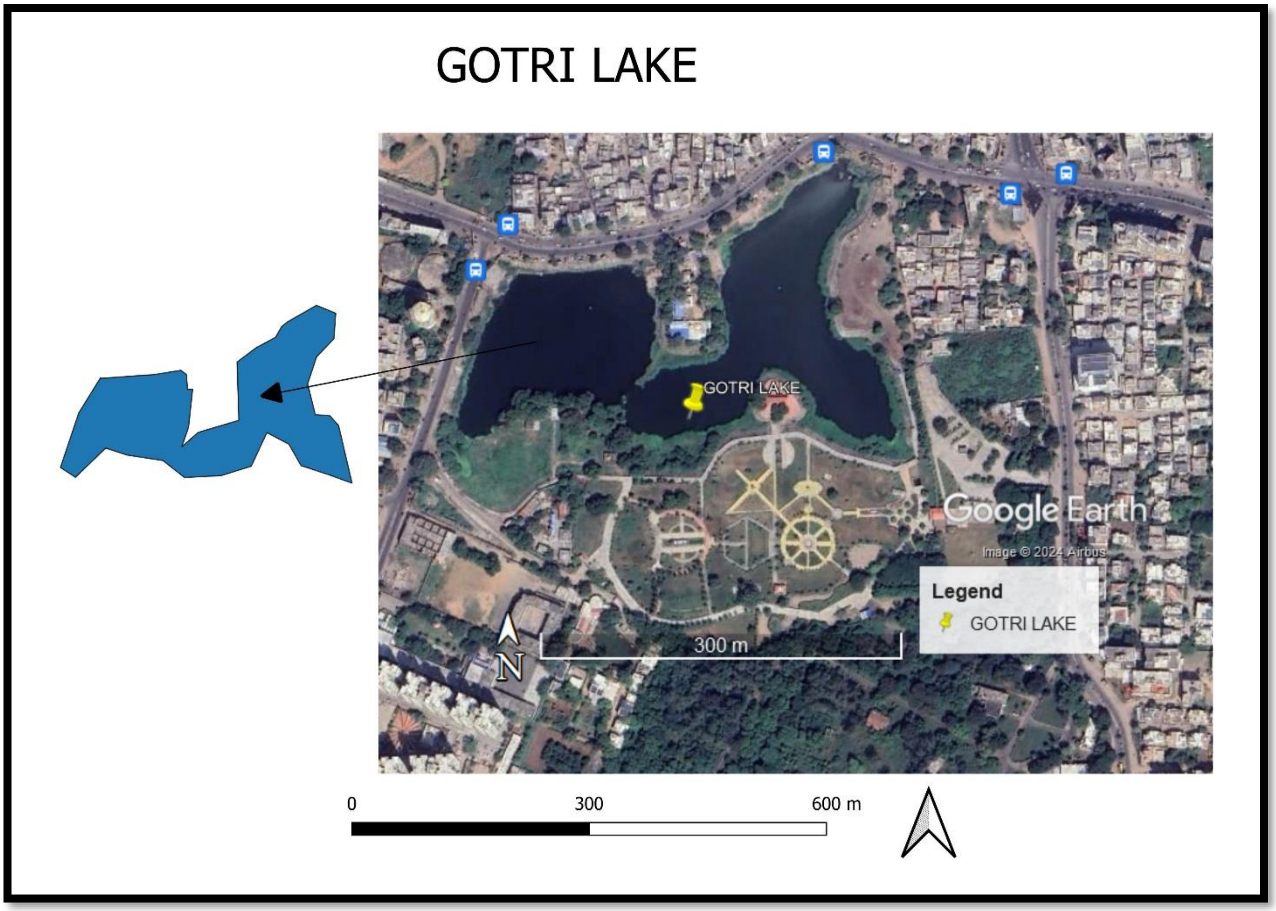

Figure 9 Gotri lake boundary

22°18'50.36"N Latitude and 73° 8'6.99" E Longitude is the location of Gotri lake (Figure 9), with a huge municipal garden situated adjacent to the south side of the boundary. A temple is situated at the north side of the lake at the center dividing the lake into two sections. The north side of the boundary is surrounded by street vendors selling food, vegetables, and flowers. Road connectivity is seen at 3 sides of the lake boundary i.e., north, west, and east of the lake. People living near the lake boundary use lake water for washing clothes, and utensils and bathing on daily basis. Fishing activity was observed in the lake twice in 15 days. Primary source polluting the lake is street vendors surrounding the lake boundary throwing garbage in the lake body and people visiting the temple throwing waste directly into the water body. Idol immersion during festive season is also one of the major activities that can contribute to the deterioration of water body. The materials used to make idols, such as plaster of Paris, clay, and synthetic paints, can release harmful chemicals into the water. Eutrophication, which is the excessive growth of algae and other plants in the water which is observed in water bodies throughout the study period. Eutrophication level decreases when lake cleaning activity is carried out in the water body.

Harni Lake

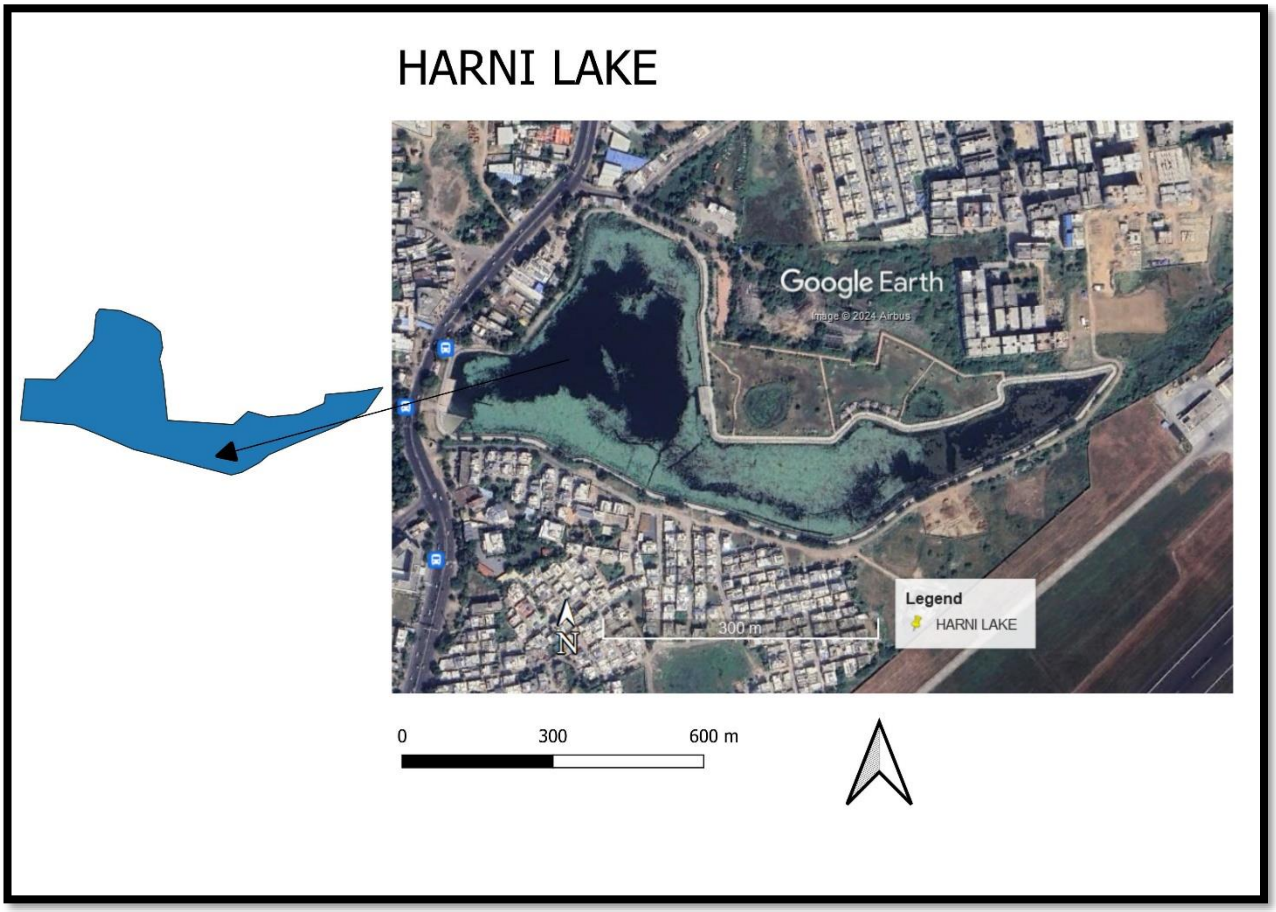

Figure 10 Harni lake boundary

Harni lake (Figure10), located at 22°20'16.62"N Latitude and 73°13'12.55"E Longitude has Sculpture Park, garden and slum houses on the north side of its boundary. Within the walking path of the lake boundary slum houses are located. Residential houses are located on the west side of the lake boundary. The airport runway is located on the east side of the boundary. Road connectivity and street vendors are found on the west side of the boundary. The west side of the boundary is a highly exposed part of the whole lake body as mainly all activities such as washing clothes, utensils, bathing, and dumping of waste by nearby residing people and street vendors are observed. Lotus presence is observed during the study period covering 75% of the lake body with lotus broad leaves adding to the lower transparency and high turbidity of the water body. Idol immersion during festive season is also observed in this water body.

Dhobi Lake

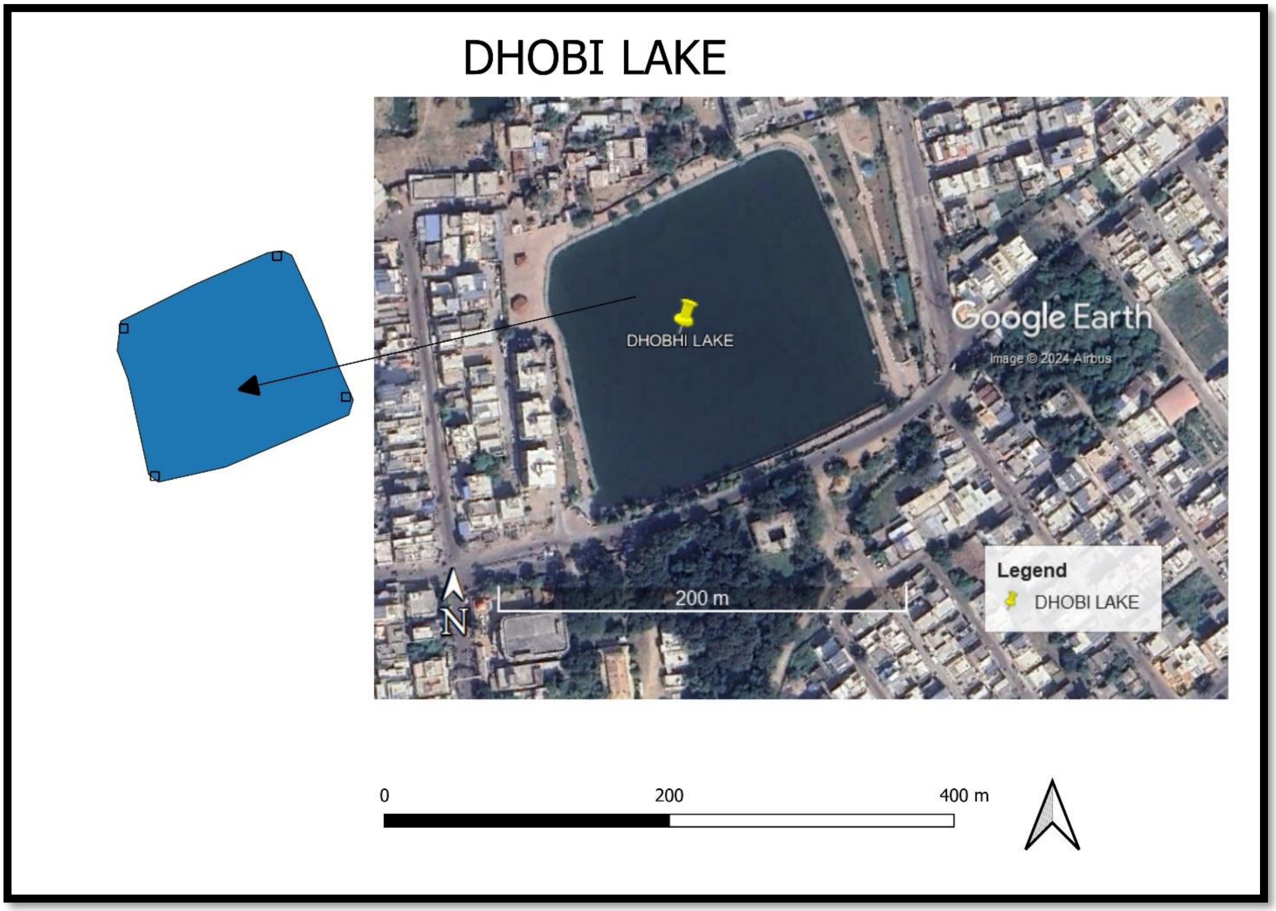

Figure 11 Dhobi lake boundary

All four sides of the Dhobi lake (Figure 11), located at 22°18'45.79''N Latitude and 73°13'9.77''E Longitude, are surrounded by residential area. The walking and seating area is developed around the periphery of the lake boundary. Anthropogenic activities are not observed in this lake but idol immersion during festive season and dumping of waste by nearby passers is observed. The Southwest and Northwest side of the lake boundary is highly exposed because of road connectivity and entry points within the lake. During festive seasons, addition of water to the lake using tankers was observed. Fishing activity was observed in this lake body once a week.

Gorwa Lake

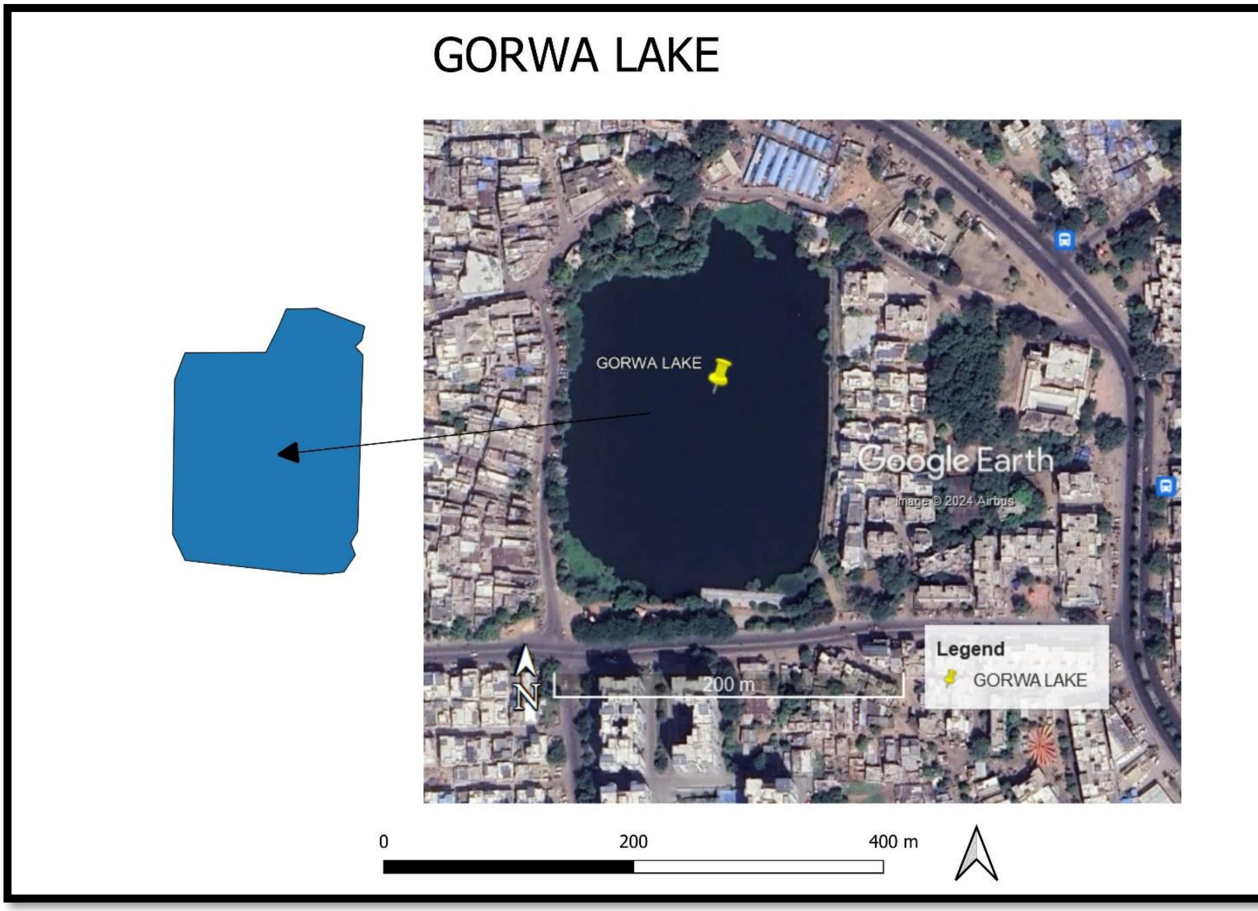

Figure 12 Gorwa lake boundary

Gorwa lake (Figure 12) is located at 22°19'50.04"N Latitude and 73° 9'31.83" E Longitude. The west and south side of the lake boundary has road connectivity. Residential houses surround the east side of the lake boundary. The north side of the lake has small shops and an open area where the dumping of waste is observed. The east side of the lake has an open passage from where there is continuous input of water. South side of the boundary has a walking and seating area at periphery of lake. Nearby passers are seen dumping the waste adding to the pollution load of the water body. Cleaning of the lake was observed twice during 4 years of study. Idol immersion during festive seasons was observed in 2018-19.

Danteshwar Lake

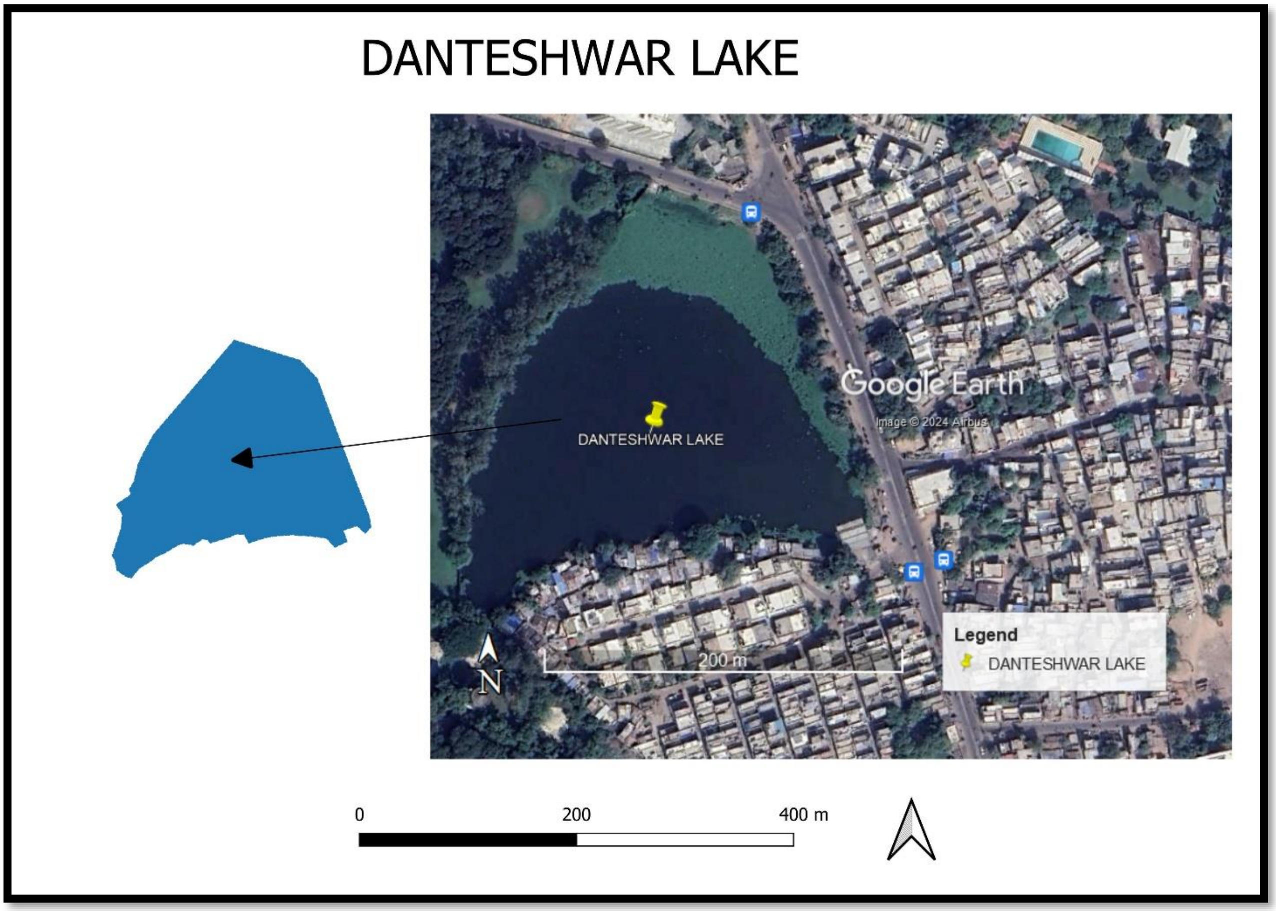

Figure 13 Danteshwar lake boundary

Danteshwar lake (Figure 13) is located at 22°16'33.82"N Latitude and 73°12'38.54"E Longitude. The north and east side of the boundary is connected by road. Slum houses are present on the south side periphery of the lake boundary. The house's sewage output is directly entering the lake body. Fishing activity is observed in this lake body every Sunday. The south side of the lake is contaminated by residents staying nearby by dumping of waste and anthropogenic activities like washing clothes, and utensils. The north and east side of the lake is contaminated by nearby passers who are seen dumping waste into the water body. The west side of the boundary is completely closed.

Motnath Lake

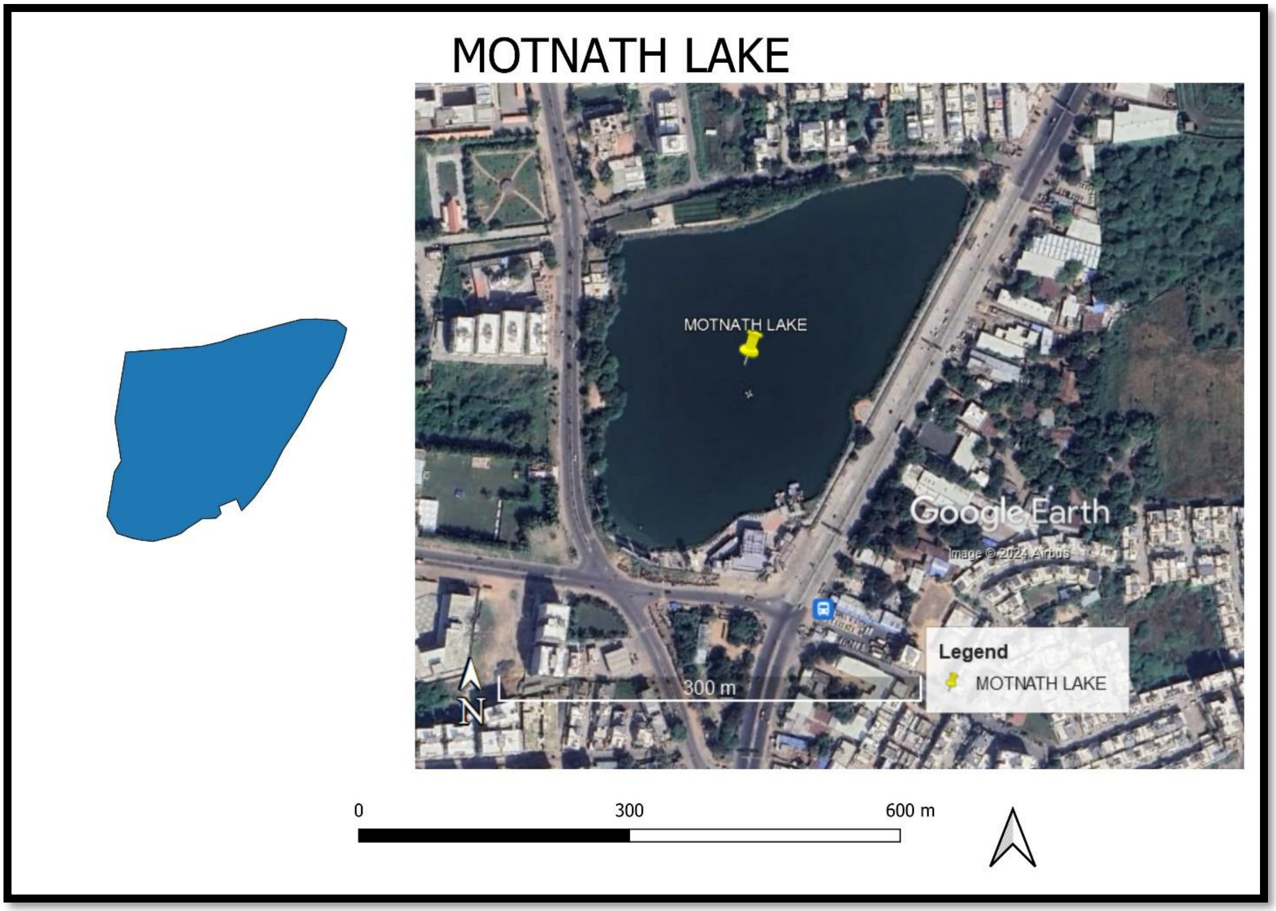

Figure 14 Motnath lake boundary

Motnath lake (Figure 14) is within 22°20'39.62"N Latitude and 73°13'10.48"E Longitude. In 2018 the lake was open from all four sides. Its renovation work started in 2019 and completed in 2020. Lake zone was developed including many activities like speed boat, floating balloons, and boating. Within the Lake boundary Food court and Banquet Hall were developed on the south side. The lake is connected to the road from all four sides of the lake boundary.

Bapod Lake

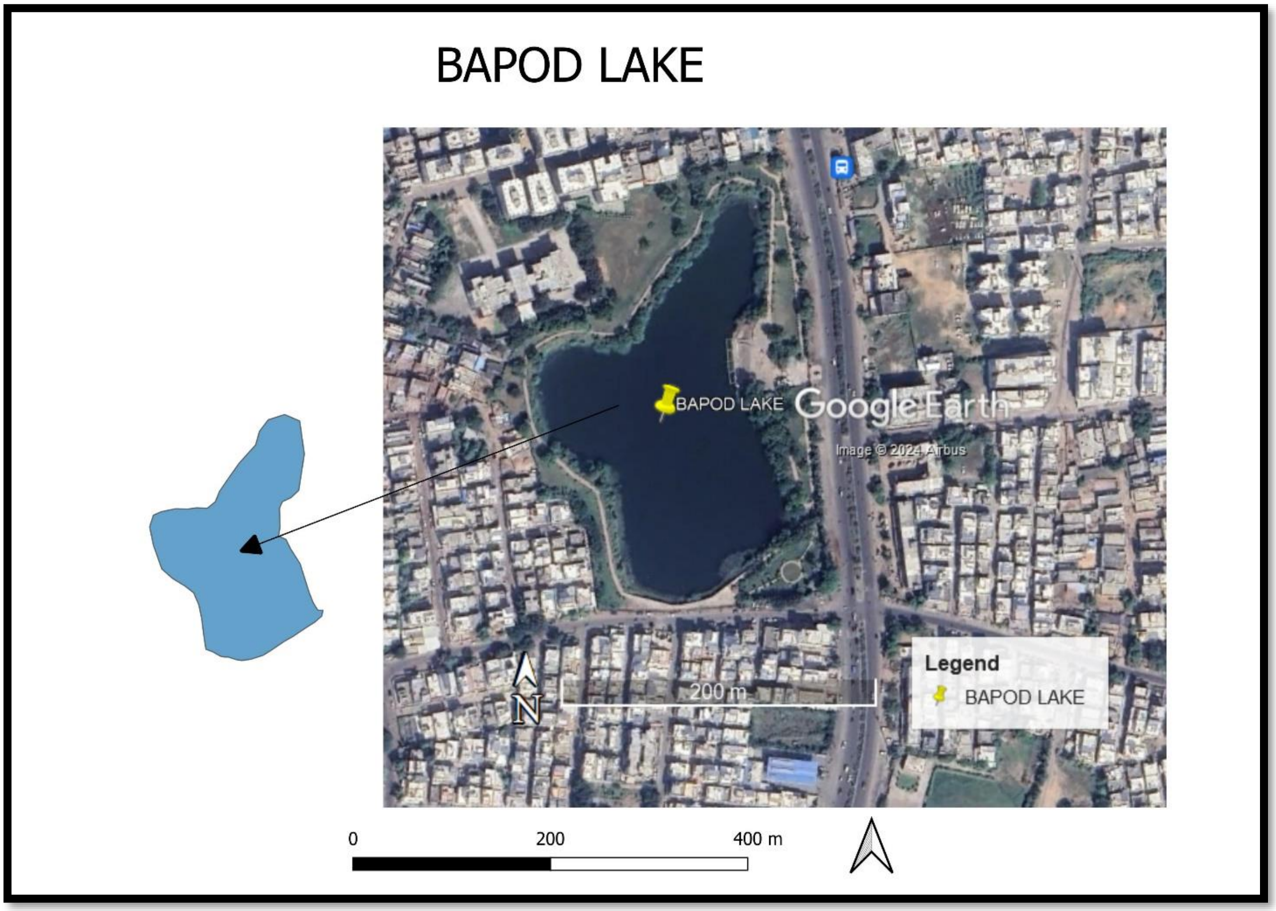

Figure 15 Bapod lake boundary

Bapod lake (Figure 15) is situated at 22°18'15.59"N Latitude and 73°14'16.34"E Longitude. The east side of the boundary is connected to main road and is main entry point into the lake. A Garden is situated at the southeast side of the lake boundary. The west and north side of the lake boundary is surrounded by residential area. A temple is situated within the lake boundary. Walking path is developed along the north-to-east side of the lake. Fishing activity is observed. The dumping of waste by people attending temple is seen by nearby passers. Idol immersion is also observed during the festive season.

Kamala Lake

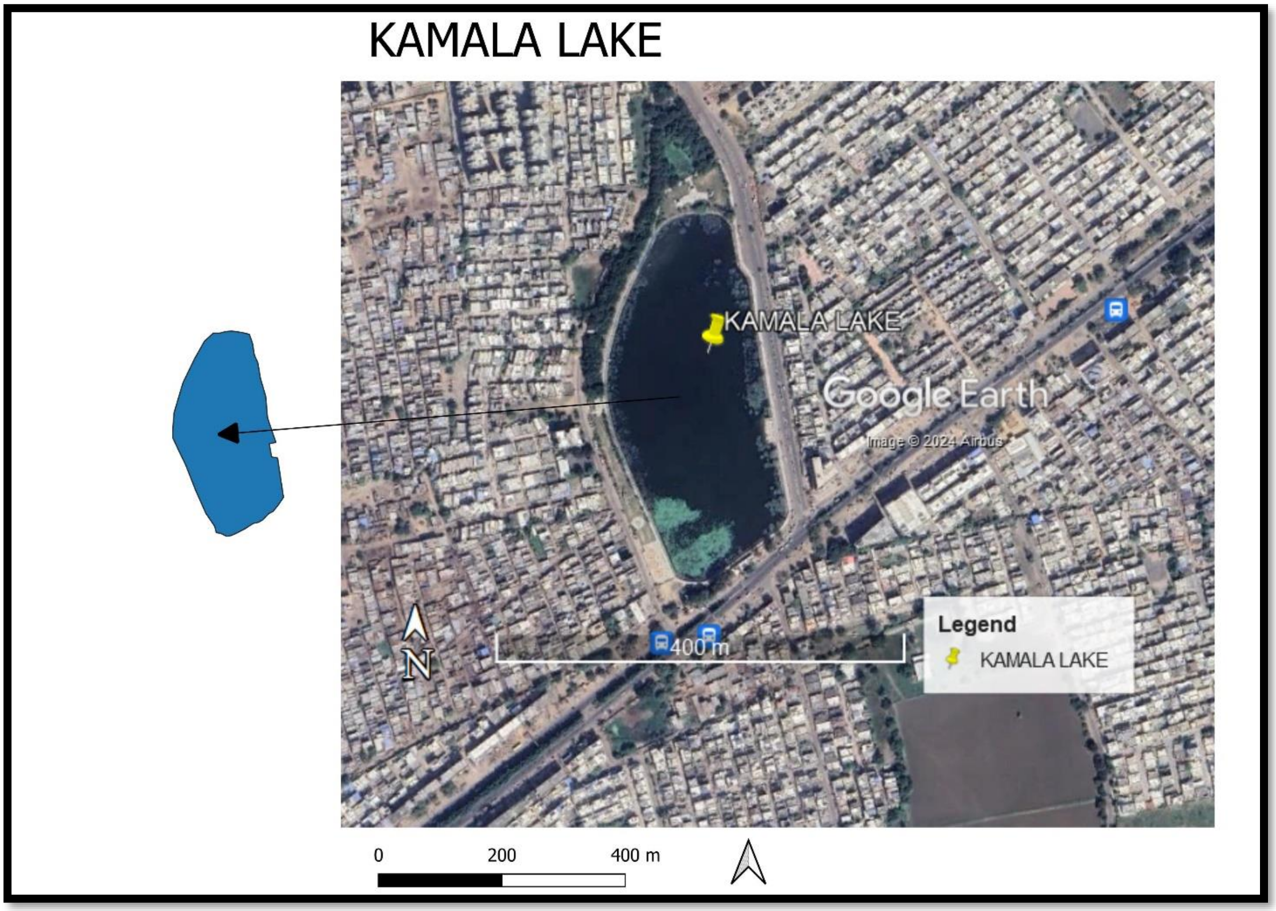

Figure 16 Kamala lake boundary

Kamala lake (Figure 16) is located at 22°19'13.26"N Latitude and 73°14'53.31"E Longitude. Three side of the lake boundary i.e., north, west, and east are surrounded by residential area. A temple and main road connectivity is around the south side of the boundary. A walking path is developed covering all four sides of the lake boundary. Anthropogenic activities like washing clothes, utensils and bathing were observed on the east side of the lake. Lotus presence was observed during the study period. A garden is adjacent to the north side of the lake boundary.

All the selected water bodies are highly impacted by the anthropogenic activities leading to increase in pollution load of the sample body. Urban development is observed around all selected water bodies and lake beautification is done for all water bodies. Site visit for all 9 water bodies was carried out every month to know the physical variation, activities taking place around water bodies, use of water and cleaning/ maintenance of water bodies. Photos of all 9 lakes are included in Annexure of the Thesis.

3.2 Materials and Methodology

3.21 Sampling and Sample analysis

Water samples were collected in all seasons for a period of 4 years. The sampling stations were selected based on their consistent use, water body-human intervention percentage, and ease of access. The water samples were collected manually from the surface and sub-surface area of the water body and transferred to airtight 2-L polyethylene bottles. Before sampling, the bottles were rinsed thrice with sample water. To prevent unexpected changes in physicochemical properties, these samples were transported to the laboratory in an icebox.

Table 7 Water quality parameters, analytical methods, and the instrument used in the study

Parameters	Unit	Analytical methods/ Instruments Used
pH		Hanna pH meter
Temperature	°C	ACETEQ multi thermometer
Conductivity	µS/cm	Hanna DIST EC Tester
Total Dissolved Solids	mg/L	HM Digital TDS-3
Turbidity	NTU	Nephelometric Method
Total Suspended Solids	mg/L	Vacuum Filtration Method
Dissolved Oxygen	mg/L	Winkler – Azide Modification Method
Biological Oxygen Demand (5 days)	mg/L	Bottle Incubation method
Chemical Oxygen Demand(Chromium method)	mg/L	Closed Reflux method
Alkalinity	mg/L	Volumetric Titration method
Acidity	mg/L	Volumetric Titration method
Total Hardness	mg/L	EDTA Titrimetric method
Calcium Hardness	mg/L	EDTA Titrimetric method
Magnesium Hardness	mg/L	EDTA Titrimetric method
Chloride	mg/L	Volumetric Titration ($AgNO_3$) method
Phosphate	mg/L	Vanadomolybdophosphoric Acid Colorimetric Method
Nitrate	mg/L	UV/Vis Spectro-photometric method
Colour	Pt-Co	UV/Vis Spectro-photometric method
Fluoride	mg/L	Thermo Scientific Orion 040908 Electrode
Ammoniacal Nitrogen	mg/L	Titrimetric Method
Total Kjeldahl Nitrogen	mg/L	Macro-Kjeldahl Method
Sulphate	mg/L	UV/Vis Spectro-photometric method
Total Coliform	MPN	Multiple-Tube Fermentation Technique
Fecal Coliform	MPN	Multiple-Tube Fermentation Technique

The samples were analysed for pH, total dissolved solids, total suspended solids, conductivity, temperature, turbidity, colour, fluoride, acidity, alkalinity, hardness, Ca- Hardness, Mg-Hardness, chemical oxygen demand, dissolved oxygen, biological oxygen demand, chloride, ammoniacal nitrogen, total Kjeldahl nitrogen, nitrate, phosphate, sulphate, total coliform and fecal coliforms following the procedures listed in APHA (2017). pH, Temperature, Conductivity, and Total Dissolved Solids were measured on-site. Table 7 lists the parameters measured and the method / instrument used for the purpose.

3.2.2 Different indices used in study period

A total of 15 Indices have been used in the study period for calculation of Water Quality Index. Details, equations, and range classification of all 15 indices are listed below.

3.2.2.1 National sanitation foundation water quality index (NSFWQI)

A water quality index method was developed by Brown by paying great rigor in selecting parameters, developing a common scale, and assigning weights to individual parameters Uddin et al., 2020). The attempt was supported by the National Sanitation Foundation (NSF) and therefore NSFWQI was used to calculate the WQI of various water bodies which were critically polluted. This mathematical expression was considered as a uniform and meaningful method for assessing the overall quality of freshwater (Matta *et al.*, 2020). In this method, a total of 9 parameters - temperature, pH, turbidity, fecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, nitrates, and total solids are used for index calculation. The water quality data are recorded and transferred to a weighting curve chart, where a numerical value of Qi is obtained (Kumar & Alappat, 2009). The mathematical expression for NSFWQI is given by:

$$\mathbf{NSFWQI} = \sum_{i=1}^{n} wiqi \qquad \textbf{(1)}$$

where *qi* represents the assigned curve-based sub-index value for the ith variable, which is ranged from 0 to 100, *wi* is the weighting coefficient for ith parameter with a range from 0 to 1. Summation of *wi* is equal to 1. *n* is the number of total variables considered, the NSFWQI rating scale thus divides water quality into five classes, and accordingly water is considered as very bad (0–25), bad (25–50), medium (50–75), good (70–90) or excellent (90–100).

3.2.2.2 National sanitation foundation water quality index (NSFWQI) modified by CPCB

Given the parameters monitored in India under the NWMP and to maintain uniformity while comparing the WQI across the nation, the NSF WQI has been modified and relative weights been assigned by CPCB. The modified weights as per CPCB and the equations used to determine the sub-index values are given in Table 8. Sub-Index Equation and Index range classification with color codes for interpretation given by MPCB is given in Table 9 and Table 10. Colour coding was niated by MPCB for easy interpretation of index data to the common people.

Table 8 Weightage given by NSF and CPCB

Parameters	Original Weights from NSF	WQI Modified Weights by CPCB
Dissolved Oxygen (DO)	0.17	0.31
Fecal Coliform (FC)	0.15	0.28
pH	0.12	0.22
BOD	0.10	0.19
Total	**0.54**	**1.00**

Table 9 Sub index equation used to calculate NSF WQI for DO, FC, pH and BOD

Water Quality Parameters (units)	Range Applicable	Equation
Dissolved Oxygen (DO) (% Saturation)	0 - 40	0.18 + 0.66 X % Saturation DO
	40 - 100	(-13.55) + 1.17 X % Saturation DO
	100 - 140	163.34 - 0.62 X % Saturation DO
pH	02 - 05	16.1 + 7.35 X (pH)
	05 - 7.3	(-142.67) + 33.5 X (pH)
	7.3 - 10	316.96 - 29.85 X (pH)
	10 - 12	96.17 - 8.0 X (pH)
Fecal Coliform (FC) (counts/100 mL)	$1 - 10^3$	97.2 - 26.6 X log FC
	$10^3 - 10^5$	42.33 - 7.75 X log FC
BOD (mg/L)	<2, >12	0
	0 -10	96.67 - 7 X (BOD)
	10 - 30	38.9 - 1.23 X (BOD)

Table 10 NSF index classification range

WQI	Quality classification	Class by CPCB	Class by MPCB	Remarks	Colour code
63 - 100	Good to Excellent	A	A-I	Non-Polluted	
50 - 63	Medium to Good	B	Not Prescribed	Non-Polluted	
38 - 50	Bad	C	A-II	Polluted	
38 and	Bad to Very Bad	D, E	A-III, A-IV	Heavily Polluted	

Source: MPCB Surface Water Quality Report – 2022

3.2.2.3 The Overall index of pollution OIP)

It was developed by Sargaonker et al. at the National Environmental Engineering Research Institute (NEERI), Nagpur, India to assess the status of surface waters, specifically under Indian conditions. A general classification scheme has been formulated based on a concept similar to the one proposed by Prati and giving due consideration to the classification scheme developed by CPCB. OIP was developed for Indian rivers based on the selection of 13 parameters which include Turbidity, pH, Color, DO, BOD, TDS, Hardness, Cl, SO_4, NO_3, Total Coliform, As and F (Sargaonkar and Deshpande, 2003). The OIP rating scale is also divided into five quality classes and considered as Excellent (0-1), Acceptable (1-2), Slightly Polluted (2-4), Polluted (4-8), and Heavily Polluted (8-16) according to Indian standards and/or other accepted guidelines and standards such as World Health Organization and European Community (Poonam et al., 2013; Gradilla-Hernández *et al.*, 2020). The equation for calculation of the index is shown below:

$$\mathbf{OIP = \frac{1}{n}\sum_{i=1}^{n} Pi} \qquad \textbf{(2)}$$

where, Pi = *pollution index value for the* i*th parameter*, n = *number of parameters.*

3.2.2.4 Overall Water Quality Index (OWQ)

OWQ index was developed by NIH (National Institute of Hydrology) for drinking purposes under the surface water category. These parameters include turbidity, color, total dissolved solids (TDS), pH, dissolved oxygen (DO), biochemical oxygen demand (BOD), Secchi depth, hardness, chloride, fluoride, nitrate, total phosphate, iron, sulfate, arsenic, and total coliform. OWQI helps in understanding the quality of water by integrating the complex voluminous data and generates a score to describe the status of water quality. The OWQI rating scale is divided into five quality classes and considered as heavily polluted (0–24), poor (25–49), fair (50–74), good (75–94), and excellent (95–100). To gauge the influence of each parameter on a common single scale, the score generated by each parameter was averaged out. The following weighted average aggregation function is used for this purpose (Singh et al., 2015).

$$\mathbf{OWQI} = \sum_{i=1}^{n} \mathbf{wiYi} \qquad \mathbf{(3)}$$

Where,

wi = weight of the ith water quality parameter

Yi = sub-index value of the ith parameter

3.2.2.5 Nemerow Pollution Index

WPI by Nemerow and Sumitomo is a method for evaluating water quality in an ecosystem that was established in the 1970s in the United States. Later, the Indonesian Ministry of Environment approved it in Ministerial Decree No.115/2003, which addresses rules for determining water-quality condition (Al-Othman, 2019). The WPI is a function of Ci/Lj, where Ci is the concentration of parameter i and Lj is the concentration permissible value (PV) of parameter. The following equation expresses the WPI for a certain water use j (WPIj) (Jubaedah et al., 2015)

$$WPI = \frac{\sum_{i}^{n}=1\sqrt{(Ci+Lij)max^2+(Ci+Lij)avg^2}}{2} \qquad \mathbf{(4)}$$

where Ci is the measured concentration of i^{th} parameter, Lij is the allowed value (PV)of i^{th} parameter for j^{th} water consumption (i.e. fisheries), and (Ci/Lij)max and (Ci/Lij)avg are the maximum and average Ci/Lij values for the assigned water usage, respectively (Liu et al., 2016; Lodhaya et al., 2017). The PV system employed is based on Indonesian Government Regulation No. 82/2001, specifically for the use of fisheries water (Tanjung & Hamuna, 2019; Nachiyunde et al., 2013). Table 11 shows the range values for corresponding water quality status for NPI.

Table 11 Nemerow water quality range classification

NPI range	Water Quality Status
0-1	Good Quality
1-5	Slightly Polluted
5-10	Moderately Polluted
>10	Water heavily Polluted

3.2.2.6 Integrated Water Quality Index

There was a need to universally recognize water quality indicators (WQI) that is flexible enough to indicate drinking water acceptability over the world. To achieve this, a new water quality metric was created. Considering the observation that the concentration of any parameter, both below and above the ideal limit, will contribute to the total increase in the index value; this index was named as the Integrated Water Quality Index (IWQI). Traditional WQI evaluates either desirable or permissible limits as the standard allowable limit, but in the IWQI, both limits are examined, minimizing uncertainty about the adoption of standard values. The IWQI will provide valuable information to prioritize and maintain the water quality of drinkable sources and lessen the effects of using low-quality groundwater resources on human health. It is adaptable, unbiased, simple to compute, and timesaving (Mukate et al., 2019). Table 12 shows the range classification for the index..

The BIS defines the DL and PL values for the corresponding parameters based on their threat to health.

Range = Permissible limit (PL) - Desirable limit (DL) **(5)**

Modified Permissible Limit (MPL) = Permissible Limit - (20%Range) **(6)**

The range has been redefined as the percentage of the parameter's range that falls outside of the 20% deficit of the range and the acceptable limit. The values which are less than minimum required concentration and above modified permissible limit will affect the water quality, while the values in between DL and MPL can be supposed to be excellent for drinking

$$SI_1 = 0 \tag{7}$$

If, the observed value ith parameter (Pi) is above DL but less than MPL then, the sub index (SI_1) will be zero, i.e. DL≤Pi≥MPL.

$$SI_2 = (DL - Pi)/DL \tag{8}$$

if the value of ith parameter is less than the desirable permissible limit then use SI_2 i.e. Pi≤DL

$$SI_3 = (Pi - MPL)/MPL \tag{9}$$

if Pi is greater than the modified permissible limit (MPL) then follow the SI_3 for calculation i.e. Pi≥MPL

Where,

SI=Sub Index

Pi=Water quality of ith parameter

DL=Desirable Limit

MPL=Modified permissible limit

$$IWQI = \sum_{j=1}^{n} SIij \tag{10}$$

SIi j=Sub-index value of ith sample and jth water quality parameter

Table 12 Integrated water quality index range classification

WQI Value	Class	Explanation
<1	Excellent	Excellent for drinking
1-2	Good	Good for drinking
2-3	Marginal	Acceptable for Domestic
3-5	Poor	Not acceptable for drinking
>5	Unsuitable	Unacceptable

3.2.2.7 The New Water Quality Index

Two stages were used to build the WQI equation. The first involved ranking different aspects of water quality according to their importance. DO, total phosphates, fecal coliform, turbidity, and specific conductivity are among the characteristics included in the new WQI. Second, numerous types were evaluated, with DO receiving the most weight, followed by fecal coliform and total phosphates. The percentage saturation indicates the temperature influence. The least influence was given to turbidity and specific conductance. A final version that preserves the index in a simple equation and a tolerable numerical range was chosen. Small numbers that are simple for management decision-makers, stakeholders, and the general public to use were produced using the logarithm. Based on how each variable affected the water conditions, the powers of the variables for the WQI were determined (Said et al., 2004). Standardizing the variables is not necessary to generate this index. The computations are made even simpler by getting rid of the sub-indices (% of each variable's ideal scenario). This yields the equation 11. Table 13 shows the range classification for the index.

$$\mathbf{WQI = \log [\ (DO)^{1.5} / (3.8)^{TP} (Turb)^{0.15} (15)^{Fcol/1000} + 0.14\ (SC)^{0.5}]} \qquad \textbf{(11)}$$

Table 13 New water quality index range classification

Index Table	
>3	Excellent
2 to 3	Acceptable
2 to 1	Poor
< 1	Needs Management Practices

3.2.2.8 Universal Water Quality Index

To simplify characterisation of the quality of surface water used for drinking water supply, the Universal Water Quality Index (UWQI) was created. By representing the suitability of water for a specific use – drinking water supply rather than general supply – UWQI offers advantages over pre-existing indices and was developed by researching the international standards (Boyacioglu, 2007). The UWQI was developed based on the following water quality standards:

- ‘The quality required of surface water intended for the abstraction of drinking water in the Member States 75/440/ EEC’ set by the Council of the European Communities (EC, 1991)
- ‘The classification of inland waters according to quality -Turkish water pollution control regulation - WPCR’ (Official Gazette, 1988)

- Other reported scientific information

After identifying the index's water quality parameters, mathematical formulae were developed for each parameter that converted the actual concentration values into the index's various quality indices. After giving variables weights, sub-indices were combined using the weighted sum method to produce an overall index value (Uddin et al., 2020). Development of a sub-index: The suggested classification for the UWQI and concentration ranges for a few selected characteristics based on standards are as follows:

- Class I: excellent
- Class II: acceptable
- Class III: polluted

The weighted sum approach was used to aggregate the sub-indices. Another task involved weighting variables related to water quality.

➢ Because microbiological pollutants fall under the group with the highest potential for harming human health, chemical factors were given less weight than biological parameters.

➢ High weight was given to the variables that are known to be related to health.

On a fundamental importance scale, the temporary weights varied from 1 to 4. The final weight factor was then calculated by dividing each weight by the sum of all weights as shown in equation 12. Table 14 shows the mathematical equation used for all parameters. Table 15 shows the weightage given to parameters for index calculations and Table 16 shows the index Range classification.

$$\boldsymbol{WQI = \sum_{i=1}^{n} wiIi} \quad \textbf{(12)}$$

where:

wi = weight for ith parameter

Ii=sub-index for ith parameter

Table 14 Mathematical equation for universal water quality index

Variable	Range	Sub-index function
BOD	X<3 3≤X<5 5≤X<7 X≥7	Y=100 Y = -25X+175 Y = -22.5X+162.5 Y =0
Nitrate	X≤5 5<X≤10 10<X≤20 X>20	Y =100 Y = -10X+150 Y = -4.5X+95 Y =0
Arsenic	X≤0.02 0.02<X≤0.05 0.05<X≤0.1 X>0.1	Y =100 Y = -1666.7X+133.33 Y = - 900X+95 Y =0
Dissolved oxygen	X?8 8<X≤6 6<X≤3 X<3	Y =100 Y =25X -100 Y =15X- 40 Y =0
Fluoride	X≤1 1<X≤2 X>2	Y =100 Y = - 95X+194.17 Y =0
Total phosphate	X≤0.02 0.02<X≤0.16 0.16<X≤0.65 X>0.65	Y =100 Y = -357.14X+107.14 Y = -91.837X+64.694 Y =0
Mercury	X≤0.0001 0.0001<X≤0.0005 0.0005<X≤0.002 X>0.002	Y =100 Y = -125000X+112.5 Y = -30000X+65 Y =0
Selenium	X≤0.01 0.01<X≤0.02 X>0.02	Y =100 Y =4500X+95 Y =0
Cyanide	X≤0.01 0.01<X≤0.05 0.05<X≤0.1 X>0.1	Y =100 Y = -1250X+112.5 Y = -900X+95 Y =0
Cadmium	X≤0.003 0.003<X≤0.005 0.005<X≤0.010 X>0.010	Y =100 Y = -25000X+175 Y = -9000X+95 Y =0
Total coliform	X≤50 50<X≤5000 5000<X≤50000 X>50000	Y =100 Y = -10.857lnX+142.47 Y = -21.715lnX+284.95 Y =0
pH	6.5≤X≤8.5 5.5≤X≤6.4 and 8.6≤X≤9 X<5.5 and X>9	Y =100 Y =50 Y =0

Table 15 Weightage for universal water quality index

Category	Variable	Rating	Weight factor
Health hazard	Total coliform	4	0.114
	Cadmium	3	0.086
	Cyanide	3	0.086
	Mercury	3	0.086
	Selenium	3	0.086
	Arsenic	4	0.113
	Fluoride	3	0.086
	Nitrate-nitrogen	3	0.086
Operational monitoring	DO	4	0.114
	pH	1	0.029
Oxygen depletion	BOD	2	0.057
	Total phosphate	2	0.057

Table 16 Universal water quality index range classification

Rank	WQI value
Excellent	95-100
Good	75-94
Fair	50-74
Marginal	25-49
Poor	0-24

3.2.2.9 Prati's implicit index of pollution

Prati created this ranking based on the water-quality standards. Using mathematical equations, the concentration values of all contaminants were converted into pollution levels stated in new units. These mathematical equations were created in a way that made the new units proportional to the pollution effect in comparison to other parameters. A pollutant's impact on the index score will be significant even if it is present in lower concentrations than other pollutants based on the extent to which it makes the environment worse (Uddin et al., 2020). The initial stage was to classify water quality in relation to all criteria using water-quality standards. The actual value of one pollutant was used as the reference index in the second stage, when it was taken as a reference (Prati et al., 1971). The final phase involved creating mathematical equations to convert each of the other contaminants' values into subindices. The polluting potential of the parameters connected to a chosen reference parameter was considered throughout this modification. To ensure that the resulting transformation would be applicable not only to small values of pollutant concentrations but also to those surpassing class V, these functions were constructed using the analytical properties of various curves. Selected parameters and their range classification is given in Table 17. Subindex equation and range classification is given in Table 18 and 19.

Table 17 Classification of water quality for the development of Prati's Index

Parameter	Excellent	Acceptable	Slightly Polluted	Polluted	Heavily Polluted
pH	6.5-8.0	6.0-8.4	5.0-9.0	3.9-10.1	<3 to >10.1
DO (% Sat)	88-112	75-125	50-150	20-200	<20 to >200
BOD5 (ppm)	1.5	3.0	6.0	12.0	>12.0
COD (ppm)	10	20	40	80	>80
Permanganate	2.5	5.0	10.0	20.0	>20.0
Suspended solids (ppm)	20	40	100	278	>278
NH_3 (ppm)	0.1	0.3	0.9	2.7	>2.7
NO_3 (ppm)	4	12	36	108	>108
Cl (ppm)	50	150	300	620	>620
Iron (ppm)	0.1	0.3	0.9	2.7	>2.7
Manganese (ppm)	0.05	0.17	0.5	1.0	>1.0
ABS (ppm) Alkyl Benzene Sulphonates	0.09	1.0	3.5	8.5	>8.5
CCE (ppm) Carbon Chloroform Extract	1.0	2.0	4.0	8.0	>8.0

Table 18 Subindex functions of Parti's Index

Parameter	Subindex
Dissolved Oxygen (%)	$Ii = 0.08x + 8,\ 50 < x < 100,$ $Ii = 0.08x - 8,\ 100 < x.$
pH (units)	$Ii = -4x^2 + 14,\ 0 <, x < 5,$ $Ii = -2x + 14,\ 5 < x < 7,$ $Ii = x^2 - 14x + 49,\ 7 < x < 9,$ $Ii = -0.4x^2 + 11.2x - 64.4, 9 < x < 14$
5-Day BOD (ppm)	$Ii = 0.66666x$
COD (ppm)	$Ii = 0.10x$
Permanganate (ppm)	$Ii = 0.04x$
Suspended Solids (ppm)	$Ii = 2^{[2.1 \log (0.1x - 1)]}$
Ammoniacal Nitrogen (ppm)	$Ii = 2^{[2.1 \log (10x)]}$
Nitrates (ppm)	$Ii = 2^{[2.1 \log (0.25)]}$
Chlorides (ppm)	$Ii = 0.000228x^2 + 0.0314x, 0 < x < 50,$ $Ii = 0.0000132x^2 + .0074x + 0.6,\ 50 < x < 300$ $Ii = 3.75\ (0.02x - 5.2)^{0.5},\ 300 < x$
Iron (ppm)	$Ii = 2^{[2.1 \log (10x)]}$
Manganese (ppm)	$Ii = 2.5x + 3.9\sqrt{x}\quad 0 < x < 0.5,$ $Ii = 5.25x^2 + 2.75,\quad 0.5 < x$
Alkyl Benzene sulphonates (ppm)	$Ii = -1.2x + 3.2\sqrt{x},\quad 0 < x < 1,$ $Ii = 0.8x + 1.2,\quad 1 < x$
Carbon Chloroform Extract (ppm) (mg/L)	$Ii = x$

Table 19 Prati's water quality index range classification

Range	Status Of Water
0-1	Excellent
1 to 2	Acceptable
2 to 4	Slightly Polluted
4 to 8	Polluted
>8	Heavily Polluted

3.2.2.10 Dinius Index

This index was groundbreaking because it attempted to create a basic social accounting system to calculate the costs and effects of pollution control measures. A precursor to the "planning" or "decision-making" indices is Dinius' WQI (Dinius, 1972). Eleven criteria were chosen. It had a descending scale, just like Horton's index and the NSF-WQI, and values were expressed as a percentage of perfect water quality, which is equal to 100. The subindices in Dinius' index, like those of Prati and McDuffie-Haney, were created after a survey of the published scientific literature (Dinius, 1987). Dinius studied the water quality described by various authorities to varying degrees of pollution factors and constructed 11 subindex equations based on this information. The index was derived as the weighted total of the subindices, like Horton's index and the additive NSF-WQI. Second Dinius Index was developed by Dinius (1987) by creating a multiplicative water-quality index with extensive use of Delphi in decision making. The index includes 12 contaminants for six water applications - public water supply, recreation, fish, shellfish, agriculture, and industry - dissolved oxygen, 5-day BOD, coliform count, E. coli, pH, alkalinity, hardness, chloride, specific conductivity, temperature, colour, and nitrate (Sedeño-Díaz & López-López, 2007). Weightage and sub index equation for the index is given in Table 20 and range classification for index interpretation is given in Table 21.

Table 20 Weightage and sub index equation for Dinius Index

Parameter	Dimension	Weight	Function
DO	%Saturation	0.109	0.82DO - 10.56
5-Day BOD	mg/L, at 20 °C	0.097	108(BOD) - 0.3494
Coli	MPN-Coli/100 mL	0.090	136(COLI) - 0.1311
E. coli	Fecal-Coli/100 mL	0.116	$106(E\text{-}COLI)^{-0.1286}$
Alkalinity	ppm $CaCO_3$	0.063	110(ALK) - 0.1342
Hardness	ppm $CaCO_3$	0.065	552 (HA) - 0.4488
Chloride	mg/L, fresh water	0.074	391(CL) - 0.3480
Sp. Conductance	mmhos/cm 25 °C	0.079	506(SPC) - 0.3315
Nitrate	as NO_3, mg/L	0.090	125(N) - 0.2718
Temperature	°C	0.077	$10^{2.004 - 0.00382 (Ta-Ts)}$
Colour	Colour units - Pt std	0.063	127(C) - 0.2394
pH	pH < 6.9		$10^{0.6803 - 0.1856}$ (pH)
	pH - units (6.9 - 7.1)	0.077	1
	pH > 7.1		$10^{3.65-0.2216}$ (pH)

Table 21 Dinius water quality index range classification

Range	Interpretation
90-100	Purification Not Necessary
80-90	Minor Purification Required
50-80	Necessary Treatment
40-50	Doubtful
0-40	Not Acceptable

3.2.2.11 Dhamija and Jain 1995

WQI formed with 9 parameters which were assigned weights (Abbasi & Abbasi, 2012).

The unit weight (*wi*) for each parameter was calculated as

$$\mathbf{Wi} = \frac{Wi}{\sum i=1} \quad \mathbf{(13)}$$

Each subindex was given by

$$(\mathrm{SI})_{\mathrm{I}} = \mathrm{qiwi} \quad \mathbf{(14)}$$

where *qi* is the quality rating of the i^{th} parameter. Then,

$$\mathbf{WQI} = \sum_{i=9}^{n} qiwi \quad \mathbf{(15)}$$

The rating scale was set up in the 0-100 range.
Index parameters ranges and weightage selection is given in Table 22 and 23.

Table 22 Assignment of weightage for Dhamija and Jain Index

Degree of Pollution	Permissible	Slight	Moderate	Severe
Rating (qi)	100	80	50	0
pH	7-8.5	8.6-8.8	8.9-9.2	>9.2
		6.8-7.0	6.5-6.7	<6.5
Total Hardness (mg/L)	<100	101-300	310-500	>500
Calcium Hardness (mg/L)	<75	76-137	138-200	>200
Magnesium Hardness (mg/L)	<30	31-90	91-150	150
Total Alkalinity (mg/L)	50	51-85	86-120	>120
Dissolved Oxygen (mg/L)	6	4.4-4.9	3-4.5	<3
Total Solids (mg/L)	500	500-1000	1000-1500	>1500
Total Suspended Solids (mg/L)	<30	30-65	65-100	>100
Chloride (mg/L)	<200	201-400	401-600	>600

Table 23 Rating scale for Dhamija and Jain index

Parameters	Standards	Weights	Unit Weights
pH	7.0 ─ 8.5	4	0.16
Total Hardness (as $CaCO_3$) mg/L	100 ─ 500	2	0.08
Calcium mg/L	75-200	2	0.08
Magnesium mg/L	30 ─ 150	2	0.08
Total Alkalinity mg/L	<120	3	0.12
Dissolved Oxygen mg/L	>6	4	0.16
Total Solids (mg/L)	500 ─ 1500	4	0.16
Total Suspended Solids (mg/L)	<100	2	0.08
Chloride (mg/L)	200 500	2	0.08

3.2.2.12 Weighted arithmetic water quality index method

Weighted arithmetic method, for determining water quality index, is extensively used for assessing water quality. A key step in this method is the allocation of weights to individual parameters. Individual factors are were determined according to their relative importance. A parameter's weight typically depends on the standards-established upper limit that it is permitted to exceed. Even though they fluctuate less, factors with lower allowed limits typically have a potential to change the water quality to a greater extent; for this reason, they are given high weights (Kachroud et al., 2019). Higher permitted limit parameters are less harmful to the water quality since they have a smaller impact on the water quality; as a result, they are given lower weights (Kumar et al., 2022). As a result, it can be said that the weight given to a particular parameter is inversely proportional to its permissible limits (Krishan et al., 2016; Bhadrecha & Mankodi, 2018). Index Classification is given in Table 24. The weights are generally assigned as numerical values between 0 and 1. The calculation involves followings steps:

1. Data collection for various water quality parameters.
2. Calculating constant K value using the formula

$$K = \frac{1}{\sum 1/Si} \quad (16)$$

where Si is standard permissible for ith parameter.

3. Calculating quality rating scale (Qi) for each parameter by below given equation.

$$\mathbf{Qi = 100 * \left(\frac{Vi - V0}{Si - S0}\right)} \quad \mathbf{(17)}$$

where Vi is estimated concentration of ith parameter in the analysed water

V_0 is the ideal value of this parameter in pure water

$$\mathbf{V_0 = 0 \text{ (except pH = 7.0 and DO = 14.6 mg/L)}} \quad \mathbf{(18)}$$

4. Calculating unit weight (Wi) for individual water quality parameter by using the equation.

$$\mathbf{Wi = \frac{K}{Si}} \quad \mathbf{(19)}$$

5. Calculating water quality index.

$$\mathbf{WQI = \frac{\sum QiWi}{\sum Wi}} \quad \mathbf{(20)}$$

Table 24 Weighted Arithmetic Mean method index range classification

Range	Interpretation
0 - 25	Excellent
26 – 50	Good
51 – 75	Poor
76 – 100	Very Poor
>100	Unsuitable

3.2.2.13 Bascaron Index

The Bascarón WQI was created by Bascarón in 1979, primarily for Spain, and has since been used in several studies around the globe (Pesce & Wunderlin, 2000). It is a highly flexible index which allows the introduction or exclusion of parameters according to the needs or limitations of the obtained data. This index was generally designed to include twenty–six water quality parameters, with total sum of all parameters' weights of 54. Weightage and range classification is given in Table 25 and Index classification is given in Table 26.

The Subjective water quality index, WQI_{sub}

$$WQI_{sub} = k\frac{\sum Ci * Pi}{\sum Pi} \quad (21)$$

where k is a subjective constant. Ci is the value assigned to each parameter after normalization. Pi is the relative weight assigned to each parameter. The range of Pi values is from 1 to 4, with 4 denoting the parameter having the greatest significance for aquatic life. It portrays how river contamination could appear to someone who is unfamiliar with environmental issues (Uddin et al., 2022). Depending on the state of the river, it can take one of the following values:

1.00 = water without apparent contamination (clear or with natural suspended solids).

0.75 = light contaminated water (apparently), indicated by light non-natural color, foam, light turbidity due to no natural reasons.

0.50 = contaminated water (apparently), indicated by non-natural color, light to moderate odor, high turbidity (no natural), suspended organic solids, etc.

0.25 = highly contaminated water (apparently), indicated by blackish color, hard odor, visible fermentation, etc.

The Objective water quality index, WQI_{obj}

The objective water quality index (WQI_{obj}) was calculated using equation (11) but with k =1 in all the cases to account only for variations due to measured parameters

Table 25 Bascaron weightage and sub index classification

Parameter	pH	DBO_5 (mg/L)	Dissolved oxygen (mg/L)	Tempera-ture(°C)	Total coliforms (nº/100 mL)	Colour (Pt Co)	Turbidity (NTU)	Perman-ganate reduc- tion (mg/L)	Deter-gents (mg/L)	Percent-age value C_i
Weight	**1**	**3**	**4**	**1**	**3**	**2**	**4**	**3**	**4**	**%**
Experimental value of the parameter	1	>15	0	>50 / > − 8	>14.000	>250	>400	>15	>3.00	**0**
	2	12	1	45 / − 6	10.000	100	250	12	2.00	**10**
	3	10	2	40 / −4	7.000	60	180	10	1.50	**20**
	4	8	3	36 / −2	5.000	40	100	8	1.00	**30**
	5	6	3.5	32 / 0	4.000	30	50	6	0.75	**40**
	6	5	4	30 / 5	3.000	20	20	5	0.50	**50**
	6.5	4	5	28 / 10	2.000	15	18	4	0.25	**60**
	9	3	6	26 / 12	1.500	10	15	3	0.10	**70**
	8.5	2	6.5	24 / 14	1.000	5	10	2	0.06	**80**
	8	1	7	22 / 15	500	4	8	1	0.02	**90**
	7	<0.5	7.5	21 /16	<50	<3	<5	<0.5	0	**100**

Parameter	pH	DBO_5 (mg/L)	Dissolved oxygen (mg/L)	Tempera-ture(°C)	Total coliforms (n°/100 mL)	Colour (Pt Co)	Turbidity (NTU)	Perman-ganate reduc- tion (mg/L)	Deter-gents (mg/L)	Percent-age value C_i
Parameter	**Hardness mg/L $CaCO_3$**	**Dissolved solids (mg/L)**	**Pesti-cides (mg/L)**	**Oil and grease (mg/L)**	**Sulphates (mg/L)**	**Nitrates (mg/L)**	**Cyanides (mg/L)**	**Sodium (mg/L)**	**Free CO_2 (mg/L)**	**C_i**
Weight	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**3**	**%**
Analytical value of the parameter	>1.500	>20.000	>2	>3	>1.500	>100	>1	>500	>60	**0**
	1.000	10.000	1	2	1.000	50	0.6	300	50	**10**
	800	5.000	0.4	1	600	20	0.5	250	40	**20**
	600	3.000	0.2	0.60	400	15	0.4	200	30	**30**
	500	2.000	0.1	0.30	250	10	0.3	150	20	**40**
	400	1.500	0.05	0.15	150	8	0.2	100	10	**50**
	300	1.000	0.025	0.08	100	6	0.1	75	9	**60**
	200	750	0.01	0.04	75	4	0.05	50	8	**70**
	100	500	0.005	0.02	50	2	0.02	25	7	**80**
	50	250	0.001	0.01	25	1	0.01	15	5	**90**
	<25	<100	0	0	0	0	0	<10	<3	**100**
Parameter	**Ammoniacal Nitrogen nitrogen (mg/L)**	**Chloride (mg/L)**	**Conducti-vity (mhos/ cm)**	**Magne-sium (mg/L)**	**Phosphate (mg/L)**	**Nitrites (mg/L)**	**Calcium (mg/L)**	**Apparent aspect (quality)**		**C_i**
Weight	**3**	**1**	**4**	**1**	**1**	**2**	**1**			**%**
Analytical value of the parameter	>1.25	>1.500	>16.000	>500	>500	>1	>1.000	**Worst**		**0**
	1.00	1.000	12.000	300	300	0.50	600	**Very bad**		**10**
	0.75	700	8.000	250	200	0.25	500	**Bad**		**20**
	0.50	500	5.000	200	100	0.20	400	**Unpleasant**		**30**
	0.40	300	3.000	150	50	0.15	300	**Inappropriate**		**40**
	0.30	200	2.500	100	30	0.10	200	**Normal**		**50**
	0.20	150	2.000	75	20	0.05	150	**Acceptable**		**60**
	0.10	100	1.500	50	10	0.025	100	**Pleasant**		**70**
	0.05	50	1.250	25	5	0.010	50	**Good**		**80**
	0.03	25	1.000	15	1	0.005	25	**Very good**		**90**
	0	0	<750	<10	0	0	<10	**Excellent**		**100**

Table 26 Bascaron water quality index range classification

Range	Interpretation
$91 \leq$ index ≤ 100	Good
$61 \leq$ index < 91	Acceptable
$31 \leq$ index< 61	Regular
$16 \leq$ index< 31	Bad
$0 \leq$ index < 16	Very bad

3.2.2.14 DOE Index

This water quality index (WQI) was first developed in 1978 by Malaysia's Department of Environment (DOE), which also began keeping track of river water quality. (Ho et al., 2019) (Environment, 2007). Establishing a baseline monitoring system for river water quality, identifying any changes in water quality, and pinpointing the sources of pollution were the objectives of proposed index for the quick mitigation of the pollution. The DOE presented the formula for calculating WQI, and a panel of experts was consulted on the parameters to be used and the relative weights to be given to each parameter. The biological oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), suspended solids (SS), pH, and ammoniacal nitrogen (NH_3-N) are the six water quality parameters used to calculate the WQI. An unequal weighting technique was used to determine parameter weight values by taking into consideration the expert panel opinions. The sum of the weight values of the parameters is equal to 1 (Hameed et al., 2017). The highest weight value was assigned for the DO (0.22) and BOD (0.19) separately. The same weight value (0.16) was used for COD and SS, respectively. A weighting of 0.15 was determined for ammoniacal nitrogen while the lowest weight value was given for pH (0.12). The WQI score was determined using a simple additive aggregation formula where the products of the parameter sub-index values (SI) and their weightings are given in Table 27 and index classification in Table 28. The WQI calculation formula is:

$$WQI = 0.22\ SIDO + 0.19\ SIBOD + 0.16\ SICOD + 0.16\ SISS + 0.15\ SIAN + 0.12\ SIpH \qquad (22)$$

Table 27 Sub-index calculation formula for DOE Index

Parameter	Value	Sub-Index Equation
DO (in % saturation)	$X \leq 8$	SIDO = 0
	$X \geq 92$	SIDO = 100
	$8 < X < 92$	$SIDO = -0.395 + 0.030X^2 - 0.00020X^3$
BOD	$X \leq 5$	SIBOD = 100.4 - 4.23X
	$X > 5$	$SIBOD = (108^{e^{-0.055X}}) - 0.1X$
COD	$X \leq 20$	SICOD = -1.33X + 99.1
	$X > 20$	$SICOD = (103^{e^{-0.0157X}}) - 0.04X$
SS	$X \leq 100$	$SISS = (97.5^{e^{-0.00676X}}) + 0.05X$
	$100 < X < 1000$	$SISS = (71^{e^{-0.0061X}}) - 0.015X$
	$X \geq 1000$	SISS = 0
NH_3-N	$X \leq 0.3$	SIAN = 100.5 - 105X
	$0.3 < X < 4$	$SIAN = (94^{e^{-0.573X}}) - 5(X-2)$
	$X \geq 4$	SIAN = 0
pH	$X < 5.5$	SIpH = 17.2 − 17.2X + 5.02X2
	$5.5 \leq X < 7$	SIpH = −242 + 95.5X -6.67X2
	$7 \leq X < 8.75$	SIpH = −181 + 82.4X -6.05X2
	$X \geq 8.75$	SIpH = 536 − 77.0X + 2.76X2

Table 28 DOE water quality index range classification

Class	Range	Status and Interpretation
I	>92.7	Very Good - Water supply 1 – Practically no treatment is necessary. Fishery 1 – Very sensitive aquatic species
II	76.5–92.7	Good - IIA: Water Supply II – Conventional treatment required. Fishery II – Sensitive aquatic species. IIB: Recreational use with body contact.
III	51.9–76.5	Average - Water Supply III – Extensive treatment required Fishery III: Common, of economic value, and tolerant species Livestock drinking.
IV	31.0–51.9	Polluted - Irrigation
V	<31	Very Polluted – None of the above

3.2.3 Eco-Heart Index

Theoretical and empirical work on the "Heartware" approach to integrated watershed management (IWM) in Malaysia led to the concept of employing the heart shape to express water quality. To help every individual understand the overall status of a water body, this simpler form of the index, known as the Eco-Heart Index (EHI), was developed (Chandrasekaran et al.., 2020;Sakai et al., 2018). This index comprises of six parameters- pH, ammoniacal nitrogen, transparency, chemical oxygen demand (COD), dissolved oxygen, and heavy metals. Eco-Heart Index mainly includes a heart-shaped tool used for assessing the water body. By looking at the heart shape, one can get an idea about the health and quality of the water body. A broken heart represents polluted or dirty water, while a full heart represents clean water. All the points are connected through a curved line, and the water quality is evaluated through the heart-shaped figure, where the three basic steps include marking, connecting, and evaluating to form a heart to assess the quality of the water body as given in figure 17. Original Classification and modified classification is given in Table 29 and 30.

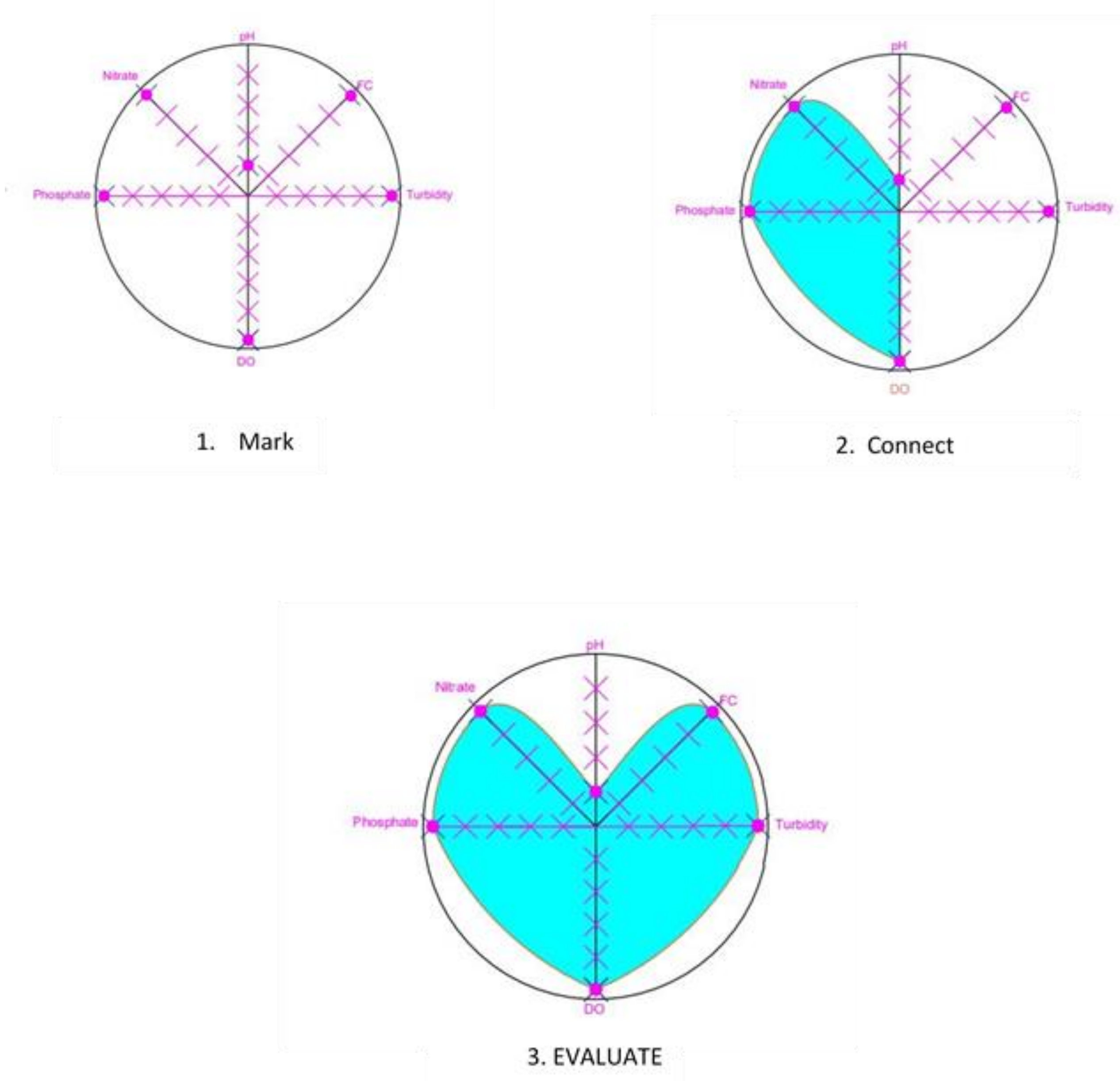

Figure 17 Concept and steps of generating Eco-heart index

((1) Marking of reading on image (2) Connecting the marked dots on image (3) Evaluating the Shape of Heart Formed)

Table 29 Original classification range for water quality assessment for Eco-Heart index

Parameter	I. (Clean)	II. (Moderate)	III. (Slightly polluted)	IV. (Polluted)	V. (Heavily polluted)
pH	6.50–7.50	6.00–6.49/ 7.51–8.00	5.50–5.99/ 8.01–8.50	5.0–5.49/ 8.51–9.00	<5.00 >9.00
Dissolved oxygen	> 6.00	5.01–6.00	3.01–5.00	1.01–3.00	0–1.00
Heavy Metals	0–0.2	0.3–0.5	0.6–1.0	1.1–2.0	> 2.0
Transparency	> 30.0	20.1–30.0	15.1–20.0	10.1–15.0	0–10.0
NH_3-N	0–0.50	0.51–1.00	1.01–2.00	2.01–5.00	> 5.00
COD	0–5	6–10	11-13	14-20	>20

If all the parameters are under the class 1 category, then a full heart is obtained indicating a clean water body. A broken heart shape appears if the water is polluted and some of the criteria are not categorized as clean (i.e., level II, III, IV, or V).

In our study we have modified the EHI by taking into consideration some different parameters out of the reported 6, according to our 3-year data set. Parameters like pH, turbidity, dissolved oxygen (DO), phosphate, nitrate, and fecal coliforms are determined, and their levels are labelled using a categorization table (Parmar & Samnani, 2023).

Table 30 Modified classification range for water quality assessment for Eco-Heart index

Parameter	I. (Clean)	II. (Moderate)	III. (Slightly polluted)	IV. (Polluted)	V. (Heavily polluted)
pH	6.50–7.50	6.00–6.49/ 7.51–8.00	5.50–5.99/ 8.01–8.50	5.0–5.49/ 8.51–9.00	<5.00 >9.00
Dissolved oxygen	5.50–6.50	4.50–5.50	3.50–4.50	2.00–3.50	<2
Fecal coliforms	0–10	$10–10^2$	$10^2–10^3$	$10^3–10^5$	$>10^5$
Phosphate	0–0.002	0.16–0.02	0.40–0.16	0.40–1.00	>1
Nitrate	0–10	10–20	20–50	50–100	>100
Turbidity	0–5	5–15	15–50	50–100	>100

3.2.4 Statistical Analysis

Descriptive Statistics measure like mean and coefficient of variation was computed in the excel 365. Microsoft Excel 365 was utilized to carry out a comprehensive statistical analysis of the various parameters of the lake water. The analysis involved the calculation of descriptive statistics such as the arithmetic mean, which provided an insight into the average value of the parameters being studied. In addition, the minimum and maximum values were identified to determine the range of the dataset. These calculations allowed for a detailed and comprehensive understanding of the characteristics of the pond water parameters under investigation.

The Spearman's correlation is a statistical measure used to determine the strength and direction of the relationship between two variables. This technique is often employed through R-studio software, which is a popular tool for statistical analysis. By comparing the ranks of the two variables, Spearman's correlation coefficient provides a way to accurately assess the extent of correlation between them. This coefficient ranges from -1 to 1, where a value of 1 indicates a perfect positive correlation, a value of -1 indicates a perfect negative correlation, and a value of 0 indicates no correlation at all. As Spearman's correlation coefficient edges closer to its upper limit of 1, it signifies a substantial amplification in the impact it exerts on delineating the relationship between the parameters under study. This makes it a valuable tool for researchers and analysts in various fields (Gosai & Mankodi 2024a)

While Principal component analysis was carried out in the R-studio version 2021.09.1. PCA was carried out reduce the dimension of the data and identify the potential parameter that significantly influence Water Quality Index (WQI).

Principal Component Analysis is a widely used multivariate technique and is known as the dimensionality reduction technique. This simply converts original variables into uncorrelated new variables and are called components (Kazi et al. 2009). This helps us to understand the variability and the similarity among the parameters (Sivasankar & Gomathi 2009). To execute this analysis various approaches are proposed and are in use. Here in this study varimax method is used to compute distance between variables and this has been carried out considering correlation matrix as a base.

It helps to identify the underlying sources that drive changes. To obtain more accurate and precise results, they have employed a method called Varimax rotation with Kaiser normalization. This particular technique is well-known for its ability to reduce the impact of several variables on each factor. This approach aligns with the methodology which seeks to identify the fundamental sources of variation in a given dataset. By using these advanced statistical methods, researchers can gain a deeper understanding of the complex factors that influence changes in surface water, thus enabling them to develop more effective strategies for managing and protecting this vital resource. (Gosai & Mankodi 2024b)