A comparative assessment of the novel water pollution index and the water quality index using empirical data: Improving water quality evaluation

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Short Report

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Abstract

Different water assessment indices have been employed in the evaluation of water quality for human use. However, these methods have their peculiar drawbacks. This study applied the novel water pollution index (WPI) against the water quality index using empirical data (packaged and groundwater sources) from some parts of Ghana. The study showed that the WPI method is flexible and easy to compute compared to WQI. In this study area, WPI ranged from 0.22–0.31 and 0.23–0.32 for packaged water obtained from production and vending sites respectively. However, the WQI outputs were 0.12–0.36 (production site) and 0.27–0.42 (vending sites). Though the water samples from both sources were excellent for drinking, the wide variation in the WQI suggests the biases resulting from the selection of the weighting factors for the various parameters. Considering the groundwater sources applied in this study, 74% as against 93% and 19% as against 5% of the samples were excellent and good water sources based on the WPI and WQI respectively. These disparities are largely attributed to the biases posed by the quality rating and weighting factors which are researcher-described.

1. Introduction

Water is an essential resource to sustaining life. The quality of water depended on is essential since it could pose public detrimental health and environmental threats (Mukate et al., 2019; Hossain and Patra, 2020). Several approaches have been employed in assessing the quality of water. However, most of these techniques have shown discrepancies in sampling size, goals, sample matrix. To integrate different water quality measures into a single index, several techniques have been developed. For instance, Horton (1965) developed an IWQI technique by employing pH, alkalinity, total solids, temperature, turbidity, dissolved oxygen, electrical conductance, biochemical oxygen demand (BOD), coliforms, phosphate, nitrate, and chloride. By converting a substantial array of data through an integrated methodology, this indexing technique produces a single numeric result that represents and classifies the quality of water (Adimalla and Li, 2018). Following its development, this water quality assessment approach has been widely employed (Tyagi et al., 2013). Findings by Brown et al. (1970) and Sutadian et al. (2016) have shown that the aforementioned index relies basically on some factors such as assigning weights and relative weights, parameter selection, and conversion to a specific scale of range.

In 2001, the Canadian Council of Ministers of the Environment (CCME-WQI) established a new WQI (CCME-WQI), which is a sophisticated approach for calculating water quality for a single sample in multiple seasons (Hossain and Patra, 2020). It only examines values that are larger than the standard guideline, and it ignores parameter values that are near to or below the standard value. Calculating the CCME-WQI of 50 water samples with each sample having two (2) exceeding parameters over the permitted limit is challenging, especially when the output values of each sample are the same or extremely close. Through the combination of subjective and objective weights using an additive model, an integrated-weight WQI (IWQI) was proposed. It demonstrates an integrated weights balance between objective entropy information of ion levels and subjective impacts of chemical components on human health risk (Gao et al., 2020).

Mukate et al. (2019) presented an integrated water quality index (IWQI) which considered both the maximum allowed and desired limits of a water parameter. The WHO guidelines, on the other hand, simply propose a maximum acceptable concentration and not refer to an upper or lower limit. Based on this, the WHO guideline for calculating IWQI may not be required (Chaturvedi et al., 2018). The appropriateness and significance of water quality vary depending on its intended use, such as domestic and agricultural purposes. Generally, one indexing method is selected for a specific purpose, indicating the lack of a comprehensive WQI that can be used to assess water quality regardless of its intended application.

Furthermore, in the case of weighted indices, excessively weighted parameters might cause an index's sensitivity to be imbalanced, limiting its applicability. Also, any change in assigned weights affects the ultimate interpretation of the total quality of water. Finally, all weighted sub-indices are added and multiplied to form a total. The output may show unsatisfactory quality even though all individual parameter concentrations are within permissible limits, as lower concentration parameters are impacted by greater assigned weights, leading to erroneous interpretation of ultimate WQI outputs (Juwana et al., 2012; Hossain and Patra, 2020). As a result, this study compares the innovative WPI and the commonly used WQI, assesses their merits and drawbacks, and evaluates their performance using empirical data.

2. Water Quality Index

WQI is an effective water quality assessment tool (Ochuko et al., 2014; Amuah et al., 2021). The idea of indexing water quality with a numerical value is dependent on biological, chemical, and physical variables considered in the study. It (NSF-WQI) was developed in the 1960s by Horton (1965). Over the years, several refinements have been made in the quest to develop a WQI that is globally accepted (Lumb et al., 2011). The Scottish Research Development Department (SRDD) created the SRDD-WQI in 1973. It is based on Brown's model and is used for determining the quality of rivers (Uddin et al., 2021). The SRDD-WQI has subsequent variants such as the House and the Dalmatian Indices. The Environmental Quality Index model was later created by Steinhart et al. (1982) to assess the quality of the Great Lakes ecosystems. A similarly significant breakthrough was the British Columbia Water Health Index (BCWQI) by the British Columbia Ministry of Environment, Lands and Parks in the mid-1990s. It was developed for the assessment of various water systems across the province in Canada (Saffran et al., 2001). Models like the Liou, Malaysian, and Almeida Indices have been created in recent years (Uddin et al., 2021). Various nations and/or agencies have used more than 35 WQI models to assess surface water quality across the world (Ewaid et al., 2020; Ustaolu et al., 2020; Miyittah et al., 2020). In most regions of the world, WQI models have been used (Uddin et al., 2021). Lumb et al. (2011) further showed that the difference in the various WQIs depends on the statistical integration and interpretation of parametric values which make them subjective. Though WQI models have been used to assess different sources of water, 82% of applications have been to understand the qualities of rivers, it has also been employed even in groundwater quality (Ramakrishnaiah et al., 2009; Khan and Jhariya, 2017; Jha et al., 2020) and packaged water quality (Amuah et al., 2021).

2.1 Procedure for computing WPI

Over the years, several refinements have been made in the quest to develop a WQI that is globally accepted (Lumb et al., 2011). Lumb et al. (2011) further showed that the difference in the various WQIs is depends on the statistical integration and interpretation of parametric values which make them subjective. Khan and Jhariya (2017) used 8 water quality parameters (chloride, nitrate, pH, alkalinity, magnesium, fluoride, hardness, and calcium) to evaluate the WQI using groundwater from the Raipur city, India using two systematic approaches; (1) determined the weightage factor of each parameter based on its significance using the formula:

- Weightage factor (W_i)

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

1

From Eq. 1, W_i = relative weight, w_i = weight of each parameter and n = number of parameters

- Quality rating (q_i)

$$qi = \left[\frac{\mathrm{Ci}-\mathrm{Ci0}}{\mathrm{Si}-\mathrm{Ci0}}\right]\mathrm{x}100$$

2

C_i = measured level (mg/L) of each chemical parameter in each water sample, C_{i0} = ideal value of the parameter in “pure” water, and S_i = standard value.

The WQI was determined by initially calculating the sub-index of each parameter using the formula:

$$\mathrm{SI} = \mathrm{wixqi}$$

3

SI is the sub-index of the i^{th} parameter and Qi represents the rating based on the level of the i^{th} parameter

WQI was derived by summing the sub-index of all the 8 parameters using Eq. 4:

$$\mathrm{WQI} = \sum \mathrm{SIi}$$

4

Using the formulae, the study concluded that the quality of water in certain areas were unsuitable for drinking purposes due to levels of Mg^{2+}, NO_3^-, and Ca^{2+} in above-threshold levels suggested by the Bureau of Indian Standards (BIS).

Singh and Kamal (2015) also used a different approach to understand the WQI of groundwater in Goa, India. Although the study used the same pattern adopted by Khan and Jhariya (2017), the approach was different as Singh and Kamal (2015) stated that the weightage average for the water quality parameters was expected to be contrariwise to the corresponding standards by the Bureau of Indian Standards for respective parameters. Hence the weightage of each parameter was calculated as:

$$\mathrm{wi} = {}^{k}/_{Si} \qquad (5)$$

W_i = unit weight for the i^{th} parameter, Si = standard for the i^{th} and i = 1, 2, 3, 4 …. i^{th}, and K = constant of proportionality.

The quality rating (qi) was calculated using the formula:

$$\mathrm{qi} = 100 \times \left[{}^{Vi}/_{Si}\right] \qquad (6)$$

V_i = the measured value of the i^{th} parameter in the groundwater sample under consideration and S_i = is the standard or permissible limit for the i^{th} parameter.

Finally, the WQI was computed using the formula:

$$\mathrm{WQI} = \sum (qi\mathrm{x}wi) / \sum wi$$

7

Where WQI = Water Quality Index, qi = quality rating, and wi = is the unit weight of the i^{th} parameter.

Table 1

Generally used WQI rating

WQI	Rating
0–25	Very good
26–50	Good
51–75	Moderate
> 75	Poor

2.2 Application of WQI in water quality assessment

The various models of WQIs have been used widely in the assessment of water resources globally (Figs. 2 and 3). Abbas et al. (2017) and Khan and Jhariya (2017) employed this procedure to evaluate groundwater quality in the Basra governorate, Iraq. Similar to Khan and Jhariya (2017), Abbas et al

(2017) assigned weights to each groundwater quality variable following its relative prudence in determining the overall quality of water for consumption. The authors arrived at the overall WQI for the study area. In their conclusion, the authors stated that the overall view of the WQI study area was high and exceeded the limitations of standards, and thus the groundwater of the study area was unsuitable for drinking. Yidana et al. (2010) in a quality assessment of groundwater in the Volta Region (V/R) of Ghana adopted the WQI assessment approach. The study assimilated the same formulae as Khan and Jhariya (2017) and Abbas et al. (2017). The steps and procedures followed by the authors were the same as Khan and Jhariya (2017) and Abbas et al. (2017). Employing WQI, Yidana et al. (2010) discussed that groundwater in the northern part of the V/R of Ghana was of excellent rating for drinking purposes. The WQI approach has been a very useful and widely used method is evaluating groundwater quality. It presents the quality of a water sample in a single value. However, there are prevailing contradictions following the development of several computation methods and water quality classifications.

2.3 Merits and demerits of WQI in groundwater quality assessment

In using WQI, (1) changes in water quality are easily identified, (2) water quality levels are appreciated clearly in ratings/values, and (3) results could be presented spatially by interpolation to understand groundwater quality of samples instead of interpolating each parameter; this is more summarized. However, (1) there are biases in determining the quality ratings, (2) a single data error could affect the entire computation, (3) many other water quality parameters are not considered in the calculation, and (4) there are contradictions in the classification of WQI computations.

3. Water Pollution Index

Hossain and Patra (2020) developed the WPI. It is an integrated approach since it transforms parameters to a single-value index to categorize water quality, allowing even little changes in the level of any input parameter to be recognized. WPI does not utilize theoretical ideal values or weights/assigned values, which might lead to biases in some traditional indices. WPI may be used on a variety of data sets. Moreover, using different indices for a range of purposes can be time-consuming and inefficient for a single study, whereas WPI can provide a conceptual view of the quality of water based on any input parameters and can be adopted for several designated purposes by using the recommended standards of the parameters considered.

3.1 Procedure for computing WPI

WPI is computed using the function:

$$PL = 1 + \left[\frac{I_C - S_d}{S_d}\right]$$

8

$$WPI = \frac{1}{n}\sum_{i=1}^{n} PLI$$

9

Where PL refers to Pollution Load, S_d is standard or the highest permissible limit for the various variables considered, I_c is observed concentration of the ith parameter, WPI is Water Pollution Index and n is n number of parameters. Table 2 presents the classification for determining WPI.

Table 2

WPI classifications (Hossain and Patra, 2020)

WPI value	Description of water for drinking
< 0.5	Excellent water
0.5–0.75	Good water
0.75–1	Moderately polluted water
> 1	Highly polluted water

3.2 Merits and demerit of WPI

- The WPI formulation eliminates the uncertainties and ambiguities resulting from varying assigned weight values by researchers.
- It can be used for large sets of data, even with dispersed and un-skewed variables.
- There are no complicated mathematical steps to compute WPI, and it is time-efficient and easier compared to other traditional techniques.
- pH content was given special attention since it has the greatest influence with a small adjustment.
- The new WPI system is not based on an element's lower desired or maximum permitted limit.
- As a result, it may be used for both relaxable and non-relaxable parameters.
- WPI does not require any type of parameters. Users may employ any kind of variable to identify the water quality for water resources management, drinking, and irrigation purposes.

However, WPI cannot be computed using parameters without recommended standards.

4. Comparative Application Of Wqi And Wpi

A sachet water (from production and vending sites) quality study by Amuah et al. (2021) revealed that all samples were “excellent” water sources according to the classifications for WQI and WPI by

Ramakrishnaiah et al. (2009) and Hossain and Patra (2020) respectively. However, WPI results were generally closer to the mean values of the raw data (Table 3). The results further showed wide differences between the WQI in the samples obtained from the production (0.12 – 0.36) and vending (0.27 – 0.42) sites. However, the WPI showed much closer relationships; 0.22 – 0.31 and 0.23 – 0.32 for samples obtained from the production and vending sites respectively. This suggests the influence of biases in the choice of the weighting factors. Using groundwater quality results in the Upper East Region (UER) of Ghana, the results showed that out of the 742 groundwater samples, 93.2% were suitable for drinking, whereas 5% were good, 0.3% were poor, and 0.8% and 0.7% respectively were very poor and unsuitable for drinking (Table 4). However, considering WPI, 74% of the groundwater sources in the area were excellent sources for human consumption. Meanwhile, 19% were good whereas 4% and 3% were moderately and highly polluted respectively.

Table 3 WQI and WPI results of sachet water (Amuah et al., 2021)

Brands	WQI		WPI	
	Production	Vending	Production	Vending
PL	0.24	0.42	0.26	0.26
YG	0.19	0.32	0.28	0.28
NN	0.20	0.35	0.29	0.28
AK	0.17	0.30	0.26	0.26
WD	0.15	0.28	0.25	0.25
AJ	0.36	0.38	0.31	0.32
ED	0.13	0.27	0.22	0.23
AC	0.12	0.27	0.24	0.24

Table 4 WQI and WPI results from the UER

WQI			WPI		
Categories	Description of water for drinking	Results	Categories	Description of water for drinking	Results
< 50	Excellent water	93.2%	< 0.5	Excellent water	74%
50-100	Good water	5%	0.5 – 0.75	Good water	19%
100-200	Poor water	0.3%	0.75 – 1	Moderately polluted water	4%
200-300	Very poor water	0.8%	> 1	Highly polluted water	3%
> 300	Unsuitable water	0.7%			

5. Comparing Wpi And Wqi/ccme-wqi

- Unlike WQI/CCME-WQI, WPI is not constrained by any parameters and assigned weights.
- WQI is mainly employed for physicochemical parameters, WPI could be employed in biological, physical, and chemical analyses of ground or surface water sources.
- WPI reduces biases encountered in the use of weightage in WQI as the use of weights (which are very subjective) is eliminated.
- Unlike in the application of CCME-WQI where there is the possibility of losing some information when using large data and variable sets. Since CCME-WQI considers only exceeded parameters, WPI considers all the variables and data and their impacts on water quality (Hossain and Patra, 2020).
- WPI is easy to apply since the only external variables included in the procedure are standards/permissible limits of the various elements considered in the analysis.

6. Conclusion

This study presents a comparative assessment of a new comprehensive and flexible index for evaluating water quality (WPI) and the widely used WQI. The study showed that compared to WQI, WPI can be applied for chemical, physical, and biological parameters of water quality. WPI provides basic or overall descriptions of the quality of water based on any purpose. The proposed WPI employs permissible standards to define ideal water quality. Compared to WQI, WPI is easier to compute and flexible to use since several parameters can be incorporated. Therefore, using WPI for suitability studies is an accurate and integrated approach understand surface and groundwater quality regarding pollution for human use. This makes it applicable and adaptable in different regions without disparities, which makes inferences on water quality assessments generally conclusive. The method eliminates the biases, weightage, opacity, and aggregation flaws presented in conventional water quality assessment methods.

Declarations

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Conflicts of interest/Competing interests

The authors declare no known competing interest

Availability of data and material

Not applicable

Code availability

Not applicable

Authors’ contribution

EEYA and PK conceptualized the paper, developed the original draft and edited the work entire work whereas PK edited the work.

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Figures

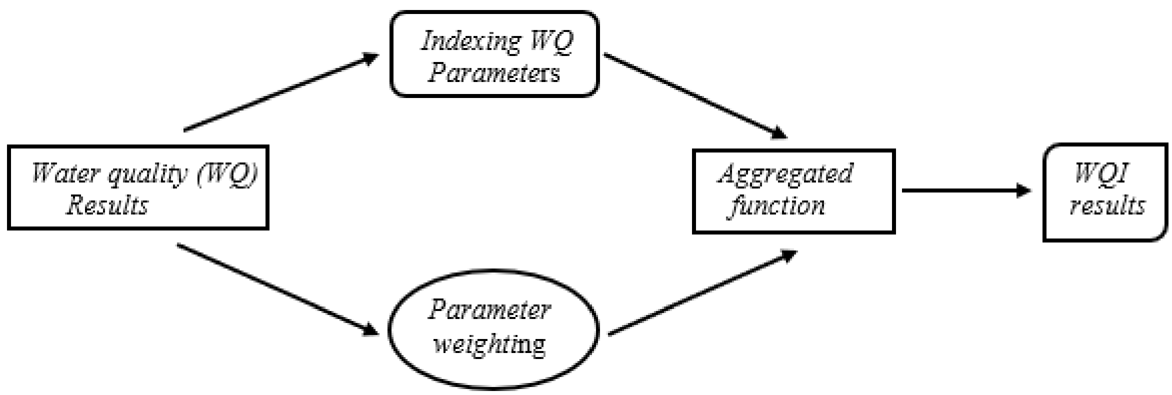

Figure 1

General model structure of WQI

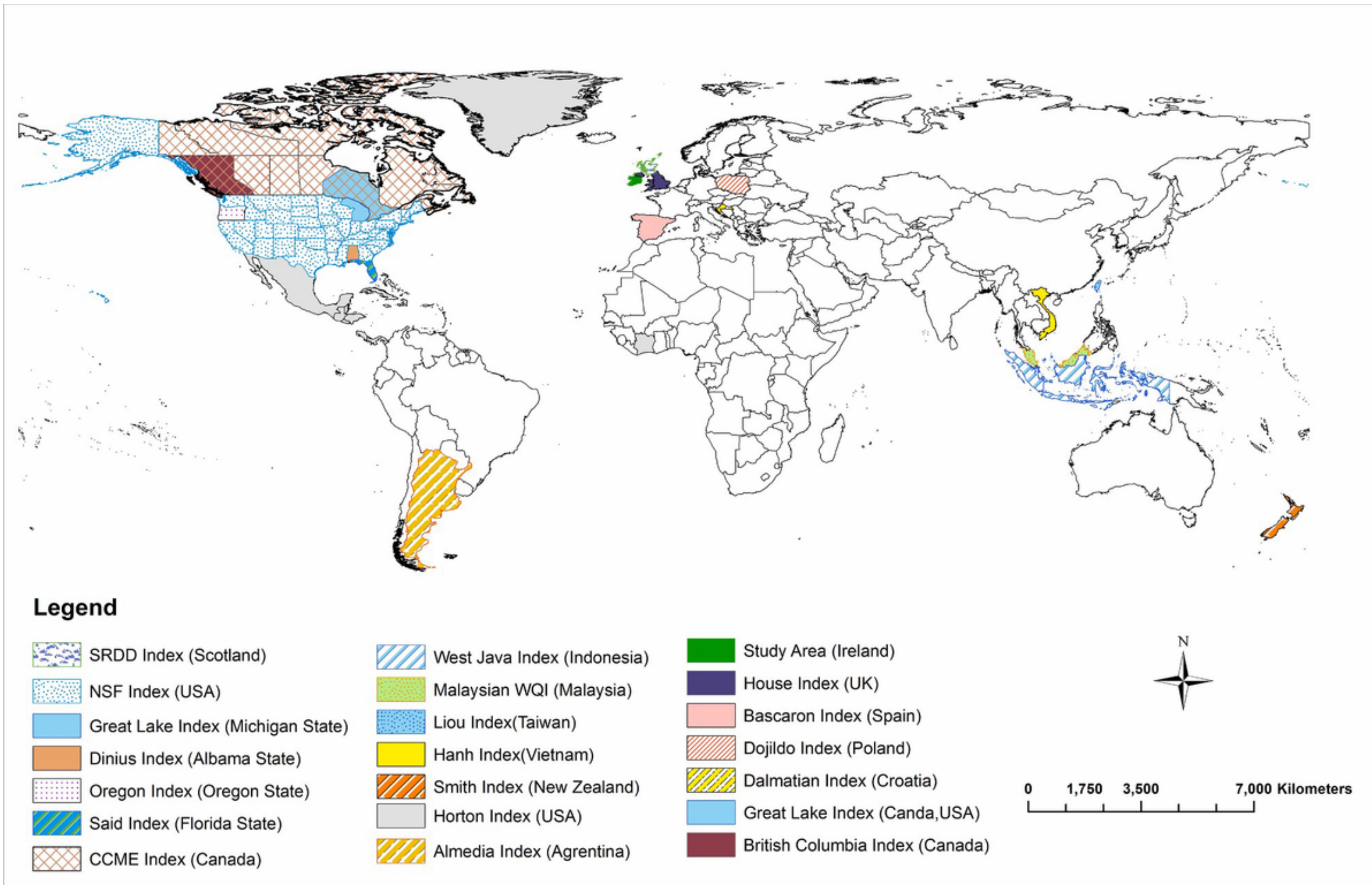

Figure 2

WQI models and areas most commonly used from 1960 to 2020 (Uddin et al., 2021)

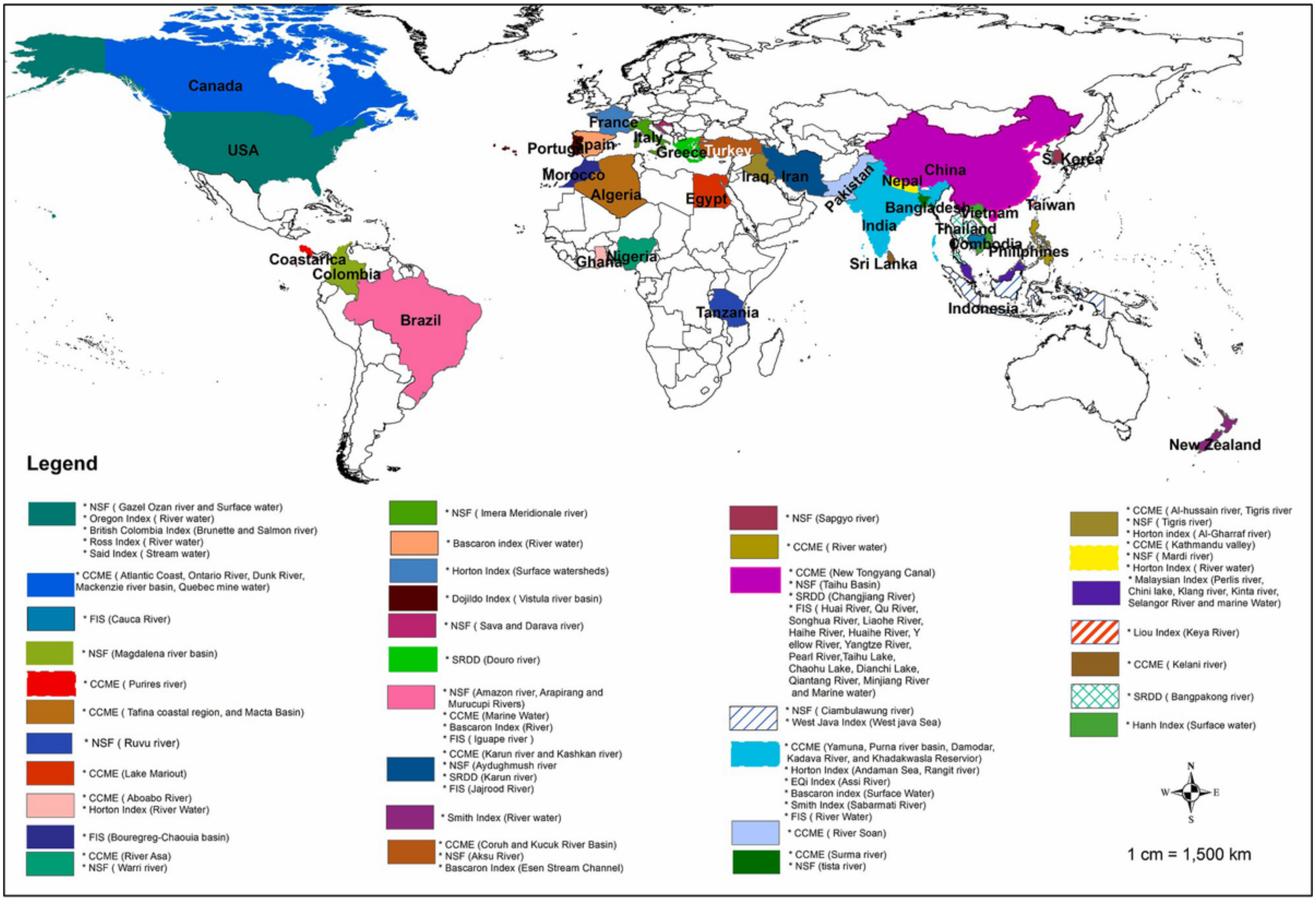

Figure 3

Countries-based and water types in which WQI has been employed (Uddin et al., 2021)