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Research Article

Towards Sustainable Development – Increasing Public Participation by Simplifying Water Quality Data Presentation in The Form of Eco-Heart Index

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Abstract

This study applies the new user-friendly and sustainable community-based water quality index known as Eco-Heart Index for monitoring and assessing water quality. Eco-Heart considers six parameters, resulting in a pictorial output in the shape of a heart. A full heart indicates excellent water quality, whereas a broken heart indicates poor water quality. This investigation used six parameters namely, pH, dissolved oxygen, phosphate, nitrate, turbidity, and faecal coliform, for determining the status of a water body. Four water bodies in the city of Vadodara were analyzed using the index to see where they fell on a scale of pollution severity. Based on the Eco-Heart dataset of 3 years, it was found that the lakes in which broken hearts occurred ranged from a shrinking heart to a deformed heart. The obtained results were compared with the widely used National Sanitation Foundation water quality index to validate the data, which showed a moderately positive correlation. Survey documentation for the applicability of the Index on ground level was also carried out using Cronbach Alpha showing a positive response of people for use of Eco- Heart Index indicating that Eco-Heart Index can be used as an alternative, easy, and sustainable tool for assessing water bodies.

Keywords: water quality; water quality index; eco-heart index; surface water body; environment monitoring; sustainability

Introduction

Water is the most important natural resource for the existence of life on earth. Owing to industrialization and urbanization, the quality of surface and groundwater has been degrading at a very high rate (Ramprasad, et al., 2020; Uddin, et al., 2021). Considering surface water; rivers, lakes, ponds, and canals play a vital role as drinking water resources. An increasing shortage of clean water is an outcome of the rapid deterioration of surface water quality because of numerous factors, including natural processes, anthropogenic activities, and overdevelopment (Carpenter et al., 1998; Chen, et al., 2003; Nielsen et al., 2012; Wu, et al., 2021). Scientists have shown considerable interest in assessing the ecological health of water bodies in recent decades (Kittinger et al., 2013; Wang, et al., 2018; Yotova, et al., 2021). There are now more intricate approaches that allow the understanding of the vitality of water bodies and their biological response to anthropogenic impact (Bilgin, 2018; Varbanov & Gartsiyanova, 2017; Yotova et al., 2021). To safeguard and control water quality, it is vital to collect important information regarding water quality conditions and its spatiotemporal variation (Romero et al., 2016; Wu, et al., 2021; Zhang, et al., 2019).

To assess the quality of air and water, individual air and water quality indices have been developed. Out of these, the air quality index (AQI) is widely used everywhere on regular basis. The source and information platforms for AQI are relatively well defined and communicated to common people. However, when it comes to the water quality index people are not much aware of it. Some reasons for such non-involvement may be many indices are developed worldwide but no specific universal index is derived; the complexity of mathematical equations used in WQI calculation, which makes it difficult for common people to understand the index at once. To overcome such gaps between science and public participation, a sustainable way of representing information to the public is developed in form of Eco- Heart Index (EHI).

Government policies are aimed at establishing the water quality criteria keeping in mind the health of living organisms of primary importance. USEPA classifies the water quality criteria under three heading namely Aquatic life criteria, Human health criteria, and Organoleptic effects criteria (United States Environment Protection Agency, 2021) In deciding the water quality criteria, EPA takes public opinion along with scientific data. In India, the Government has established channels to bring in various stakeholders in the process of monitoring water quality and improving the quality criteria (Ministry of Jal shakti, Department of water resources, 2022). To increase participation, the water quality monitoring data is shared with the public and opinions are sought about further improvement in the criteria. Going through such a mammoth amount of data is a difficult task for common people and hence there is a need to communicate water quality more simply or realistically.

Though the legal framework in India seeks public participation in getting major projects environmental clearance, the maintenance of ponds in cities and towns is still considered the responsibility of government bodies. There is a dire need to make people in the surrounding areas aware of the factors affecting the quality of water and simpler ways of expressing the water quality.

Several systems have been developed to express water quality using measured quality parameters, such as a statistical approach, model-based approach, or water quality index. In the midst of these methods used for water resource management, WQI plays a crucial role in assessing surface water quality (Mohebbi et al., 2013; Nong et al., 2020; Sutadian et al., 2015; Wu et al., 2021). In WQI, the state of a water body can be determined using mathematical formulas and models (Dash & Kalamdhad, 2021; Stoner, 1978). The most commonly used WQIs in India are the National Sanitation Foundation Water Quality Index (NSFWQI) modified by the Central Pollution Control Board (CPCB), the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), Weighted Arithmetic Water Quality Index (WAWQI), Overall Water Quality Index (OWQI), Overall Pollution Index (OIP) (Birawat et al., 2021; Matta et al., 2020; Sargaonkar & Deshpande, 2003; Singh, 2015; Sutadian et al., 2016). Among these, NSWQWI by CPCB, which considers four parameters, namely, dissolved oxygen (DO), pH, faecal coliform, and biological oxygen demand (BOD), is widely used for assessing the quality of a water body. The index value ranges from 0 to 100 depicting polluted and nonpolluted water bodies (Alexakis et al., 2016; Bala et al., 2017; Bora & Goswami, 2017; Gradilla-Hernández et al., 2020). WQI has become an essential component of interpreting the variation or state of the environment for a water body (Dosskey & Qiu, 2011; Sutadian et al., 2016; Terrado et al., 2010) for the following reasons: (a) Provides a general state of water quality for water authorities and the community as a whole (Chang et al., 2001; Ocampo-Duque et al., 2006). (b) Studies the environmental quality implications of regulatory policies and programs (Swamee & Tyagi, 2007). (c) Compares water quality from various sources and sites, without conducting a highly technical evaluation of water quality data (Sarkar & Abbasi, 2006). (d) Assists policymakers and the public in avoiding subjective evaluations and resulting biased views (Ocampo-Duque et al., 2006; Rehana & Mujumdar, 2009).

The main purpose of WQI is to disseminate information about the health of a water body; however, the goal is not fully served, as the local communities get confused with the numbers used by indices, as different ranges are set for each distinct set of developed indices (Debels et al., 2005; Jha et al., 2015; Kannel et al., 2007; Sun et al., 2016). The resultant numerical value from the calculated index is derived when compared with standards and sub-index development, making it difficult for common people to relate to it. Signboards of polluted, nonpolluted, and clean water are seen; however, not every individual can interpret the given information. Thus, to help every individual understand the overall status of a water body, a simpler form of the index was developed, known as Eco-Heart Index. This index comprises of six parameters- pH, ammonia nitrogen, transparency, chemical oxygen demand (COD), dissolved oxygen, and heavy metals (Sakai et al., 2018; Sidek, et al., 2016). 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. Theoretical and empirical work on the "Heartware" approach to integrated watershed management (IWM) in Malaysia led to the concept of employing the heart shape. A broken heart represents polluted or dirty water, while a full heart represents clean water (Bakar et al., 2013; Ramprasad et al., 2020; Sakai et al., 2018). Various parameters like pH, turbidity, dissolved oxygen (DO), phosphate, nitrate, and faecal coliforms are determined, and their levels are labelled using a categorization table. Based on the obtained results, 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 (Figure 1). 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).

This work reports an application of the Eco-Heart Index for the four lake bodies and studied its correlation with the NFSWQI to establish the validity of the index. A survey was also carried out to assess the acceptance of the Eco-heart index in common people and the people living around water bodies. Cronbach Alpha was applied to authenticate effectiveness between asked questions.

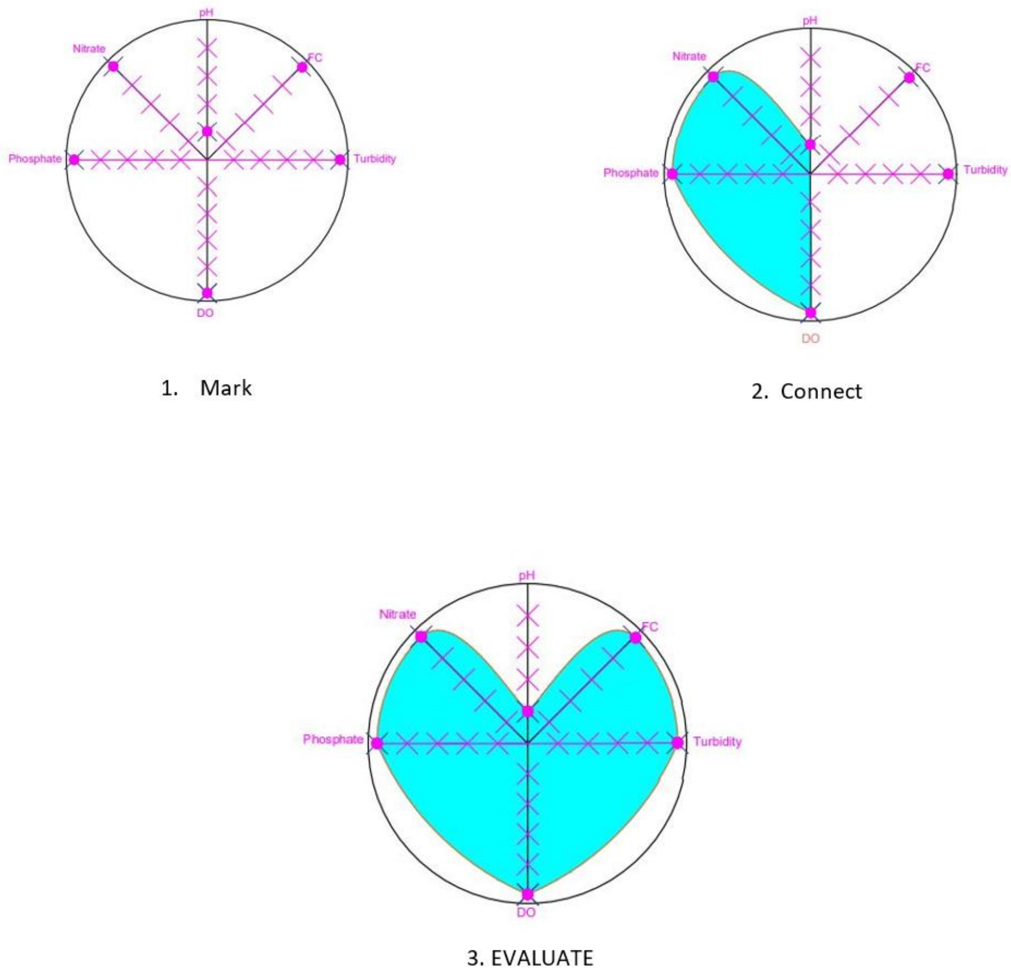

Figure 1: Concept and steps of Eco-heart Index

Material and methods

2.1 Study area

Eco-Heart Index was computed for four urban lake bodies located within the boundaries of the Vadodara municipal corporation (VMC). Vadodara City is a region in central Gujarat, India, located on the banks of the Vishwamitri River at 22°18'52" N latitude and 73°10'53" E longitude having an area of 159.95 sq km (approx.). The city is situated on a fertile plain between the Mahi and Narmada rivers, and the climate is semi-arid due to the region's high evapotranspiration capacity. The region receives 800 mm of rain per year, although infrequent strong downpour showers create urban flooding. All the lakes chosen for this study are flanked by commercial and residential developments. The water level in all four lakes varies throughout the year. In addition, people living in slums near water bodies use lake water regularly for domestic activities. A detailed map and coordinates of their locations are presented in Figure 2 and Table 1.

Name of sampling site	Sampling site code	Latitude	Longitude
Harni Lake	S1	22°20'17"	73°13'11"
Dhobi Lake	S2	22°18'43"	73°13'10"
Gotri Lake	S3	22°18'50"	73°08'03"
Sama Lake	S4	22°20'34"	73°12'07"

Table 1: Geographic coordinates of sample area.

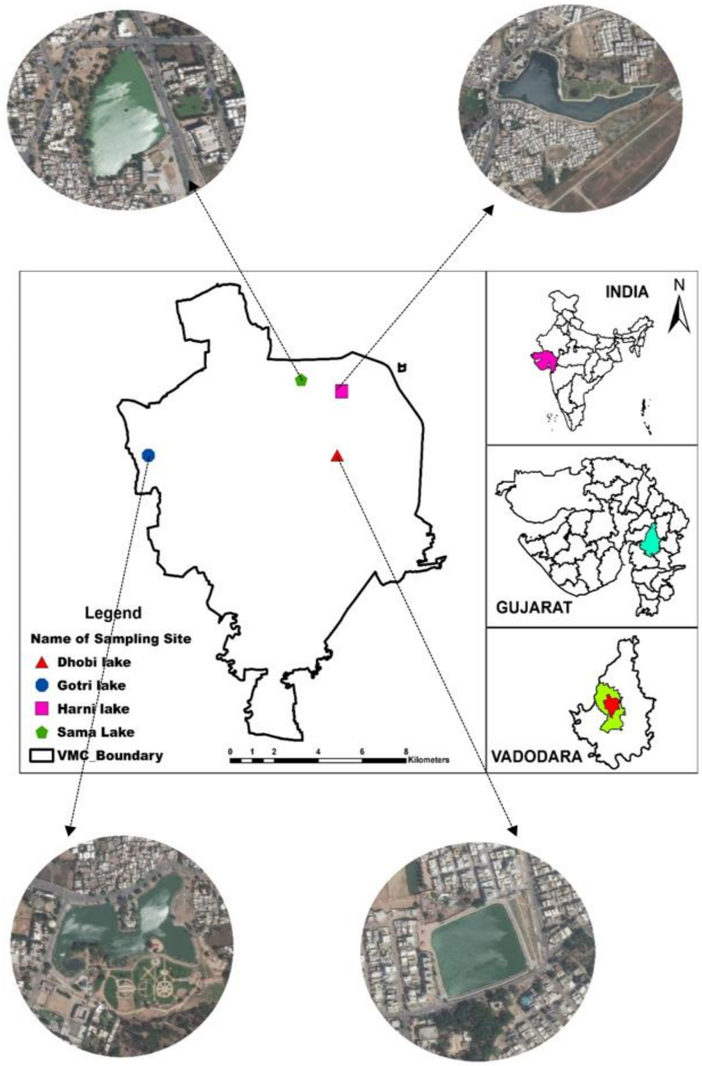

Figure 2: Location Map of the study are

2.2 Sampling and sample analysis

Water samples were collected monthly in the early morning hours between 5 a.m. and 9 a.m. for 3 years, from 2019 to 2021covering all three seasons for water assessment. The sampling stations were selected based on their consistent use, water body-human intervention percentage, and ease of access. Global Positioning System (GPS) recorded the coordinates of the sampling stations. The water samples were collected manually from the subsurface peripheral area of the water body and transferred to an airtight 2-L polyethylene bottle. Before sampling, the bottles were rinsed thrice with distilled water and thrice with sample water. To prevent unexpected changes in physicochemical properties, these samples were transported to the laboratory in an icebox. The samples were analysed within 24 h for pH, turbidity, dissolved oxygen (DO), phosphate, nitrates, and faecal coliforms following the procedures listed in APHA-2017 (APHA-American Public Health Association, American water work Association, 2017; Nathan & Scobell, 2012).

Parameters	Unit	Analytical methods/Instruments used
pH		Hanna pH meter
Turbidity	NTU	Nephelometric method
Dissolved oxygen	mg/L	Winkler–Azide modification method
Phosphate	ppm	Vanadomolybdophosphoric acid colorimetric method
Nitrate	ppm	UV/Vis Spectro-photometric method
Faecal coliform	MPN	Multiple-tube fermentation technique

Table 2: Water quality parameters, analytical methods, and instruments used in the study

ix parameters, namely, pH, turbidity, dissolved oxygen (DO), phosphate, nitrate, and faecal coliforms (FC) were determined, and their levels were labelled using a categorization table. Based on the obtained results, all the points were connected through a curved line and water quality was evaluated through the heart-shaped figure thus obtained. If all the six parameters are under the class 1 category, 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).

The six water performance indicators were chosen to capture both overall water quality and substantial pollution loads, such as eutrophication load by phosphate and nitrate, aesthetic visibility and suspended solids load by turbidity, bacterial contamination by Faecal coliform, and important lake parameters (pH and DO).

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
Faecal coliform	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

Table 3: Classification range for water quality assessment for Eco-Heart Index

Parameters used for the assessment of water quality were classified into five levels, from clean class (I) to heavily polluted (V), as shown in Table 3. The classification for all six parameters was determined using standard values given by CPCB, BIS, and different ranges decided to calculate WQI by NEERI, NIH, and WHO (Sargaonkar & Deshpande, 2003; Singh, 2015).

2.3 Correlation between Eco-Heart Index and NSFWQI

The relationship between Eco-Heart Index and the broadly used NSF index was established with the same data used here to elucidate how the Eco-Heart index is associated with the WQI's concept. WQIs were calculated using the National Sanitation Foundation Water Quality Index (NSFWQI) (Uddin et al., 2021), where selecting parameters, developing a common scale, and assigning weights was the model on which mathematical equation was developed (Matta et al., 2020). In this method, nine parameters, namely, temperature, pH, turbidity, faecal 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

$$NSFWQI = \sum_{i=1}^{n} wiqi \quad (1)$$

where qi represents the assigned curve-based sub-index value (Brown, R.M.; McClelland, N.I.; Deininger, R.A.; Tozer, 1970; Kumar & Alappat, 2009) for the ith variable, which is ranged from 0 to 100, wi represents the weighting coefficient for ith parameter with a range of 0–1. The summation of wi is equal to one. n is the number of total variables considered. The NSFWQI rating scale thus divides water quality into five classes, namely, very bad (0–25), bad (25–50), medium (50–75), good (70–90), or excellent (90–100).

Eco-Heart Index value calculation was done by the summation of all the obtained parameters and values and dividing it by the total number of parameters used in the index calculation. The formula for the same is:

$$Eco - HeartIndex = \sum \frac{pH + DO + FC + phosphate + Nitrat}{n}$$

Results and discussion

Many WQIs have been developed worldwide using mathematical formulae, artificial intelligence concepts, and software; however, conveying the results of water quality to common people is difficult. Therefore, this work applies the concept of the Eco-Heart Index and assesses its acceptability among people. Further, the validity of the Eco-heart concept was compared with the mathematically developed and widely used NSFWQI using the correlation coefficient function to study the water quality of the lake bodies of Vadodara. The following parameters were determined for 3 years: pH, turbidity, faecal coliform, phosphate, nitrate and dissolved oxygen, and their resultant values are shown in the radar graph below in Figures (3) to (6).

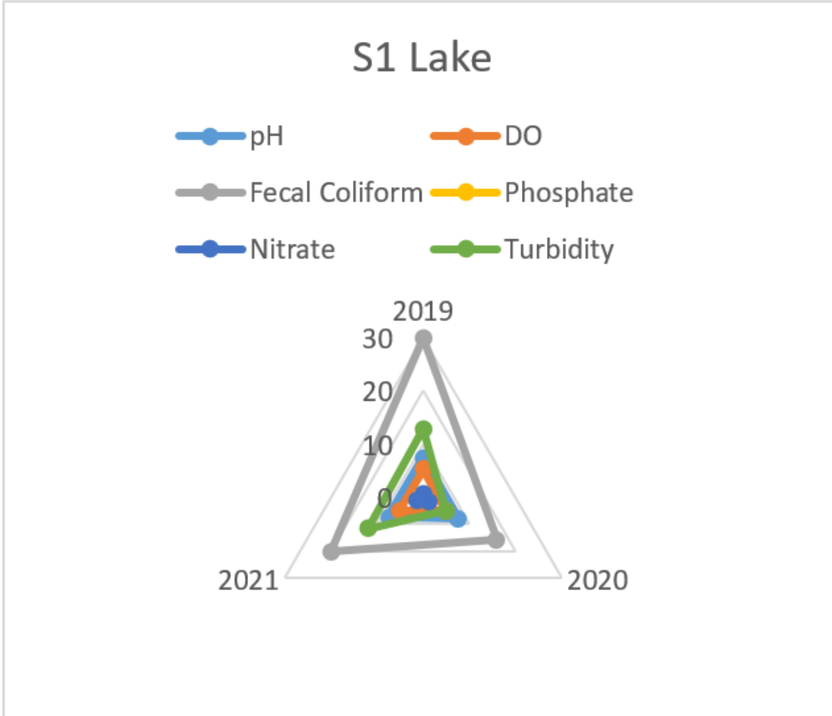

Figure 3: 3 years graph of S1 Lake for six parameters

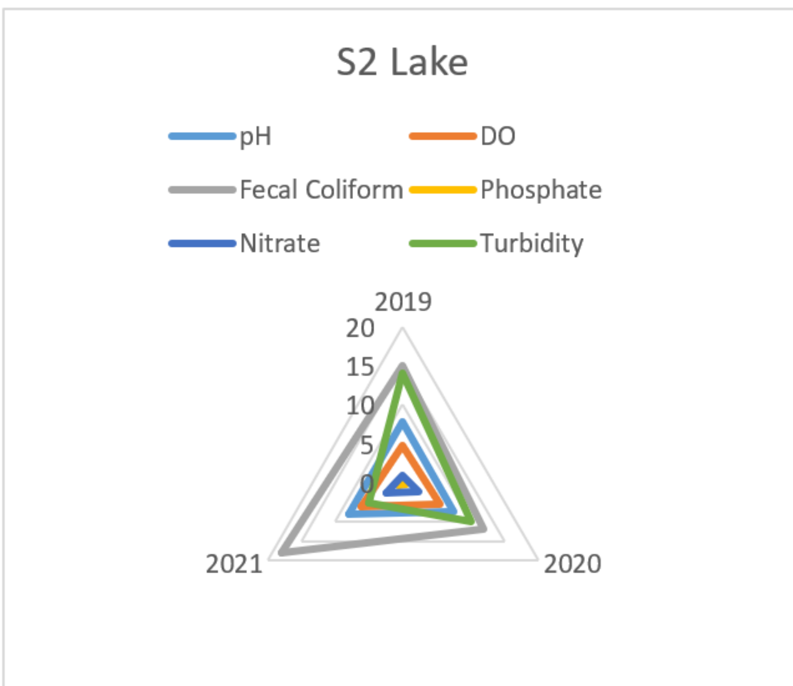

Figure 4: 3 years graph of S2 Lake for six parameters

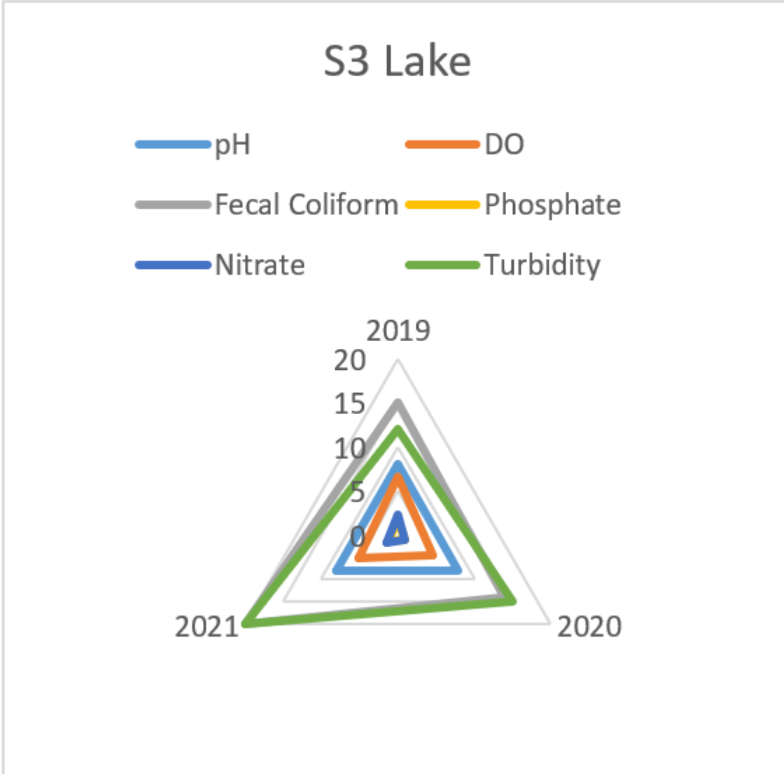

Figure 5: 3 years graph of S3 Lake for six parameters

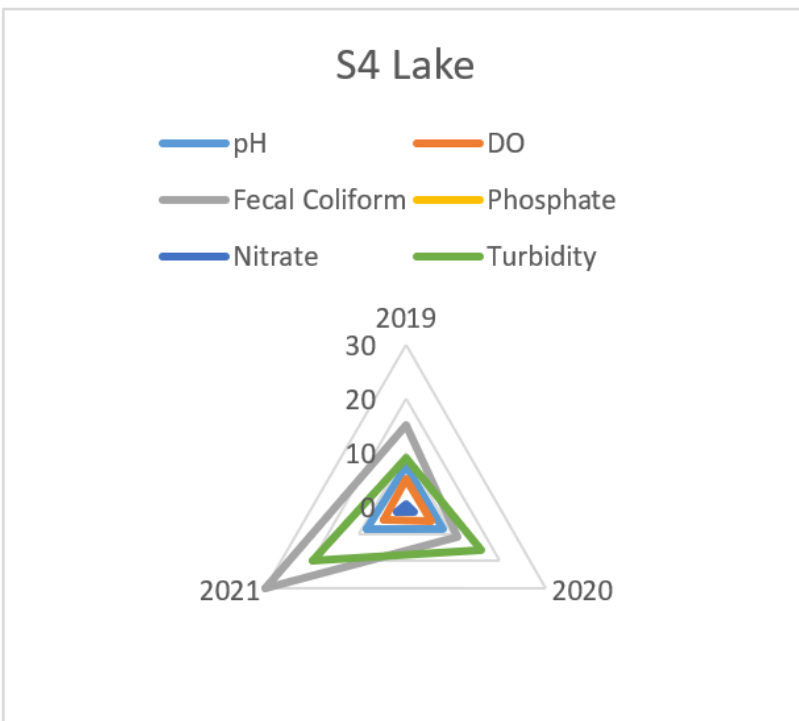

Figure 6: 3 years graph of S4 Lake for six parameters

The minimum and maximum values for all parameters range from 7.5 (S1 lake) to 8.3 (S4 lake) for pH, 4.5 (S3 lake) to 6.6 (S3 lake) for DO, 11 (S4) to 30 (S4, S1 lake) for faecal coliform, 0.13 (S1 lake) to 1.7 (S3 lake) for phosphate, 0.51 (S4 lake) to 2.48 (S2 lake) for nitrate, and 5 (S1 lake) to 20 (S4, S3 lake) for turbidity. These graphs clearly show the parameters dominating in a particular year and the same can be compared with the Eco-Heart given in Figures (7) to (10), which will directly shape the diagram of the heart. For S2 Lake, all parameters (except turbidity) were on an increasing level compared to the parameters of 2019–2020. A sudden increase or decrease in parameters was observed for all the consecutive years for the other three lakes i.e., S3, S4, and S1 Lakes.

For S1 Lake, in 2019, a small heart figure was formed with some parameter edges, namely, faecal coliform, dissolved oxygen, pH, turbidity, and phosphate, bending under the class 2 range. The figure demonstrates water as having good quality. In 2020, a deshaped heart was formed due to a single parameter value fluctuation, i.e., phosphate, while all the other parameters were in the same range as found in 2019 However, the turbidity value decreased compared to that of 2019. From a deshaped heart in 2020 to a full-fledged heart puff edges for four parameters were formed. Compared to 2020, phosphate and pH value came under class 3 from class 4 and class 1 to class 2 for pH. Nitrate, faecal coliform, and dissolved oxygen values remained the same throughout, while turbidity values increased compared to that of 2020. For three consecutive years, a nearly full heart to deshaped heart was observed, indicating the water quality to be under clean to moderate class as shown in Figure 7. The phosphate and turbidity values happened to be the limiting parameters here, which changed the dynamics of water quality.

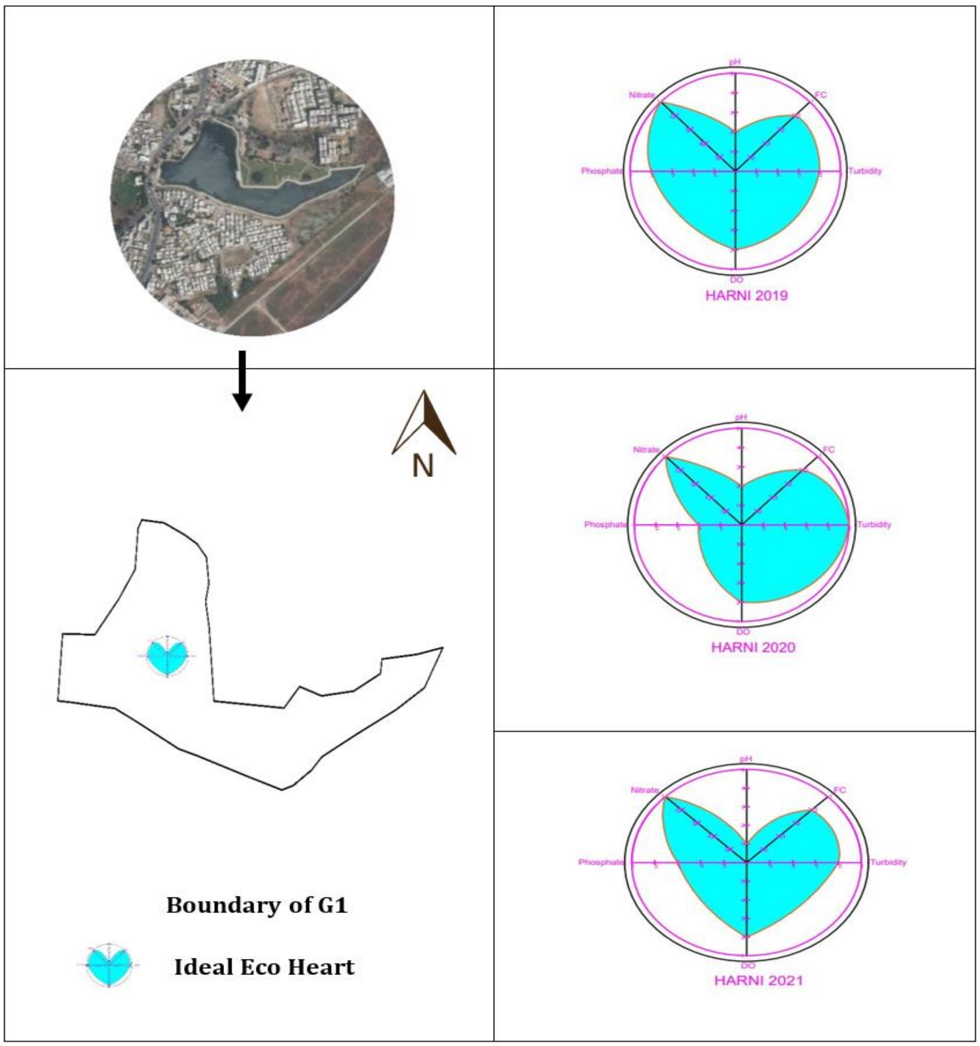

Figure 7: Eco-Heart Index of S1 Lake for 3 years 2019-2020-2021

For S2 Lake, in 2019, the half-formed heart was obtained, shrunk only from one side due to a variation in the pH value. All other parameters were found to be in the desirable range. In 2020, a shrunken heart was formed due to the high value of phosphate. Other parameters, such as DO, faecal coliform, and turbidity, were in an acceptable range. The pH value was found to be in the acceptable range when compared to the 2019 value. In 2021, again one-sided shrunken heart was formed due to a high level of phosphate. All other parameters, such as nitrate, turbidity, and DO, were in the desirable range; however, the pH value slipped down to class 3 when compared to the 2020 value. Faecal coliform remained constant, and the turbidity value decreased compared to that in 2020. For 3 years, different shapes of the heart were seen from a half-formed heart to shrunk heart due to the high level of phosphate and pH fluctuations, indicating that the water quality varied from clean to moderate to slightly polluted class as shown in Figure 8.

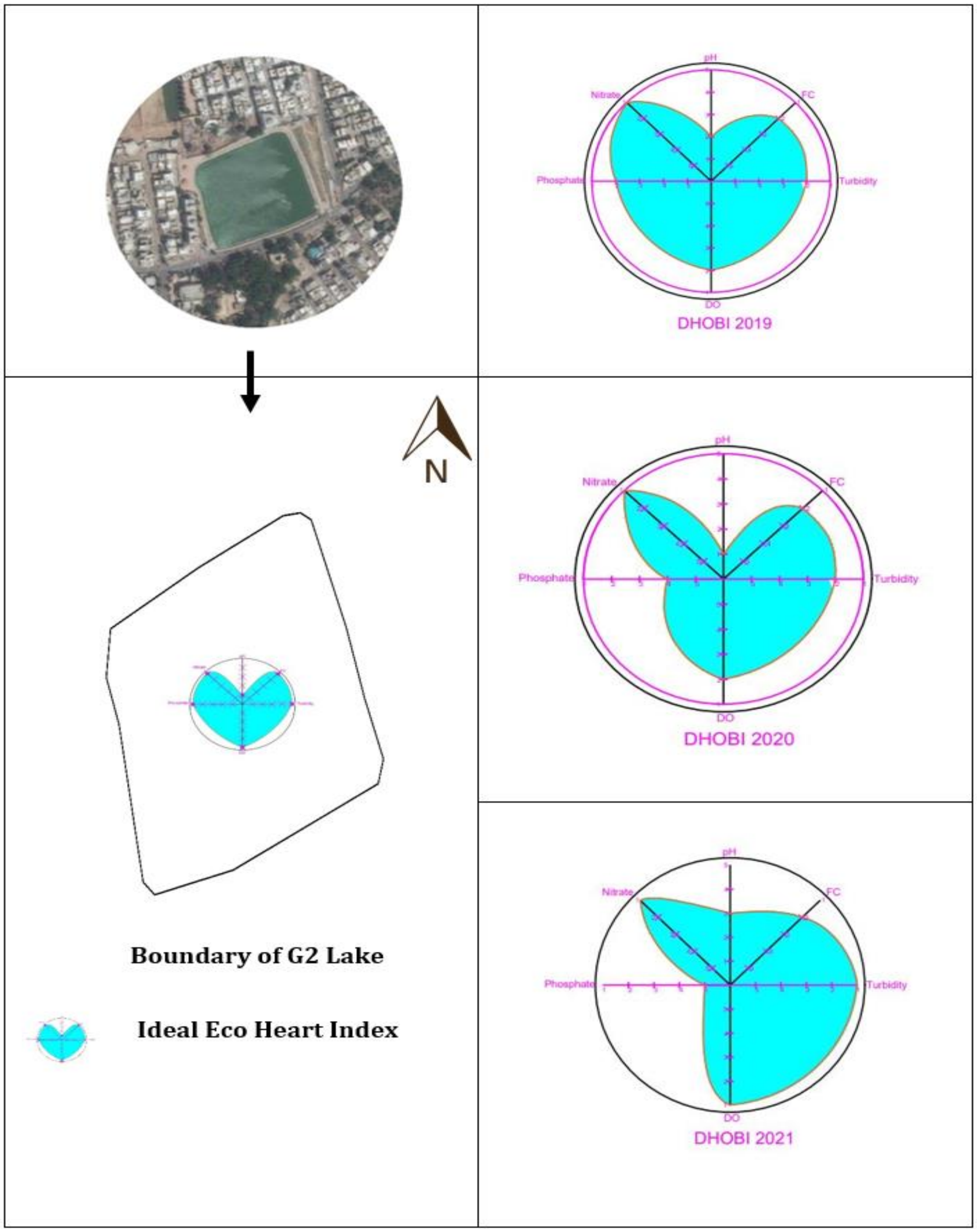

Figure 8: Eco-Heart Index of S2 Lake for 3 years 2019-2020-2021

For S3 Lake, in 2019, a broken heart is formed because of a high level of phosphate, due to which the value falls under the V range, making it heavily polluted under eutrophication pressure and some high values of pH, turbidity, and faecal coliform. In 2020 the same broken heart was formed; however, more pointed curves were present than in 2019, indicating it was a polluted water body due to the high values of pH and phosphate and small changes in resultant values of Faecal coliform and turbidity. By 2021, water quality considerably deteriorated, and a shrunk broken heart was formed due to an increase in turbidity value over the year. The values of phosphate, pH and faecal coliform remained in the same class as in 2020. For all the 3 years, a broken heart was formed mainly due to high values of phosphate and turbidity, making the water body fall under the polluted class as shown in Figure 9.

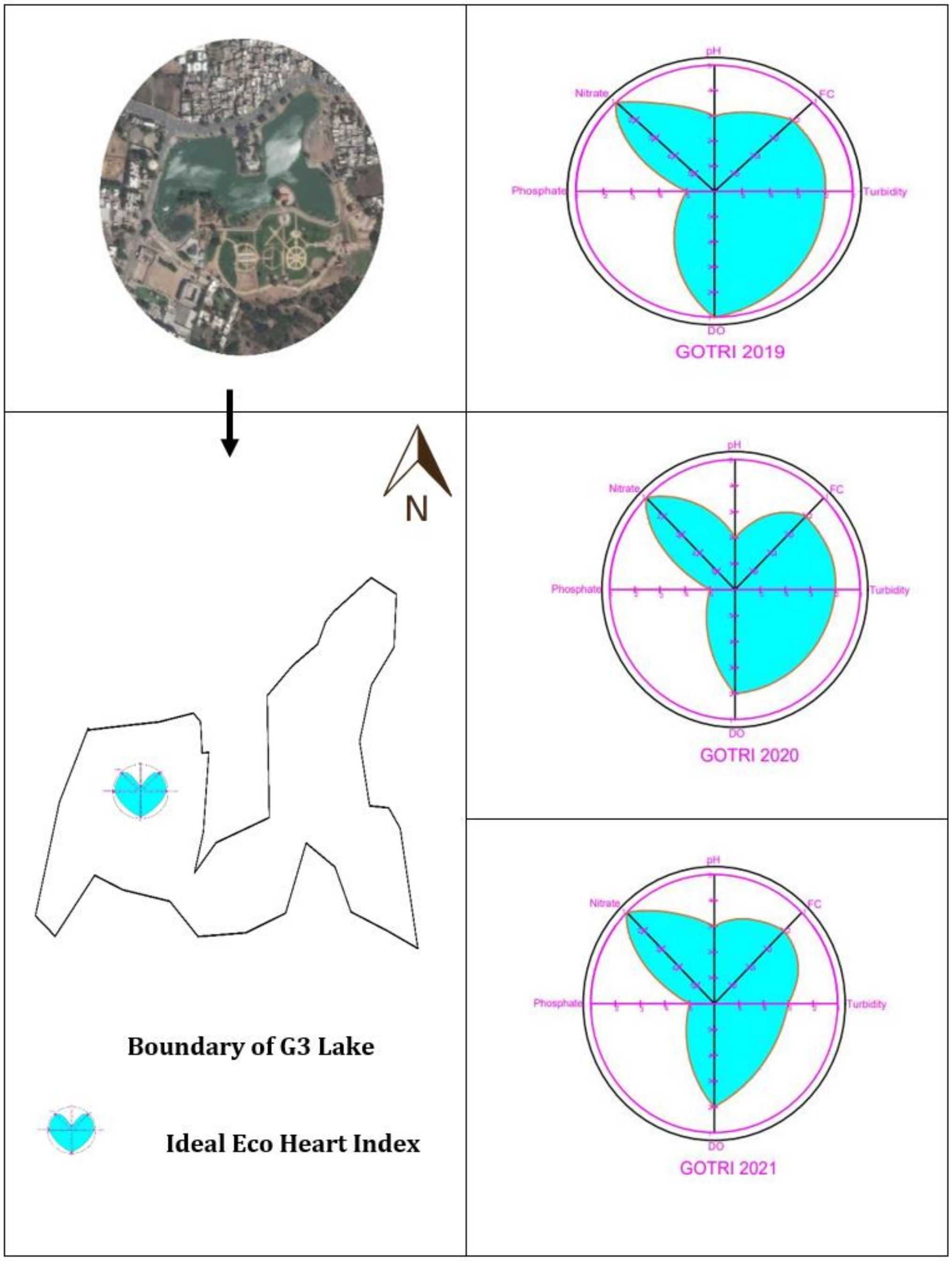

Figure 9: Eco-Heart Index of S3 Lake for 3 years 2019-2020-2021

For S4 Lake, in 2019, the heart was formed with a pointed curve for 5 out of 6 parameters, making it halfway to produce a full heart. All the other parameters fell under the acceptable range, other than phosphate, which fell under class 3, changing the entire shape of the heart. For 2020 and 2021, a deshaped heart was formed, where all the parameters were in the same class range, except phosphate, which fell under class 4. Water quality deteriorated in 2020–2021, compared to that of 2019, making it moderately to slightly polluted water as shown in below Figure 10.

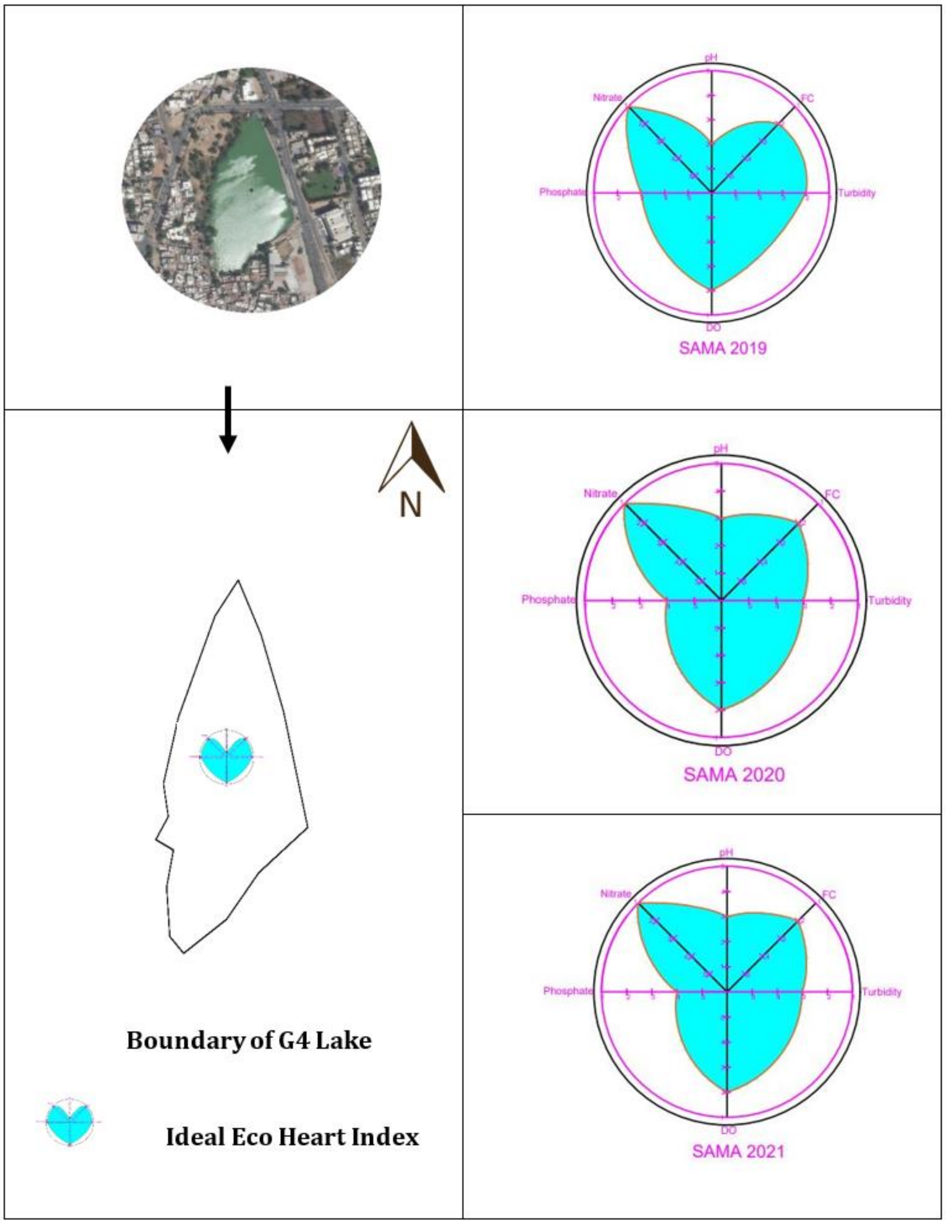

Figure 10: Eco-Heart Index of S4 Lake for 3 years 2019-2020-2021

To understand the fate of the Eco-Heart index in sustainably evaluating the status of the water body, its correlation has been established with the NSFWQI. Both indices showed a moderate positive correlation of 0.4951. A moderate relationship was observed due to the parameter selection, as both were compared using six parameters. However, in NSFWQI, nine parameters are generally considered, the parameter weightage system, which is not seen in EHI, the range classification concept used in EHI, and the weightage graph, which has been used in NSFWQI and not in EHI as it is independently derived to gain basic quality knowledge of water bodies. Despite all these variations, a positive correlation indicated that EHI could be used in assessing the status of water bodies to give the common people a basic idea about water quality. Subsequently, the scientifically developed index can also be interlinked for better and more detailed assessment.

From the results, it was observed that for 2019, all the water bodies could be classified under the clean to moderate class but for 2020 and 2021, the water quality deteriorated for all four ponds. The main parameters, which influence this, were phosphate, turbidity, and pH. A high level of phosphate was mainly due to the sewage discharge and solid waste disposal into the lake bodies, which increased the eutrophication level and lead to the contaminant layer formation by increasing the turbidity level. Thus, the turbidity level increased due to pollutant dispersion from the surrounding areas and improper disposal of solid wastes, such as paper, plastics, and flowers, as all the water, bodies were located near commercial and residential areas. pH fluctuations were observed due to varying anthropogenic activities observed at the water body (Parmar & Samnani, 2022).

All water bodies studied exhibited a deshaped heart and a full heart was not seen for a single water body, indicating that none of the water bodies fell under pristine quality. Since the contributing parameters were only one or two, the water can probably be used for better purposes using simple treatment methods.

To know the effectiveness of the Eco-Heart Index at ground level, a survey was carried out. A google form and personal interaction with people living near water bodies were used in the survey. The total sample size for the study area was 385, out of which 300 data were recorded with all responses making it 78% responses in total. 10 questions were asked with a pictorial representation of the Eco-Heart Index for people to understand the concept and how such a tool can be used for future sustainable practices. The effectiveness and connectivity of the questions asked were assessed using the Cronbach Alpha method. The Cronbach Alpha test evaluates the reliability of the questions in the questionnaire, and the results showed that they had a reliability rating of 0.97 indicating excellent reliability.

Results from the survey are presented below in Figure (11–13). 67% of the people were able to understand the idea of the Eco-Heart Index with 60% in favour of the Eco-Heart Index being the next sustainable tool. However, from the management point of view, mixed responses were gathered, some people opted for using both indices (Numerical and Pictorial) for representation, but some showed disagreement over the new index helping in the conservation of water bodies just by the use of a picture. People living around the periphery of water bodies showed a 50–50 response in use of the Eco-Heart index as many use that water on a day-to-day purpose, so according to them such activity would affect their daily chores while some opted for placing such an image on the periphery so that nearby people would stop polluting the water by throwing garbage to the water body. Such practices would prevent water from being contaminated.

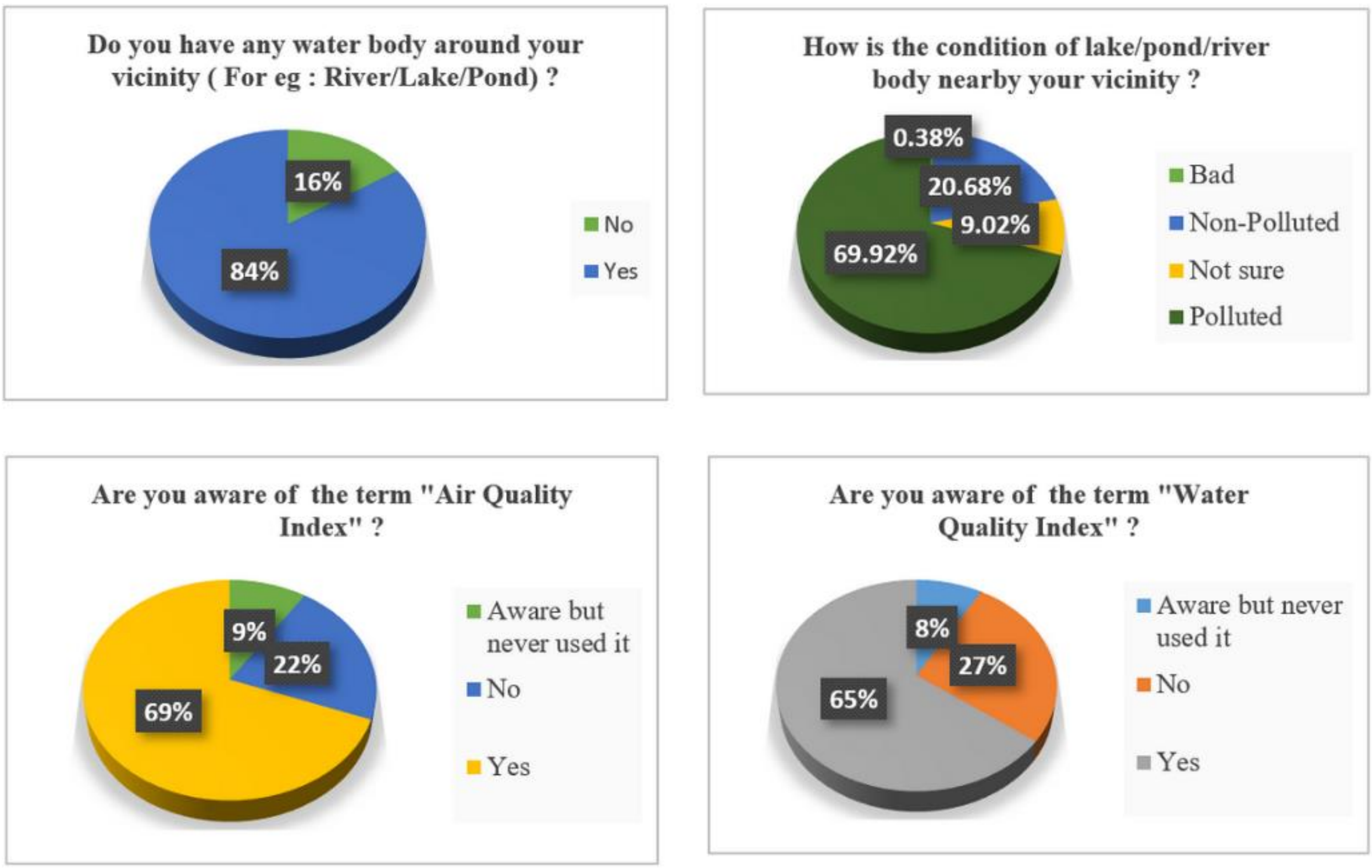

Figure 11: Survey results

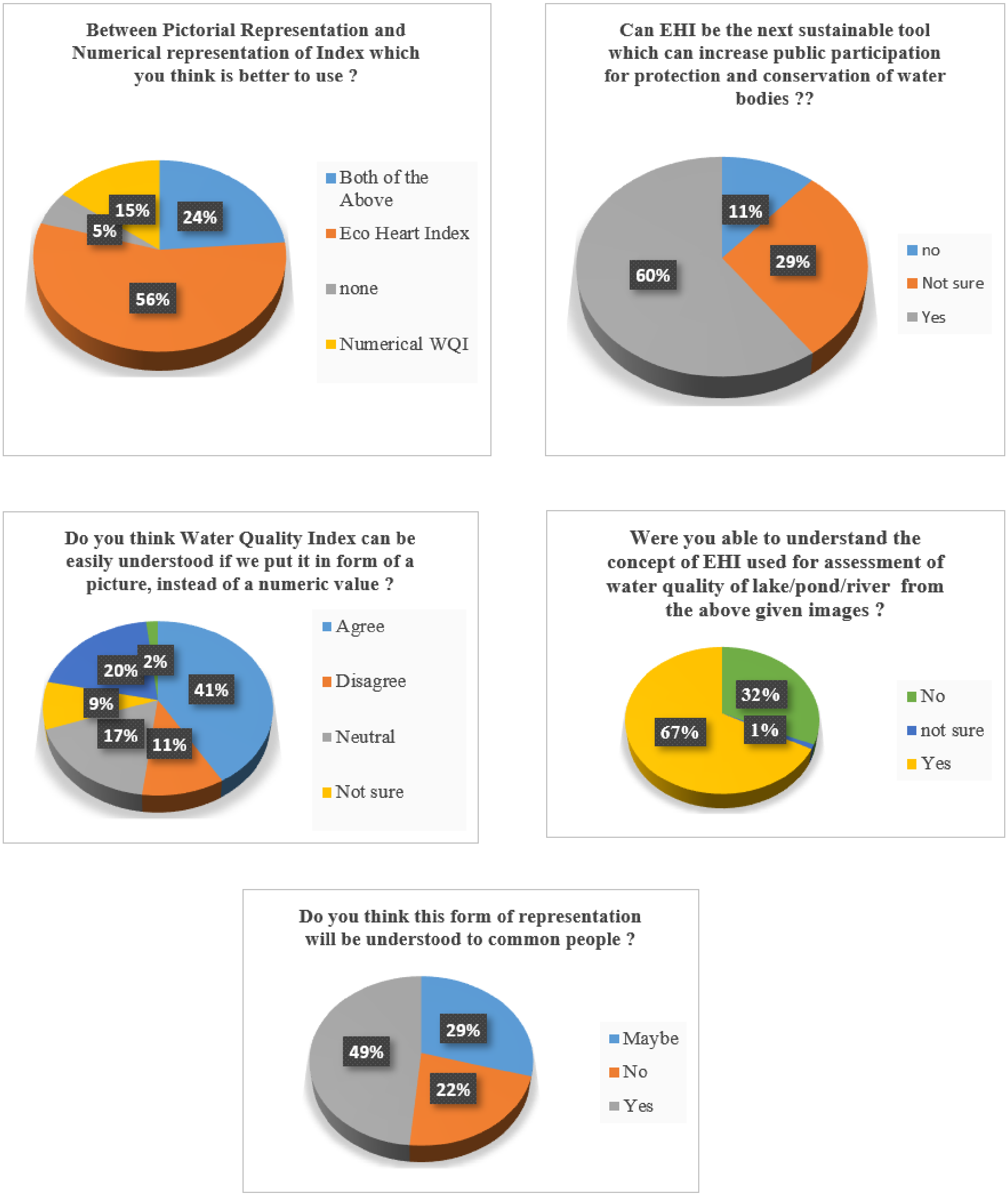

Figure 12: Survey results

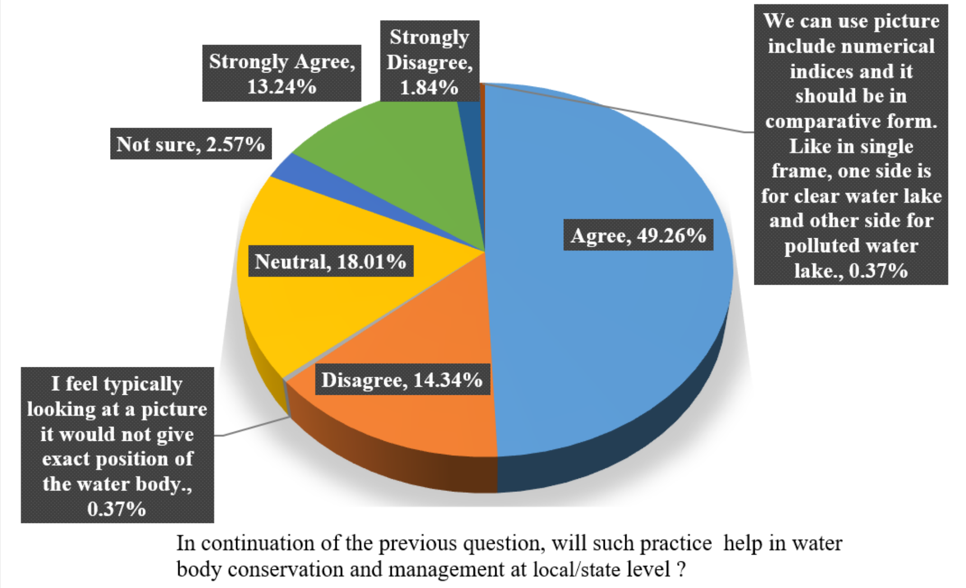

Figure 13: Survey results

Conclusion

Interpreting WQI has been one of the crucial issues for water quality assessment, and the concept of EHI helps to efficiently evaluate the status of the water body, as it is considered a community-based model for a sustainable approach, developed for the common people. Interpretation in the form of a heart shape, which symbolizes love and peace would be more attractive and would involve people's interest in understanding and accepting it and spreading awareness about the urgent need to save the water bodies by just a small figure. The current scarcity of freshwater tends to indicate the use of lake water for domestic or industrial applications, and hence, its assessment should be based on this understanding and requires modifications in the computation of WQIs. EHI is a simple tool that can be used by common people by assessing it with parameter handy tools. The involvement of six parameters gives a quick informative interpretation of the quality of water bodies, which can be modified as per the requirement of the water body. A positive correlation is formed with NSFWQI; thus, it can be used as an alternative tool for water quality evaluation. Re-categorization of the defined ranges can also be independently conducted according to the pollution load received by the water body and seasonal variation. The questionnaire survey also showed a positive response from people for the implementation of the Eco-Heart index as the new sustainable index. Thus, EHI can be considered a community-based water quality indicator with multiple functions.

Declarations

Conflict of Interest Statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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