BASIC STATISTICS IN WATER QUALITY ASSESSMENT: A REVIEW ON WATER QUALITY INDEX (WQI) MODEL

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Abstract

The water quality index (WQI) is a statistical tool for evaluating water quality which converted a large data set in to single numerical value. Most of the WQI models involves four successive steps viz. selection of parameters, estimation of values, generation of sub-indices for each parameter, calculation of the parameter weighting values, and aggregation of sub-indices to compute the overall water quality index. In this paper a study has been carried out in the genesis and evaluation of WQI model and the statistical techniques used in different models. The uncertainty in the conversion of large amounts of water quality data into a single index associated with different aggregation methods also discussed here. Finally a comparative discussion of the most commonly used WQI models viz. Horton's WQI, NSF WQI, SRDD-WQI including the different model structures and its components.

Key words: WQI, weight, aggregation etc.

1. INTRODUCTION

The suitability of water for drinking, industrial and irrigational use is always assess by physico-chemical parameters of water. Assessment and management of water quality requires the collection and analysis of large water quality parameters. The common physico-chemical parameters are pH, Electrical Conductance (EC), Turbidity, Dissolved Oxygen (DO), Alkalinity, Total Dissolved Solids (TDS), Chloride (Cl^-), Hydrogen Carbonate (HCO_3^-), Sulphate (SO_4^{2-}), Fluoride (F^-), Nitrate-Nitrogen (NO_3^--N), Sodium (Na), Potassium (K), Calcium (Ca), Magnesium

(Mg), Boron (B), Iron (Fe) and Arsenic (As). The experimental results of the physico-chemical parameters are compared with the standards guideline values such as World Health Organization (WHO) and Bureau of Indian Standard (BIS) to address the specific problems of water sources properly.

Analysis of water samples for different quality parameters generates large datasets, therefore, accurate and sufficient information from experimental data of water quality parameters is inevitable to form a public policy and to implement the water quality improvement programmes. Water Quality Index (WQI) is valuable and unique statistical approach to depict the experimental quality status of various physico-chemical parameters of water in to a singleterm that is understandable and usable by the public Tyagi*et al.*, (2013). WQI is commonly used for the detection and evaluation of water pollution and may be defined as a reflection of composite influence of different quality parameters on the overall quality of water Horton, (1965). It is helpful for the selection of appropriate treatmenttechnique to meet the concerned issues in a particular region.

The WQI is tool which expresses large numbers of experimental water quality parameter data in to a single number by aggregation of specific water quality parameters Uddin *et al.*, (2021). Usually the higher to lower score of WQI represents water quality from excellent to degraded quality.

Aggregation of different water quality data sets to WQI comprises four stages. Firstly, selection of the water quality parameters, secondly estimation of the parameter and conversion in to a single value dimensionless sub-index. Thirdly determination of weighing factor to each selected parameters and fourthly calculation of WQI by an aggregation function using the sub-indices and weighting factors for all water quality parameters. Many different WQI models have been developed with variations in model structure, the parameters included and their associated weightings, and the methods used for sub-indexing and aggregation (for details see Debels*et al.*,2005; Jha*et al.*, 2015;Sun *et al.*, 2016).

The concept of water quality to public health was first recognized in UK considering one indices of water quality called saprobic index (SI) (see Kannel*et al.*, 2007; Lumb*et al.*, 2011).

Saprobic Index (SI) is defined as the degree to specify the loading of easily degradable organic matter in flowing waters. Different organisms present in water bodies have different saprobic rates and this principle was the basis for the determination of SI Lumb*et al.,* (2011). The SI is the measure of the level of organic pollution in water.Most of the WQI model components have been developed based on expert views and local guidelines, therefore, many models are therefore region-specific (see Hsu and Sandford, 2007; Said*et al.,* 2004)

The primary aim of this work is to critically review the most commonly used WQI models in different regions of the world (Table 1). The review identified seven basic WQI models from which most other WQI models have been developed. This work also present a brief history of development of WQI models. Finally an overview of the basic structure of WQI models and describes in detail the four major structural elements of most models, namely, selection of parameters, sub-indexing of parameters, weighing of parameters and index aggregation.

2. BRIEF HISTORY OF WQI MODELS

Most of the WQI models have been developed over last 50 years. The numerical indices to assess the quality of water was first developed by Horton in 1965. Horton expressed the new method in the form of an index number system for rating water quality and defined a mathematical form of WQI by selecting, rating and integrating the 10 significant water quality parameters Horton, (1965). In 1970 Brown with support from the National Sanitation Foundation, developed a more rigorous version of Horton's WQI model, the NSF-WQI, for which a panel of 142 water quality experts informed the parameter selection and weighting Abbasi and Abbasi (2012). In the year 1973, the Scottish Research Development Department (SRDD) developed their SRDD-WQI for assessment of river water quality. Based on SRDD-WQI the Bascaron Index (1979), House Index (1986) and Dalmatian Index are developed. Steinhart *et al.* (1982) later developed the Environmental Quality Index or Great Lake Index model for the assessment of water quality in the Great Lakes ecosystems (see Noori*et al.,* 2019, Uddin *et al.,* 2017).

During 1995 British Columbia Ministry for Environment developed another important WQI called British Columbia WQI (BCWQI) to evaluate the quality status of many waterbodies in the province of British Columbia, Canada Saffran*et al.,* (2001).

The Water Quality Guidelines Task Group of the Canadian Council of Ministers of the Environment modified the BCWQI and developed the CCME WQI in 2001 (Saffran*et al.*, 2001, Lumb *et al.*, 2011). At present more than 35 WQI models have been reported by different countries and agencies and 82% of applications have been to assess the river water quality (see Abbasi and Abbasi, 2012, Uddin *et al.,* 2021).

Table 1: Most commonly used WQI models and regions of use

Sl No.	Name of WQI	Region of Use	Sl No.	Name of WQI	Region of Use
1	SRDD Index	Scotland	10	Hanh Index	Vietnam
2	NSF Index	USA	11	Smith Index	New Zealand
3	Dinius Index	Albama State	12	Horton Index	USA
4	Great Lake Index	Canada & USA	13	Almedia Index	Argentina
5	Oregon Index	Oregon State	14	House Index	UK
6	Said Index	Florida State	15	Bascaron Index	Spain
7	CCME Index	Canada	16	Dojildo Index	Poland
8	West Java Index	Indonesia	17	British Columbia Index	Canada
9	Malaysian Index	Malayasia	18	Liou Index	Tiwan

3. THE GENERAL WQI MODEL STRUCTURE

The general structure of most of the WQI models contains following four stages (Abbasi and Abbasi, 2012; Sutadian*et al.*, 2018).

Stage I: Selection of the water quality parameters: One or more water quality parameters are selected for inclusion in the assessment

Stage II: Generation of the parameter sub-indices: Conversion of parameter concentrations to unit less sub-indices

Stage III: Assignment of the parameter weight values: Parameters are assigned weightings depending on their significance to the assessment

Stage IV: Computation of the water quality index using an aggregation function: The individual parameter sub-indices are combined using the weightings to give a single overall index. Finally a rating scale is usually used to classify the water quality based on the overall index value.

Parameter selection is the initial stage of the WQI process. Considerable variation was observed between different models in terms of types and number of parameters selected and the reasons for selecting them. The number of parameters used in different models ranges from 4 to 26, but most of the models employed 8 to 11 water quality parameters. The CCME WQI, the Roos WQI and the Said WQI models used only four parameters while the Bascaron WQI model recommended twenty-six (26) parameters Uddin *et al.,* (2021). The most commonly included parameters are temperature, turbidity, pH, suspended solids (SS), total dissolved solids (TDS), faecal coliforms (FC), dissolved oxygen (DO), biochemical oxygen demand (BOD) and nitrate nitrogen (NO_3-N).Selection of parameters based on data availability, expert opinion or the environmental significance of a water quality parameter.

Sub-indexing of parameters is the process to convert parameter concentrations into unitless number known as parameter sub-indices Abbasi and Abbasi (2012). Most of the WQI models used standard guideline values of water quality such as WHO to establish the sub-indices Sutadian*et al.,* (2016). While most of the reviewed models the CCME model and the Dojildo model omitted the step and performed the final aggregation function using the parameter concentrations directly Dojlido*et al.* (1994).

In the Horton WQI, the Dinius WQI, the Dalmatian WQI, the Liou WQI and Said WQI the measured parameter concentrations directly used as the sub-index values without any conversion process.

In the NSF WQI model used the linear interpolated functions based on recommended water quality standard range with the estimated values to compute the sub-index values (Lobato*et al.* 2015, Tomas *et al.* 2017). The sub-index scale ranged between 0 and 100; when parameter concentrations were found below the standard, then the sub-index value was assigned 100, otherwise, 0 (Lobato*et al.* 2015, Misaghi*et al.* 2017). The West Java WQI model used simple linear interpolation function using following equations:

$$S_i = S_1 - \left[(S_1 - S_2) \frac{(X_i - X_1)}{(X_2 - X_1)} \right] \dots \dots \dots \dots (1)$$

$$S_i = S_1 - \left[(S_1 - S_2) \frac{(X_1 - X_i)}{(X_1 - X_2)} \right] \ldots\ldots\ldots\ldots (2)$$

Where, where Si is the sub-index value for water quality parameter *i*computed for the measured value *Xi*. S1 and S2 are the maximum and minimum sub-index values for the maximum and minimum guideline values (X1 and X2) for parameter *i*. Eq. (1) is used when the measured parameter value is higher than the upper guideline value otherwise Eq. (2) is used Sutadian*et al.* (2016).

In some index model the sub-index is calculated for a parameter by dividing the measured value of the parameter by the maximum permissible value of the parameter.The Environmental Quality Index (EQI) or Great Lakes Index used rating curve functions for transforming measured values of water quality parameters to dimensionless values Sutadian *et al.* (2017). The Oregon WQI model applied logarithmic transformations and a nonlinear regression Cude (2001). The rating curve technique is used in the Almeida WQI, the House WQI and the HanhWQI models. The rating curve system was developed based on water quality parameter standard guidelines that were formulated by legislative bodies or concerned authorities such as WHO, BIS etc. Sutadian*et al.* (2016).

Parameter weighting is based on the relative importance of the water quality parameter Sarkar and Abbasi (2006). The majority of WQI models applied unequal weighting techniques where the sum of all of the parameter weight values was equal to 1. The Horton WQI, Bascaron WQI and Ameida WQI models also used unequal weighting but the weightings were integers and the sum of the total weight were greater than 1. In the Oregon WQI model assigned an equal weighting to each selected parameters. On the other hand, the CCME WQI, the Smith WQI, and the DojildoWQI models did not used the weight values for estimating the final score.

Two approaches have been commonly used for obtainingappropriate parameter weight values; expert opinion and Delphi technique to inform the parameter weighting process Sarkar and Abbasi (2006). The Horton WQI, NSF WQI, SRDD WQI, Ross WQI, House WQI, Dalmatian WQI and Almeida WQI models used the Delphi technique to develop their parameter weightings whereas the House WQI adopted the key personnel interview technique for the appropriate parameter weight values. The West-Java WQI model applied the Analytic Hierarchy Process (AHP) technique for formulating parameter weight values Sutadian*et al*. (2017).

Aggregating functions means aggregation of the parameter sub-indices into a single water quality index score. Most models have used either additive functions or multiplicative functions or a combination of the two.

Additive Aggregation:

Mathematically it is express as

$$WQI = \sum_{i=1}^{n} w_i S_i$$

Where *Si* is the sub-index value for parameter *i*, *wi*(which ranges from 0 to 1) is the corresponding parameter weight value and *n* is the total number of parameters.

The Horton WQI, SRDD WQI, NSF WQI, House WQI, Malaysian WQI and Dalmatian WQI models employed the additive aggregation function.

Multiplicative Aggregation:

The multiplicative aggregation function expressed as:

$$WQI = \prod_{i=1}^{n} (S_i)^{w_i}$$

The modified NSFWQI, West Java WQI and LiousWQI models used this aggregation function.

Combination of additive and multiplicative aggregating functions also used in several models for obtaining the final WQI score Abbasi and Abbasi (2012). Taiwan WQI and the NSF WQI model uses both additive and multiplicative functions.

Square Root of the Harmonic Mean Function:

Mathematically,square root of the harmonic mean function is

$$WQI = \sqrt{\frac{n}{\sum_{i=1}^{n} \frac{1}{{S_i}^2}}}$$

Oregon WQI model used this aggregation method.

Minimum Operator Function:

In this method the minimum sub-index values for parameters are taken as the total water quality index values. Smith developed this index to assess the water quality of the rivers and streams in New Zealand. Mathematically,

$$WQI = Min(s_i + s_{i+2} + s_{i+3} + \cdots . I_{sub})$$

Unique Linear/Non-linear Aggregation Functions:

The WQI models (Said WQI) in which the parameter concentrations are uses as the sub-index values, aggregates the final WQI using the following unique logarithmic function.

$$WQI = log\left[\frac{(DO)^{1.5}}{0.14(SC)^{0.5} + (3.8)^{TP}(Turbi)^{0.15}(15)^{fecal}/_{10000}}\right]$$

4. SOME COMMON WQI MODELS

Horton's Water Quality Index:

Horton derived a WQI considering eight water quality parameters viz. sewage treatment, dissolved oxygen (DO), pH, coliform density, specific conductance, carbon chloroform extract, alkalinity and chlorides. A rating scales from 0 to 100 for each parameter were assigned and each parameter wasthen weighed (weighting factor 1 to 4) according to itsrelative impact on quality. The parameters which have more significant on quality, given the weight of 4. Horton assigned weight 4 to sewage treatment, DO and pH and chloride and alkalinity were given the weightof 1. Another two parameters temperature and obvious pollution (m_1 and m_2) also included in the form of multiplicative factors in the mathematical expression.

The parameter weight values were established by using the Delphi technique. Environment significance and relative impacts were considered for giving weight values. The expert panel assigned weight values between 1 and 4 to the various water quality parameters. Horton proposed 1 for four parameters (special conductivity, chlorides, alkalinity and carbon chloroform extract), 2 for one parameter (faecal coliforms) and 4 for three parameters (DO, sewerage treatment and pH). The mathematical expression was

$$WQI = \left[\frac{w_1S_1 + w_2S_2 + w_3S_3 + \cdots \dots \dots \dots \dots . +w_nS_n}{w_1 + w_2 + w_3 + \cdots \dots \dots \dots \dots w_n}\right] m_1m_2$$

Here, obvious pollution refersto tangible pollution which includes formation of sludge, deposits,presence of oil, debris, foam, etc. that creates coloror odor nuisance.

In the above expression, *S* represent the rating number also called sub-index assigned to each parameters ranging from 0–100, *w*'s are weighting factors from 1 to 4, *n* stands for number of parameters used for evaluating the WQI. In Horton's WQI method *n* was equal to 8, $m_1$is a correction factor for temperature (0.5 when temperature is less than 34°C, otherwise 1), m_2 is the correction factor for pollution (0.5 or 1).The resultant water quality index also hadvalues in the range from 0 to 100 with higher values signifyinga better quality and vice versa.

In 1970, Brown completed a critical review and rated as well as recommended the weight values to the additional parameters temperature and obvious pollution and developed a new weight average aggregation function as follows:

$$WQI = \sum_{i=1}^{n} w_i S_i$$

The Horton model recommends the following five water quality classes for the value of the final water quality index: Very good (WQI = 91–100), Good (WQI = 71 – 90), Poor (WQI = 51 – 70), Bad (WQI = 31 – 50) and Very bad (WQI = 0 – 30).

National Sanitation Foundation Water Quality Index (NSFWQI):

It is a modified version of Horton's model developed by Brown. In this modelthe Delphi technique was used to select the water quality parameters (Tomas et al., 2017). A total of 11 parameters are proposed; temperature, turbidity and total solids, pH and dissolved oxygen, faecal coliforms and BOD, total phosphate and nitrates**,** pesticides and toxic compounds. (Abbasi and Abbasi, 2012; Sutadian*et al.,* 2016). The parameter sub-indexing was developed based on expert panel judgment. Sub-index values ranged from 0 to 1 where the sub-index value was considered 1 when the measured value was found to be within the recommended guideline values and 0 otherwise Sutadian *et al.* (2016).

The model uses unequal parameter weight values which summation equal to 1. Originally weight values were obtained by employing an expert panel but subsequent applications of the model have used modified weight values. The original NSF model prescribed weight values for DO (0.17), FC (0.16), pH (0.11), BOD (0.11), temperature (0.10), total phosphate (0.10), nitrates (0.10), turbidity (0.08) and total solids (0.07).

The aggregation of sub-indices used both additive and multiplicative functions. The model proposed five water quality classes: Excellent (WQI = 90–100), Good (WQI = 70–89), Medium (WQI = 50–69), Bad (WQI = 25–49), Very bad quality (WQI = 0–24).

Scottish Research Development Department (SRDD) WQI:

The SRDD model has been continually developed by the Scottish Research Development Department since 1970 to evaluate surface water quality Sutadian *et al.* (2016). Most temperate and tropical-sub-tropical countries such as Iran, Romania and Portugal apply the SRDD model due to its flexibility and regional convenience.

The SRDD model also applied the Delphi technique for selecting water quality parameters. A total of 11 parameters temperature, conductivity and suspended solids, DO, pH and free and saline ammonia, total oxide, nitrogen, phosphate, BOD) and *Escherichia coli* (*E. coli*) were considered for this model. The parameter sub-index values were obtained using the Delphi technique (Bordalo, 2001; Shah and Joshi, 2015; Gupta *et al.,* 2017). Sub-index values range from 0 to 100. The rating curve technique was applied to calculate sub-indices; the curves were developed based on expert opinions.

The model uses fixed, unequal weightings to the parameters that their summation equal to 1. The SRDD recommended weight values were for DO (0.18), BOD (0.15), free and saline ammonia (0.12), pH (0.09), total oxidized nitrogen (0.08), phosphate (0.08), suspended solids (0.07), temperature (0.05), conductivity (0.06) and E. Coli. (0.12).

The aggregation of parameters uses the following modified additive function:

$$SRDD - WQI = \frac{1}{100}\left(\sum_{i=1}^{n} S_i w_i\right)^2$$

The model proposed a seven-category rating scale for evaluating water quality as Clean (WQI = 90 – 100), Good (WQI = 80 – 89), Good without treatment (WQI = 70 – 79), Tolerable (WQI =

40 – 69), Polluted (WQI = 30 – 39), severely polluted (WQI = 20 – 29) Piggery waste (WQI = 0 – 19).

5. DISCUSSIONS AND CONCLUSIONS

In all WQI models provide rating scale for evaluating the water quality hiding the true nature of the water quality as well as the most impacting parameter in water quality, which is known as model eclipsing problem (Mahmood, 2018; Banerjee and Srivastava, 2009). The eclipsing problem can be caused by inappropriate sub-indexing rules, parameter weightings that do not reflect the true relative influences of parameters, or inappropriate aggregation functions (Smith, 1990; Abbasi and Abbasi, 2012). The Smith WQI model recommended using the minimum operator index aggregation function to minimize eclipsing problems.

Furthermore, for the same water quality data different aggregation functions formulate different WQI index ratings. Thus, it is difficult to identify the exact water quality status of the water source. The aggregation function has been shown to be a major source of uncertainty (Smith, 1990, Ramachandramoorthy *et al.,* 2010). The correctness of the model depends on the selection of parameters. The number of parameters used in different models ranges from 4 to 26. Some model fixed the parameters some has flexibility in selection of parameters. Most of the model do not uses toxic parameters. The extreme value parameters are also important from statistical point of view. Non availability of data due to insufficient instrument facility may lead the model in different way.In this study we have seen the various WQI models used in water quality assessment. This review was conducted to investigate the structures and mathematical formulations used in WQI models. Study shows that most of the model comprises four stages. In all models uses common parameters. Less numbers of model uses toxic chemicals. It is necessary to develop new WQI models including the toxic parameters.

REFERENCES

[1] Tyagi, S., Sharma, B., Singh, P. and Dobhal, R. (2013). Water quality assessment in terms of water quality index. *American J. Water Resource,* 1(3), 34–38.

[2] Horton, R. K. (1965). An index number system for rating water quality. *J. Water Pollution Control Federation*, 37(3), 300–306.

[3] Uddin, G., Nash, S. and Olbert, A. I. (2021). A review of water quality index models and their use for assessing surface water quality. *Ecological Indicators*, 122, 107218.

[4] Debels, P., Figueroa, R., Urrutia, R., Barra, R. and Niell, X., (2005). Evaluation of water quality in the Chill´an River (Central Chile) using physicochemical parameters and a modified Water Quality Index. *Environ. Monit. Assess*. https://doi.org/10.1007/ s10661-005-8064-1.

[5] Jha, D. K., Devi, M. P., Vidyalakshmi, R., Brindha, B., Vinithkumar, N. V. and Kirubagaran, R., (2015). Water quality assessment using water quality index and geographical information system methods in the coastal waters of Andaman Sea, India. *Mar. Pollut. Bull*, 100, 555–561. https://doi.org/10.1016/j.marpolbul.2015.08.032.

[6] Kannel, P. R., Lee, S., Lee, Y. S., Kanel, S. R. and Khan, S. P., (2007). Application of Water Quality Indices and Dissolved Oxygen as Indicators for River Water Classification and Urban Impact Assessment. *Environ. Monit. Assess*, 132, 93–110. https://doi. org/10.1007/s10661-006-9505-1.

[7] Sun, W., Xia, C., Xu, M., Guo, J. and Sun, G., (2016). Application of modified water quality indices as indicators to assess the spatial and temporal trends of water quality in the Dongjiang River. *Ecol. Indic*. 66 https://doi.org/10.1016/j.ecolind.2016.01.054.

[8] Lumb, A., Sharma, T. C. and Bibeault, J. F. (2011). A Review of Genesis and Evolution of Water Quality Index (WQI) and Some Future Directions. *Water Qual Expo Health* (2011) 3, 11–24, DOI 10.1007/s12403-011-0040-0.

[9] Said, A., Stevens, D. K., Sehlke, G. (2004). An innovative index for evaluating water quality in streams. *Environ Manag*, 34(3), 406–414.

[10] Hsu, C. and Sandford, B. A. (2007). The Delphi Techniques: Making sense of consensus. *Pract. Assess. Res. Eval.*, 12, https://doi.org/10.1576/toag.7.2.120.27071.

[11] Abbasi, T. and Abbasi, S. A. (2012). Water-Quality Indices. *Water Quality Indices*, 353–356. https://doi.org/10.1016/B978-0-444-54304-2.00016-6.

[12] Steinhart, C. E., Schierow, L. J. and Sonzogni, W. C. (1982). An environmental quality index for the great lakes. *JAWRA J. Am. Water Resour. Assoc*. https://doi.org/10.1111/ j.1752-1688.1982.tb00110.x.

[13] Saffran, K., Environment, A., Cash, K. and Canada, E. (2001). Canadian Water Quality Guidelines for the Protection of Aquatic Life CCME Water Quality Index, User's Manual. Quality 1–5.

[14] Sutadian, A. D., Muttil, N., Yilmaz, A. G. and Perera, B. J. C. (2016). Development of river water quality indices–a review. *Environ. Monit. Assess*, 188, 1–29. https://doi.org/ 10.1007/s10661-015-5050-0.

[15] Dojlido, J., Raniszewski, J. and Woyciechowska, J. (1994). Water quality indexapplication for river in Vistula River basin in Poland. *Water SciTechnol*, 30(10). 57–64.

[16] Lobato, T. C., Hauser-Davis, R. A., Oliveira, T. F., Silveira, A. M., Silva, H. A. N., Tavares, M. R. M. and Saraiva, A. C. F. (2015). Construction of a novel water quality index and quality indicator for reservoir water quality evaluation: A case study in the Amazon region. *J. Hydrol*., 522, 674–683. https://doi.org/10.1016/j.jhydrol.2015.01.021.

[17] Tomas, D., Curlin, M. and Mari´c, A. S. (2017). Assessing the surface water status in Pannonian ecoregion by the water quality index model. *Ecol. Indic.*, 79, 182–190. https://doi. org/10.1016/j.ecolind.2017.04.033.

[18] Misaghi, F., Delgosha, F., Razzaghmanesh, M. and Myers, B., (2017). Introducing a water quality index for assessing water for irrigation purposes: A case study of the GhezelOzan River. *Sci. Total Environ*, 589, 107–116. https://doi.org/10.1016/j. scitotenv.2017.02.226.

[19] Sutadian, A. D., Muttil, N., Yilmaz, A. G. and Perera, B. J. C. (2017). Using the Analytic Hierarchy Process to identify parameter weights for developing a water quality index. *Ecol. Indic*., 75, 220–233. https://doi.org/10.1016/j.ecolind.2016.12.043.

[20] Cude, C. G. (2001). Oregon water quality index: A tool for evaluating water quality management effectiveness. *J. Am. Water Resour. Assoc*. https://doi.org/10.1111/ j.1752-1688.2001.tb05480.x.

[21] Sarkar, C., Abbasi, S. A. (2006). Qualidex – A new software for generating water quality indice. *Environ. Monit. Assess*. 119, 201–231. https://doi.org/10.1007/s10661-005- 9023-6.

[22] Bordalo, A. (2001). Water quality and uses of the Bangpakong River (Eastern Thailand). *Water Res.*, 35, 3635–3642. https://doi.org/10.1016/S0043-1354(01)00079-3.

[23] Smith, D. G. (1990). A better water quality indexing system for rivers and streams. *Water Res*. https://doi.org/10.1016/0043-1354(90)90047-A.

[24] Noori, R., Berndtsson, R., Hosseinzadeh, M., Adamowski, J. F. and Abyaneh, M. R., (2019). A critical review on the application of the National Sanitation Foundation Water Quality Index. *Environ. Pollut.* https://doi.org/10.1016/j.envpol.2018.10.076.

[25] Uddin, M. G., Moniruzzaman, M. and Khan, M. (2017). Evaluation of Groundwater Quality Using CCME Water Quality Index in the Rooppur Nuclear Power Plant Area, Ishwardi, Pabna, Bangladesh. *Am. J. Environ. Prot.*, 5, 33–43. https://doi.org/ 10.12691/env-5-2-2.

[26] Shah, K. A. and Joshi, G. S. (2015). Evaluation of water quality index for River Sabarmati, Gujarat, India. *Appl. Water Sci.* https://doi.org/10.1007/s13201-015-0318-7.

[27] Gupta, N., Pandey, P. and Hussain, J. (2017). Effect of physicochemical and biological parameters on the quality of river water of Narmada, Madhya Pradesh. India. *Water Sci*., 31, 11–23. https://doi.org/10.1016/j.wsj.2017.03.002.

[28] Mahmood, A. (2018). Evaluation of raw water quality in Wassit governorate by Canadian water quality index. *MATEC Web Conf.*, 162, 122–129. https://doi.org/10.1051/ matecconf/201816205020.

[29] Banerjee, T. and Srivastava, R. K. (2009). Application of water quality index for assessment of surface water quality surrounding integrated industrial estate-Pantnagar. *Water Sci. Technol.* https://doi.org/10.2166/wst.2009.537.

[30] Ramachandramoorthy, T., Sivasankar, V. and Subramaniam, V. (2010). The seasonal status of chemical parameters in shallow coastal aquifers of Rameswaran Island, India. *Environ Monit Assess*, 160, 127–139.