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Assessment of Water Quality by RSM and ANP: A Case Study in Tripura, India

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Abstract: Assessment of water quality is essential to check suitability of water for use in various purposes. Indexing is a practical and concise way of representing the overall quality of water. Many such indexing methods are available with different goal and purpose. For indexing purpose importance of different Water Quality Parameters needs to be determined first. In the present study, importance of Water Quality Parameters were determined on the basis of important criteria like potential hazards, cost of mitigation, utilization scope and popularity among the researchers. The importance of criteria were determined by Response Surface Methodology (RSM), whereas the scoring of importance was performed by Analytic Network Process (ANP). For validation of the proposed index, a case study was performed by water quality data of different water bodies in Tripura, India. The proposed Water Quality Index of the sample water bodies were then compared with the Water Quality Indices of National Sanitation Foundation (NSF WQI). Results indicate that the proposed index is very close to NSF WQI. Thus the proposed index seems to be successful in expressing the overall quality of water.

Key words: Water quality index, analytic network process, response surface methodology, Tripura, India.

Introduction

Clean water being a limited but absolutely essential resource, assessment of water quality is always of a great concern. A concise, convenient and easy to conceive way of water quality assessment is to express it by means of Water Quality Index (WQI). In this study, an objective and non-preferential WQI was attempted to develop.

Water Quality Index

The quality of water can be measured using a range of indicators. In practice, as no single measure is likely to give a true representation of the state of the resource, composite indicators are often used which aggregate measures in different ways. These usually take the form of a WQI, which is a concise numerical representation of the overall quality of water. It has been popularised owing to its convenience, both in terms of calculation as well as its ease of interpretation (Tyagi et al., 2013). In essence, the WQI is a function of the Water Quality Parameters considered and their concentrations (Equation 1).

Equation 1: WQI is a function of parameters and their concentration

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$$WQI = f(P, C)$$

where P = Water quality parameters, C = Concentration of water quality parameters, and $C \in R \wedge C > 0$, R being the set of real numbers.

Despite a lack of uniformity in representations of water quality around the world, most nations rely on indices as indicators. Many of these operate by normalizing the observed data according to study objectives. Typically these objectives are related to notions of favourable and un-favourable, or "good" and "bad" which provides the basis for interpretation of data. Indeed, weights are attributed based on the comparison of observed data with the criteria inherent in the study's approach.

Many examples of studies evaluating the suitability of water quality indices are present, which suggest that they do indeed represent a practicable and reasonable representation of the quality of water in a particular domain. For example, Pesce and Wunderlin (2000) studied the relative accuracy of competing water quality indices, assessing the Suquia River in Argentina. Here, the first index was calculated based on the observation of 20 parameters. The second index utilized "objective" and "subjective" methods to assign weights to different parameters. The third index however utilized only three key parameters namely; dissolved oxygen, conductivity, and turbidity to assess water quality. In all of these measures data for each parameter represented in the index was normalized and reduced to a single scale. Of these various methods, the third index was found to correlate particularly closely with objective measures of water quality.

Another study by Stambuk-Giljanovik (2003) analyzed indices, assessing the quality of water in Croatia. In this study also, observing parameters and normalizing them according to a given set of criteria was carried out in order to synthesize values on a common scale. They were then tested with respect to water quality parameters that were observed over the course of a year (with monthly readings) in 50 locations around Croatia. The results suggested that arithmetic indices were most optimally adapted in instances where differences in water quality in terms of geographical location were being assessed.

Similarly, Liou et al. (2004) investigated water quality indicators based on Taiwanese data. In this comprehensive study a range of factors including particulate, pH, toxicity, temperature, organic chemical concentration etc. were utilized to compile an index. The standardized scorings method was then used to give values between 0 to 100 from a set of normalized parameters. Results suggest that this method well represents the state of water quality. In India also the indices developed by Sargaonkar and Deshpande (2003) known as the Overall Index of Pollution (OIP) has also been effective in assessing the quality of water in Indian rivers.

WQI is therefore a useful tool for the concise representation of the overall quality of water which enables managers to avoid considering a number of Water Quality Parameters (WQP) together. Advatages include its capacity for subjectivity, in that it can be developed for use in specific scenarios (e.g. WQI for shrimp culture), it can also be objective, by being open to development for use generally. Needless to say, several WQI were developed and are still being developed to fulfil the needs of different purposes.

Available Water Quality Indices and Their Limitations

As different WQP have different degrees of influence on the overall water quality, the Priority Values (PV) (i.e. quantitative importance of WQP with respect to the overall water quality) of the WQP are required to be determined to calculate the WQI. In the initial studies (Horton, 1965; Brown et al., 1970; Dunnette, 1979) and later research work (Bhargava, 1983; House & Ellis, 1987), the PV of WQP were determined usually from the subjective opinions of experts (Avvannavar and Shrihari, 2008). Often the criteria for determining the relative importance of parameters were not clearly outlined which served to challenge the reliability of some results.

Broadly, in recent works, the trend has been to develop a WQI that is more general and objective in nature (BCWQI, 1995; CWQI-CCME, 2001; WAWQI – Chauhan and Singh, 2010) than its predecessors. In these studies WQI were often calculated by quantifying the failure of the parameters to meet the objective values on a long-term basis. In effect these studies appeared to undervalue several parameters by forgoing the evaluation of their individual characteristics. Indeed as the selection of parameters and objective values depends upon the purposes and considerations of the users, these indices may be subjective or even biased (Terrado et al., 2010).

MCDM and Its Use in Assessing Water Quality

Multi Criteria Decision Making (MCDM) methods are developed to select the best alternative considering multiple criteria together. Generally, weights (both quantitative and qualitative) are assigned to the criteria and alternatives according to their relative importance. The alternative with the highest score is considered to be the best one. There are several MCDM methods that can be applied based upon the scenario. In case of WQI, weights (PV) are assigned to multiple WQP on the basis of their importance (i.e. capacity to influence the overall water quality). Therefore, MCDM can surely be used to develop WQI.

The use of MCDM methods like Weighted Sum Method (Boyacioglu, 2007), Grey Relational Analysis (Ip et al., 2009), Fuzzy Logic Decision Making (Mourhir et al., 2014), Analytic Hierarchy Process (Karbassi et al., 2011) and their combinations (Ocampo-Duque et al., 2006; Carbajal-Hernándeza et al., 2012) were found to be successful in the determination of the PV of WQP for achieving different decision making goals in an objective and non-preferential manner. However, in past studies Hazard, Cost and Utility were never seen to be considered together in spite of being important criteria.

Water Quality Index Developed for This Study

In the weight based WQI, there are two areas of primary concern—assignment of weights to the selected WQP according to their relative importance, and assignment of weights (Q values) to the concentrations of those WQP according to their influence on overall quality of water. The present study attempted to provide a methodology for estimation of the PV of different WQP, based on their Potential Hazards, Cost of Mitigation, Utilization Scope and Popularity among the researchers, to make it less dependent on subjective judgements. MCDM methods were used to determine the weights of the criteria and WQP to make the outcome reliable. The relative importance values (weights) of the criteria were determined by Response Surface Methodology (RSM) to remove any preferential treatment. The PV of WQP were then determined by Analytic Network Process (ANP) on the basis of those criteria weights.

Objective and Scope

The objective of this study is to determine the PV of WQP for WQI in an objective and non-preferential method to make the index free from subjectivity, irrationality and omission of important parameters. Also, the PV to be determined on the basis of important criteria like Hazard, Cost of Treatment, Utility and Popularity among the researchers, so that they can be holistic in nature.

Methodology

There were two primary steps for this study: (i) Development of the WQI (RSM-ANP WQI), in which the PV of WQP were determined by RSM and ANP, and (ii) Validation of the developed WQI through case study.

Development of RSM-ANP WQI

In the RSM-ANP WQI, proposed in this study, the PV of WQP were determined by MCDM methods to reduce subjectivity and preferential treatment (Figure 1). An established WQI – the NSF WQI – was taken as the reference WQI for this study. The RSM-ANP WQI was compared with NSF WQI through a case study for validation (Figure 1).

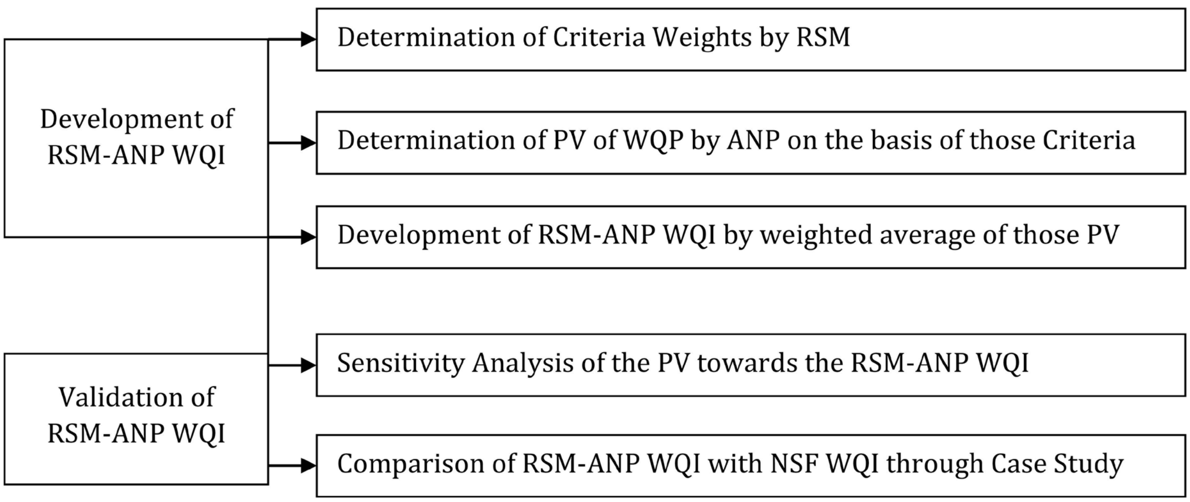

Figure 1: Schematic diagram of the study methodology.

Determination of Weights of the Criteria by RSM

Four different criteria (viz. Hazard Potential, Cost Potential, Utility and Popularity) are proposed in order to determine the relative importance of the selected parameters.

Hazard potential: The potential extent of the hazards a particular WQP may impose on the environment is if its concentration is beyond permissible limits. Hazard potential is a non-beneficial criterion, i.e. greater hazard potential will diminish the overall quality of water.

Cost potential: Cost potential is the cost of treatment required for a WQP, if its concentration is beyond the permissible limit. It is also a non-beneficial criterion.

Utility: Utility of a WQP is how important a particular WQP is in representing the overall water quality. Utility is a beneficial criterion, i.e. the higher the utility of a WQP, the more it is representative of the overall quality of water.

Popularity: Popularity is how popular a particular WQP is among the researchers. Popularity is also a beneficial criterion.

RSM is an objective method designed to determine the optimized value through a set of controlled experiment (Allen, 2006). The relative importance (weights) of the criteria were determined by RSM. Different criteria were treated as different experimental conditions that could then be applied in the RSM. Matrices were developed with the extreme values (denoted as "–1" and "+1" in RSM) and mid values (denoted as "0" in RSM) for both the criteria and Q values of different WQP as defined in NSF WQI. Each value of the criteria was multiplied by each values of WQP for each of the extreme conditions ("–1", "0" and "+1") to form a Product Matrix. The highest values among the sum of each rows was taken as the importance score of a criterion (Figure 2).

Determination of PV of WQP by ANP

The WQP were selected for this study from a metastatic analysis of extensive literature survey. The mostly used WQP in the literature surveyed were selected. The PV of those WQP were then determined by ANP.

ANP is a MCDM where the best alternative can be selected from a given set of alternatives on the basis of some defined criteria. The process is structured in a network with all the criteria, sub-criteria and alternatives being different nodes (Saaty, 2005). Nodes can also be further grouped into clusters. The weights of alternatives are determined through pairwise comparison on the basis of criteria and the criteria are also scored on the basis of alternatives.

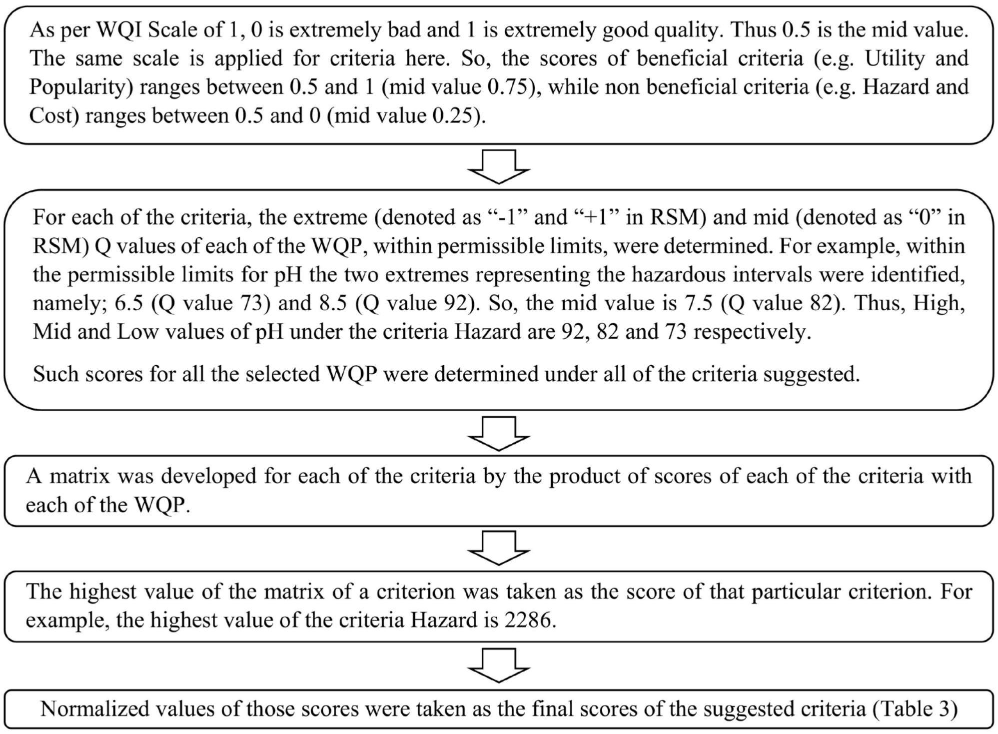

Figure 2: Determination of criteria weights by RSM.

In this study the WQP were taken as the alternatives and scored on the basis of selected criteria. The final scores of the WQP were taken as their PV. As the NSF WQI was used as the reference WQI in this study, the PV of WQP in RSM-ANP WQI must be in the same scale as the PV of WQP in NSF WQI for reliable comparison. Therefore, each of the PV of WQP, determined for this study by RSM and ANP, were multiplied with the Correction Factor (Equation 2) to bring them in the same scale as in NSF WQI.

Equation 2: Calculation of the correction factor

$$C = \frac{\sum P_{NSF}}{\sum P_{RSM}}$$

where P_{NSF} = weights of the common parameters in NSF and P_{RSM} = weights of the common parameters in RSM-ANP WQI.

Calculation of the Index

The RSM-ANP WQI was then developed, using the corrected PV of the WQP, determined by different RSM and ANP methods, by integrating their weighted average (Equation 3).

Equation 3: Calculation of WQI

$$WQI = \frac{\sum_{i=1}^{n} W_i Q_i}{\sum_{i=1}^{n} W_i}$$

where Q_i = Q value for i^{th} water quality parameter, W_i = weight associated with i^{th} water quality parameter and n = number of water quality parameters.

Validation of RSM-ANP WQI

The RSM-ANP WQI was validated by Sensitivity Analysis, Comparison with NSF WQI and descriptive statistics.

Case Study

A case study was performed to compare the RSM-ANP WQI with NSF WQI. The selected WQP of 38 water bodies in west of Tripura, India were measured. The Q-values of the concentrations of the WQP were calculated as per the method of NSF WQI. The RSM-WQI and NSF WQI were then calculated by integration of weighted average of the PV and Q-values of the WQP (Equation 3).

Sensitivity Analysis

Sensitivity Analysis of the WQP was performed with respect to RSM-ANP WQI, using the *SensIt* Sensitivity Analysis application (www.treeplan.com). The sensitivity of different WQP towards the WQI were then compared with their respective PV to check whether the most sensitive WQP were also the most important ones or not.

Comparison with an Established WQI

The WQI, developed using different MCDM methods, were then compared with an already established WQI to check the accuracy of the WQI developed for this study. NSF WQI (Brown et al., 1970) was selected for this purpose, as:

(i) It is an established WQI with a wide acceptance (Sharma et al., 2008)
(ii) RSM-ANP WQI follows the similar method to calculate the WQI—by assigning weights to the WQP and their concentrations
(iii) Both the WQI have common WQP

The RSM-ANP WQI was compared with NSF WQI graphically and statistically through a case study.

Descriptive Statistics

Different descriptive statistical analysis, e.g. Mean Average Percentage Deviation (MAPD) from NSF, Standard Deviation, Skewness, Kurtosis and 85$^{\text{th}}$ Percentile, of the RSM-ANP WQI were performed to check data reliability.

Results and Discussion

Selection of Parameters

Eight WQP were selected by metastatic analysis, on the basis of their number of occurrence in the literature surveyed (Table 1). It was found that DO was considered in most of the literature surveyed (59 out of 182 literatures) and turbidity was considered in the least (32 out of 182 literatures).

Table 1: Occurrence of different WQP in literature surveyed

Sl	*Parameters*	*Abbreviation used*	*Occurrence in literature surveyed*
1	Dissolved oxygen	DO	59
2	Biochemical oxygen demand	BOD	54
3	pH	pH	49
4	Total phosphate	PO_4	43
5	Temperature	Temp	41
6	Total nitrate	NO_3	37
7	Total solids	TS	36
8	Turbidity	Tur	32

Determination of the PV of WQP

The PV of the selected parameters were determined by RSM and ANP.

Weights of the Criteria

The weights of the criteria were determined by RSM (Figure 3) and ranked accordingly (Table 2).

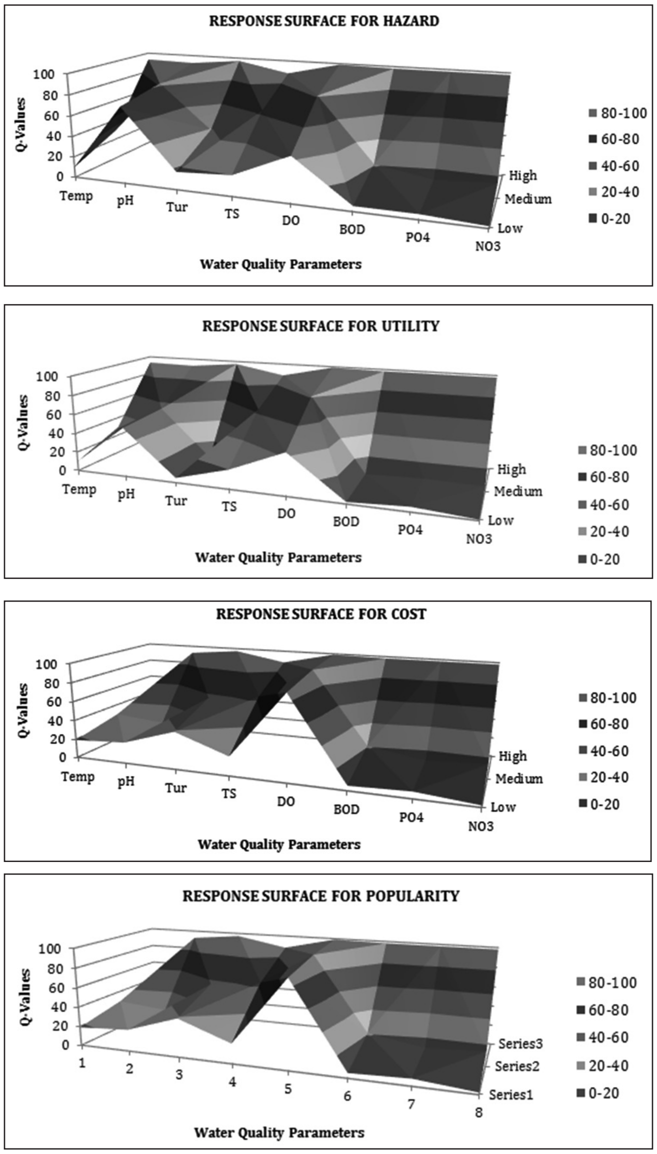

Figure 3: Response surface of the criteria.

Table 2: Scoring and ranking of criteria

Criteria	*Score*	*Rank*
Hazard	0.3444	1
Cost	0.3222	2
Utility	0.1722	3
Popularity	0.1612	4

The relative importance of Hazard was found to be the maximum, whereas that of Popularity was found to be the minimum.

Scoring of the WQP

The scoring of the parameter were done on the basis of the selected criteria using ANP (Table 3). DO was the most and TS was the least important among the selected WQP, which is also seconded by some other studies (Štambuk-Giljanović, 1999; Yisa and Jimoh, 2010; Massoud, 2011).

Table 3: PV of the WQP

Parameters	*PV of WQP*	*Corrected PV of WQP*	*Weights of WQP in NSF WQI*
DO	0.19	0.16	0.17
pH	0.17	0.14	0.11
BOD	0.12	0.10	0.11
T	0.12	0.10	0.10
PO_4	0.11	0.09	0.10
NO_3	0.12	0.10	0.10
Tur	0.08	0.07	0.08
TS	0.10	0.08	0.07

The PV of WQP of RSM-ANP WQI is found to be more or less similar to that of NSF WQI (Table 3). This can also be treated as a validation for RSM-ANP WQI.

Calculation of Index

After the PV of the WQP were determined, the WQI were calculated by weighted average method (Equation 3) from the water quality data of the case study.

Validation of RSM-ANP WQI

The RSM WQI and NSF WQI were calculated from the case study. RSM-ANP WQI was then validated by Sensitivity Analysis and comparison with NSF WQI.

Case Study

The WQP values were used to calculate both RSM WQI and NSF WQI by integration of the sub indices (Equation 3).

Sensitivity Analysis

Sensitivity of the PV towards the WQI are ranked and compared with the PV (Table 4). It is found that though the PV ranking is not identical to Sensitivity ranking, their patterns are somewhat similar. Thus, the most important WQP were also the most sensitive one and *vice versa*.

Table 4: Sensitivity analysis of the WQP

Parameters	*PV*	*PV rank*	*Sensitivity*	*Sensitivity rank*
DO	0.16	1	0.37	1
pH	0.14	2	0.18	3
BOD	0.10	3	0.35	2
T	0.10	3	0.04	5
PO_4	0.09	4	0.05	4
NO_3	0.10	3	0.01	6
Tur	0.07	5	0.00	7
TS	0.08	4	0.00	7

Comparison with NSF WQI

The RSM-ANP WQI was found to be very close to NSF WQI (MAPD = 1.87%) and followed similar pattern (Figure 4).

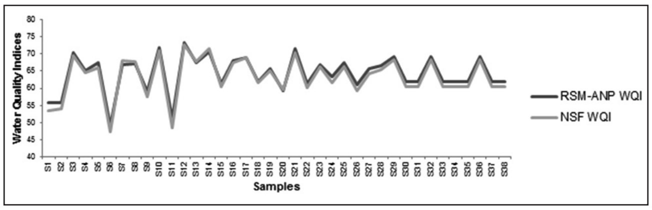

Figure 4: Comparison graph of RSM-ANP WQI and NSF WQI.

Descriptive Statistics

The low standard deviation of 5.5 (Table 5) shows that little difference exists among the water qualities of different sampling water bodies. This fact is also supported by low kurtosis (0.73) of the WQI, which suggests that the distribution of the WQI values is rather flat. The lower skewness (–0.80) depicts that the distribution of the WQI is rather symmetrical. The high 85th percentile value (69.33) suggests that most of the samples were of medium or bad quality (WQI $\leq$ 69); only 15% of the total samples are good. So is indicated by the mean WQI (64) which denotes the average quality of water in the study area is of Medium quality. All the statistical analysis of RSM-ANP WQI was found to be very close to those of NSF WQI (Table 5).

As the WQI, proposed in this study, is close to the reference WQI (NSF WQI), it can be considered as a valid WQI. Thus, the method of this study is successful in determination of the PV of WQP in an objective and non-preferential way.

Conclusion

The present study attempted to determine the PV of WQP in an objective and non-preferential way. MCDM methods like RSM and ANP were used to score the WQP on the basis of important criteria like Hazard Potential, Utility, Cost of Mitigation and Popularity among the researchers. The RSM-ANP WQI was developed from the PV of WQP, determined by RSM and ANP. A case study was performed to compare the RSM-ANP with NSF WQI, which is an established WQI, to check its accuracy.

Results indicate that the RSM-ANP WQI is very close to NSF WQI. Thus, the method proposed in this study is validated. So, it can be concluded that the proposed method is successful in determining the PV of WQP. The RSM-ANP WQI seems to be a objective, reliable, accurate and holistic WQI.

However, working with another set of criteria may produce different PV of the WQP, which can be the scope of another study.

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Table 5: Descriptive statistics of the RSM-ANP WQI and NSF WQI

Index	*Mean*	*Standard deviation*	*Skewness*	*Kurtosis*	*85th percentile*
RSM-ANP WQI	64	5.50	-0.80	0.73	69.33
NSF WQI	63	5.97	-0.83	0.66	68.55

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