Ecological Water Quality Index associated with factor analysis to classify surface waters

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ABSTRACT

The object of this study was the development of a new water quality index called the Ecological Water Quality Index (EWQI) which is flexible enough to represent the ecological status of surface waters by assessing chemical quality based on supranational legislation. Eleven variables including nutrients, salts and total parameters were selected as index components. Threshold values were assigned to seven water-quality classes as defined by the legislation and were used to develop mathematical equations to convert observed values to index scores. Depending on the ecological importance of the parameters, weights were assigned to each variable and then a weighted sum method was performed to aggregate sub-indices. The applicability of the method was demonstrated in two basins located in Turkey. Factor analysis was applied to optimize the index component selection process. Several alternatives were tested to comprise at least one variable from each defined factor class (e.g. salinity content) to calculate an index score representing ecological status. Results showed that there were slight differences between index scores of the various tested alternatives. These differences did not cause misclassification of surface waters. The study showed that the EWQI method combined with factor analysis could be a practical and efficient way to represent the ecological status of surface waters.

Key words | ecological status, Ecological Water Quality Index, factor analysis, index component

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HIGHLIGHTS

- In the study an Ecological Water Quality Index (EWQI) was developed.
- Applicability of the method was demonstrated in two basins.
- Groups of nutrients, salts and total parameters were selected as index components.
- Factor analysis was applied for index component (variable) selection.
- EWQI method integrated with factor analysis is practical and efficient for classifying waters.

INTRODUCTION

In parallel to population growth and industrialization, surface waters are vulnerable to pollution from anthropogenic activities. Water availability and quality are significantly declining due to the lack of efficient management plans and uncontrolled pollution sources in most of the countries in the world. Due to accumulation and transport processes, surface waters are vulnerable to pollution that limits their uses for various designated uses (El Najjar *et al.* 2019).

Water quality monitoring is important for investigating temporal and spatial variations in surface waters and for efficient monitoring, many physico-chemical, microbiological and hydrological quality variables should be analysed. In water quality assessment processes, physical, chemical, and microbiological variables analysed in water samples are compared with reference threshold values (e.g with water quality guidelines) (Simeonov *et al.* 2003; El Najjar

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et al. 2019). On the other hand, water quality monitorıng is a cost-expensive process and has led researchers/practitioners to optimize monitoring activity. Reducing the number of tested parameters could be an alternative but this process should not cause the loss of significant information about the status of overall water quality (El Najjar et al. 2019).

Identifying and quantifying sources of pollution is very difficult as well as complex (Schuwirth et al. 2018). On the other hand, the information produced by processing complex data sets should be understandable by technical and non-technical people. A water quality index method and also multivariate statistical methods are useful tools to address these needs.

Water quality indices aim at representing water quality with a single value that translates the list of constituents and their concentrations present in a water sample into an index score. A water quality index (WQI) method was developed by Horton in 1965 in the United States. Dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity and chloride etc. were its components. Afterwards, several indices were proposed including but not limited to the Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI), Oregon Water Quality Index (OWQI) and the National Sanitation Foundation Water Quality Index (NSFWQI) among others. Most of the indices were formulated in four steps: (a) selection of water-quality variables (index components), (b) transformation of observed values into a common scale (sub-index values), (c) assignment of weights to index components and (d) aggregation of sub-indices to calculate an overall index score representing water-quality status (Horton 1965; Boyacioglu 2007; Abbasi & Abbasi 2012; Tyagi et al. 2013; Sharma et al. 2015; Sutadian et al. 2016; Mukate et al. 2019).

It should be noted that while these indices provide an overall picture of the quality, they cannot definitely determine if a water source is suitable for designated uses, especially for drinking purposes (UNEP 2007). There may be a number of variables that were not comprised by indices that could still adversely affect the suitability of water.

Presently there is a need to develop a WQI that represents the ecological status of surface waters considering chemical quality. European water policy has identified eutrophication as a priority issue for water management. On the other hand, setting reliable and meaningful nutrient criteria supporting 'good' ecological status is an open issue in the Water Framework Directive (Poikane et al. 2019).

The Federal Government and Länder in Germany developed a water quality classification scheme prior to the Water Framework Directive's entry into force. In Germany for nutrients and some variables, there are no binding values for classification of good ecological status and it is expected that chemical water quality classification will be used in the future (BMU 2019). Since the legislation can be applicable at the European scale and also many countries in the world, this study aimed to use this ecological classification scheme based on 11 variables considering nutrients, salts and total parameters to develop a new water quality index. This will provide assignment of overall water quality into pre-defined water quality classes in the studied areas.

The specific objectives of the study were: (a) to develop a new Ecological Water Quality Index (EWQI) to determine the ecological status of surface waters based on chemical variables and assign overall water quality into predefined water quality classes; (b) to demonstrate the applicability of the developed index (EWQI) in the case of two water basins in Turkey; and (c) to apply a multivariate statistical method–factor analysis to select index components.

STUDY METHOD

The Ecological Water Quality Index was developed in four steps:

- parameter selection (index component selection),
- formulation of sub-index equations,
- assignment of weights to index components,
- formulation of overall index equation.

Index component selection

Eleven quality variables proposed by the German legislation mentioned above and comprising nitrite nitrogen (NO_2^--N), total nitrogen (TN), nitrate nitrogen (NO_3^--N), ammonium nitrogen (NH_4^+-N), total phosphorus (TP), orthophosphate phosphorus (PO_4^{3-}-P), dissolved oxygen (DO), chloride (Cl^-), sulphate (SO_4^{2-}), total organic carbon (TOC) and adsorbable organohalogens (AOX) were selected as index components to develop the new index called the Ecological Water Quality Index.

In this legislation, chemical water quality categorization has the following classes:

- Class I: No pollution
- Class I-II: Lightly polluted
- Class II: Moderately polluted
- Class II-III: Critically polluted
- Class III: Heavily polluted
- Class III-IV: Very heavily polluted
- Class IV: Excessively polluted

Class I characterizes a water body that is free from anthropogenic pollution. In this classification 90th percentile values of water-quality data sets are considered as a characteristic value representing the data sets (BMU 2019). The chemical quality classifications for nutrients, salts and total parameters for comparison values of the 90th percentile are presented in Table 1.

Formulation of sub-index equations

Sub-index equations are used to transform the different units and dimensions of water-quality variables to a common dimensionless scale. In the study, fixed sub-index values were assigned as threshold values to seven water quality classes to formulate equations. Accordingly, if the content of a variable was lower than the value set for Class I presented in Table 1, the water quality sub-index was set as '100'. Similarly, for the variable that exceeds the value set for Class IV, the sub-index was registered as '0'. Mathematical equations were formulated for each variable to obtain these fixed sub-index values (0, 20, 40, 60, 80 and 100) and regression analysis was performed for this purpose using-SPSS-20.0 software (SPSS-20 2011). Mathematical formulas are given in Table 2 and rating curves are depicted in Figure 1. In these Figures, the *X*- and *Y*-axis represent 'concentration' and 'index values' respectively. For some water quality parameters, the mathematical models were formulated by studying concentration intervals in order to obtain the best-fit equation.

Assignment of weights to index components

The assignment of weights to water-quality variables was the following step and opinions of six ecologists were asked to

Table 1 | Chemical quality classification for water-quality variables (BMU 2019)

		Total nitrogen (TN)	Nitrate (NO_3^-) nitrogen	Nitrite (NO_2^-) nitrogen	Ammonium (NH_4^+) nitrogen	Total phosphorus (TP)	Orthophosphate (PO_4^{3-}) phosphorus	Dissolved oxygen (DO)	Chloride (Cl^-)	Sulphate (SO_4^{2-})	Total organic carbon (TOC)	Adsorbable organohalogens (AOX)
Unit		mg/L										μg/L
Substance-based chemical water quality class	I	≤1	≤1	≤0.01	≤0.04	≤0.05	≤0.02	>8	≤25	≤25	≤2	'0'
	I – II	≤1.5	≤1.5	≤0.05	≤0.1	≤0.08	≤0.04	>8	≤50	≤50	≤3	≤10
	II	≤3	≤2.5	≤0.1	≤0.3	≤0.15	≤0.1	>6	≤100	≤100	≤5	≤25
	II – III	≤6	≤5	≤0.2	≤0.6	≤0.3	≤0.2	>5	≤200	≤200	≤10	≤50
	III	≤12	≤10	≤0.4	≤1.2	≤0.6	≤0.4	>4	≤400	≤400	≤20	≤100
	III – IV	≤24	≤20	≤0.8	≤2.4	≤1.2	≤0.8	>2	≤800	≤800	≤40	≤200
	IV	>24	>20	>0.8	>2.4	>1.2	>0.8	≤2	>800	>800	>40	>200

Table 2 | Mathematical equations for EWQI components

Substance	Concentration range (unit μg/L for AOX and mg/L for others)	Sub-index function	R^2
Total nitrogen (TN)	≤ 1	$Y = 100$	
	$1 < x \leq 6$	$Y = 99.97X^{-0.5}$	0.995
	$6 < x \leq 24$	$Y = -28.85\ln(X) + 91.699$	1.000
	>24	$Y = 0$	
Nitrate (NO_3^-) nitrogen	≤ 1	$Y = 100$	
	$1 < x \leq 5$	$Y = 4.7561X^2 - 43.097X + 136.72$	0.994
	$5 < x \leq 20$	$Y = -28.85\ln(X) + 86.439$	1.000
	>20	$Y = 0$	
Nitrite (NO_2^-) nitrogen	≤ 0.01	$Y = 100$	
	$0.01 < x \leq 0.2$	$Y = 1{,}275.1X^2 - 584.16X + 105.81$	1.000
	$0.2 < x \leq 0.8$	$Y = -28.85\ln(X) - 6.4386$	1.000
	>0.8	$Y = 0$	
Ammonium (NH_4^+) nitrogen	≤ 0.04	$Y = 100$	
	$0.04 < x \leq 0.6$	$Y = -21.53\ln(X) + 31.042$	0.993
	$0.6 < x \leq 2.4$	$Y = -28.85\ln(X) + 25.261$	1.000
	>2.4	$Y = 0$	
Total phosphorus (TP)	≤ 0.05	$Y = 100$	
	$0.05 < x \leq 0.3$	$Y = -33.08\ln(X) - 1.2982$	0.993
	$0.3 < x \leq 1.2$	$Y = -28.85\ln(X) + 5.2607$	1.000
	>1.2	$Y = 0$	
Orthophosphate (PO_4^{3-}) phosphorus	≤ 0.02	$Y = 100$	
	$0.02 < x \leq 0.2$	$Y = -25.48\ln(X) - 0.3415$	0.997
	$0.2 < x \leq 0.8$	$Y = -28.85\ln(X) - 6.4386$	1.000
	>0.8	$Y = 0$	
Dissolved oxygen (DO)	>8	$Y = 100$	
	$5 < x \leq 8$	$Y = 20X - 60$	1.000
	$2 < x \leq 5$	$Y = 2.2727X^2 - 3X - 3.2727$	0.998
	≤ 2	$Y = 0$	
Chloride (Cl^-)	≤ 25	$Y = 100$	
	$25 < x \leq 800$	$Y = -28.85\ln(X) + 192.88$	1.000
	>800	$Y = 0$	
Sulphate (SO_4^{2-})	≤ 25	$Y = 100$	1.000
	$25 < x \leq 800$	$Y = -28.85\ln(X) + 192.88$	
	>800	$Y = 0$	
Total organic carbon (TOC)	≤ 2	$Y = 100$	
	$2 < x \leq 10$	$Y = -36.92\ln(X) + 122.64$	0.986
	$10 < x \leq 40$	$Y = -28.85\ln(X) + 106.44$	1.000
	>40	$Y = 0$	
Adsorbable organohalogens (AOX)	0	$Y = 100$	
	$0 < x \leq 50$	$Y = 0.0167X^2 - 2.024X + 99.536$	0.999
	$50 < x \leq 200$	$Y = -28.85\ln(X) + 152.88$	1.000
	>200	$Y = 0$	

conduct this process. Factors which were taken into account by the experts to assign weights to water quality parameters are as follows:

- Availability of the substance in surface waters
- Toxic effects on aquatic life
- Eutrophication risk.

Based on the expert opinions, temporary weights were given to the studied water-quality variables and values

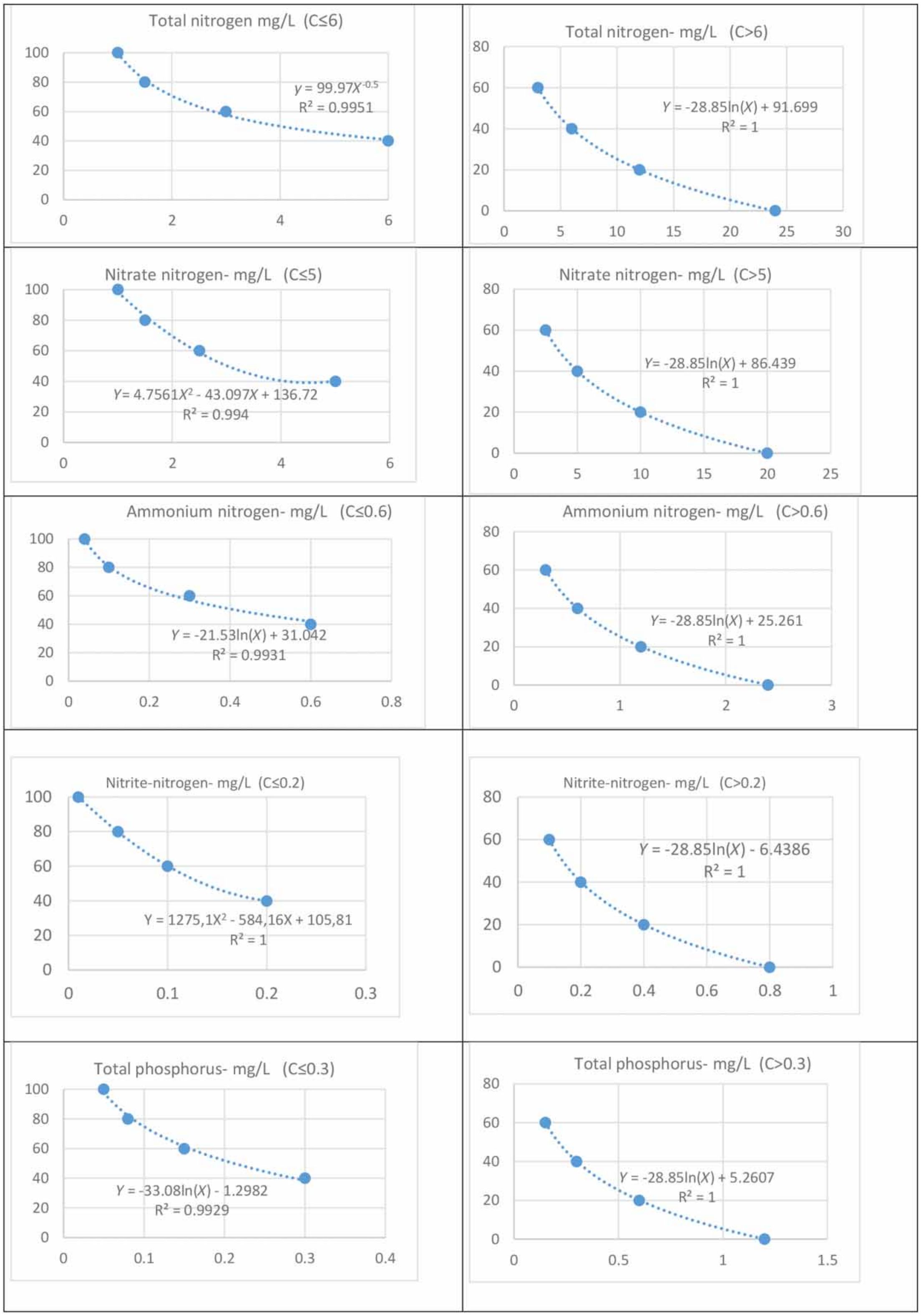

Figure 1 | Rating curves representing concentration (*X*-axis) versus sub-index scores for EWQI components (*Y*-axis). *(Continued.)*

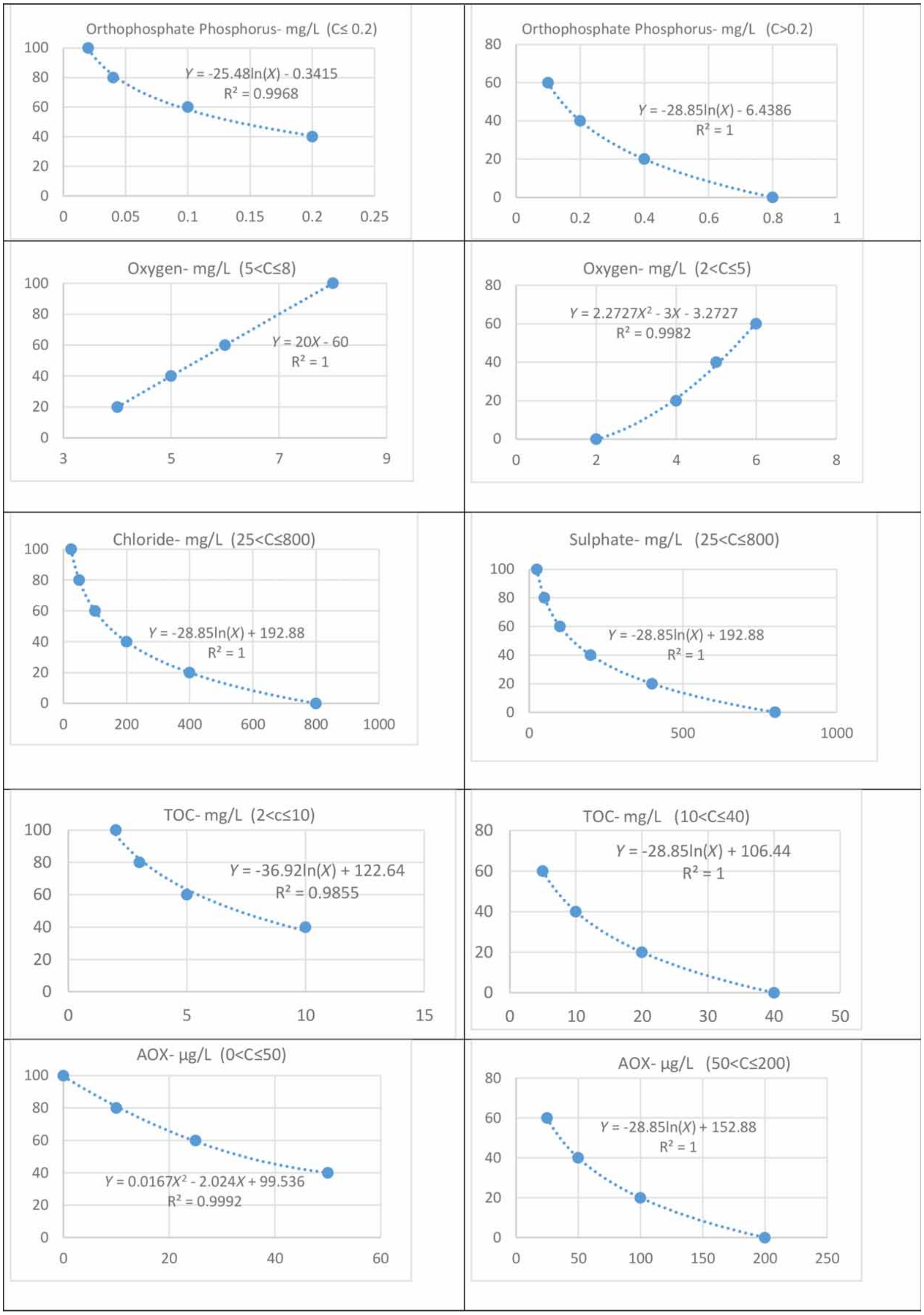

Figure 1 | Continued.

were ranged from 1 to 3 on a basic scale of importance. On this scale 1, 2, and 3 denote little, average and high importance, respectively. Each weight was then divided by the sum of all weights to arrive at the final weight factor, which is presented in Table 3.

Formulation of the overall index equation

A weighted-sum method was applied to aggregate sub-indices. For each variable, its assigned weight was multiplied by its sub-index score and then the obtained value was divided by the sum of all weights in order to calculate an overall index score (EWQI).

$$\left(\sum_{i=1}^{n} W_i * Y_I\right) / \sum_{i=1}^{n} W_i = EWQI$$

where:

W_i = weight for the i^{th} variable
Y_i = sub-index for the i^{th} variable (as reported in Table 2)

Considering pollution levels of the water and threshold values assigned to each water-quality class, an EWQI categorization scheme was proposed and is presented in Table 4.

Table 3 | Ratings and weights for EWQI components

Substance	Temporary weights (R_i)	Weight factor (W_i) = $R_i/\Sigma R$
Total nitrogen (TN)	3	0.15
Nitrate (NO_3^-) nitrogen	2	0.1
Nitrite (NO_2^-) nitrogen	1	0.05
Ammonium (NH_4^+) nitrogen	3	0.15
Total phosphorus (TP)	2	0.1
Orthophosphate (PO_4^{3-}) phosphorus	1	0.05
Dissolved oxygen (DO)	1	0.05
Chloride (Cl^-)	2	0.1
Sulphate (SO_4^{2-})	2	0.1
Total organic carbon (TOC)	2	0.1
Adsorbable organohalogens (AOX)	1	0.05

Table 4 | The proposed classification scheme for EWQI

Rank	EWQI score
No pollution	100
Lightly polluted	100–80
Moderately polluted	80–60
Critically polluted	60–40
Heavily polluted	40–20
Very heavily polluted	20–0
Excessively polluted	0

APPLICATION OF EWQI TO CLASSIFY SURFACE WATERS

The proposed EWQI was applied to classify the water quality of two basins located in western Turkey having different designated uses.

As mentioned previously, the proposed index included the evaluation of 11 water quality parameters. Instead of including 11 water-quality variables in the calculations, variable reduction alternatives were tested without causing misclassification of water quality. Water-quality variable selection was optimized using factor analysis.

Factor analysis is a multivariate statistical method that explains the correlations between the data sets in terms of the underlying factors, which cannot be observed directly. Highly correlated observations (either negatively or positively) are likely influenced by the same factors. There are three stages in factor analysis as: (a) correlation matrix is generated for all the variables; (b) based on the correlation coefficients of the variables, factors are extracted from the correlation matrix; and (c) the factors are rotated to maximize the relationship between some of the factors and variables (Yu *et al.* 2003; Gupta *et al.* 2005; Boyacioglu 2006).

In this study a factor-analysis method was applied to determine underlying factors for data sets using SPSS-20.0 software. Factor groups and variables comprised by these groups were determined for both case study areas. Then, various alternatives were tested by including/excluding water-quality variables (index components). The main approach was to comprise at least one variable from each quality group and also represent whole quality with at least one variable from each group.

Index calculations combined with factor analyses were accomplished for the two basins separately and the results are presented in the following sections.

Application of EWQI to classify surface water quality in Tahtalı Basin

Tahtalı Dam Reservoir is one of the main reservoirs supplying drinking water to the city of Izmir where approximately four million inhabitants live as of 2015 and it is located in the western part of Turkey. The location of the reservoir is seen in Figure 2. This water source is under the control of the authorities against over-extraction and pollution. The climate of the region is typical Mediterranean: hot and dry in summers and temperate and rainy in winters. The basin is approximately 550 km^2, with forest and agriculture as the primary land uses. Since the basin is in the water protection zone, there are no anthropogenic discharges to the reservoir.

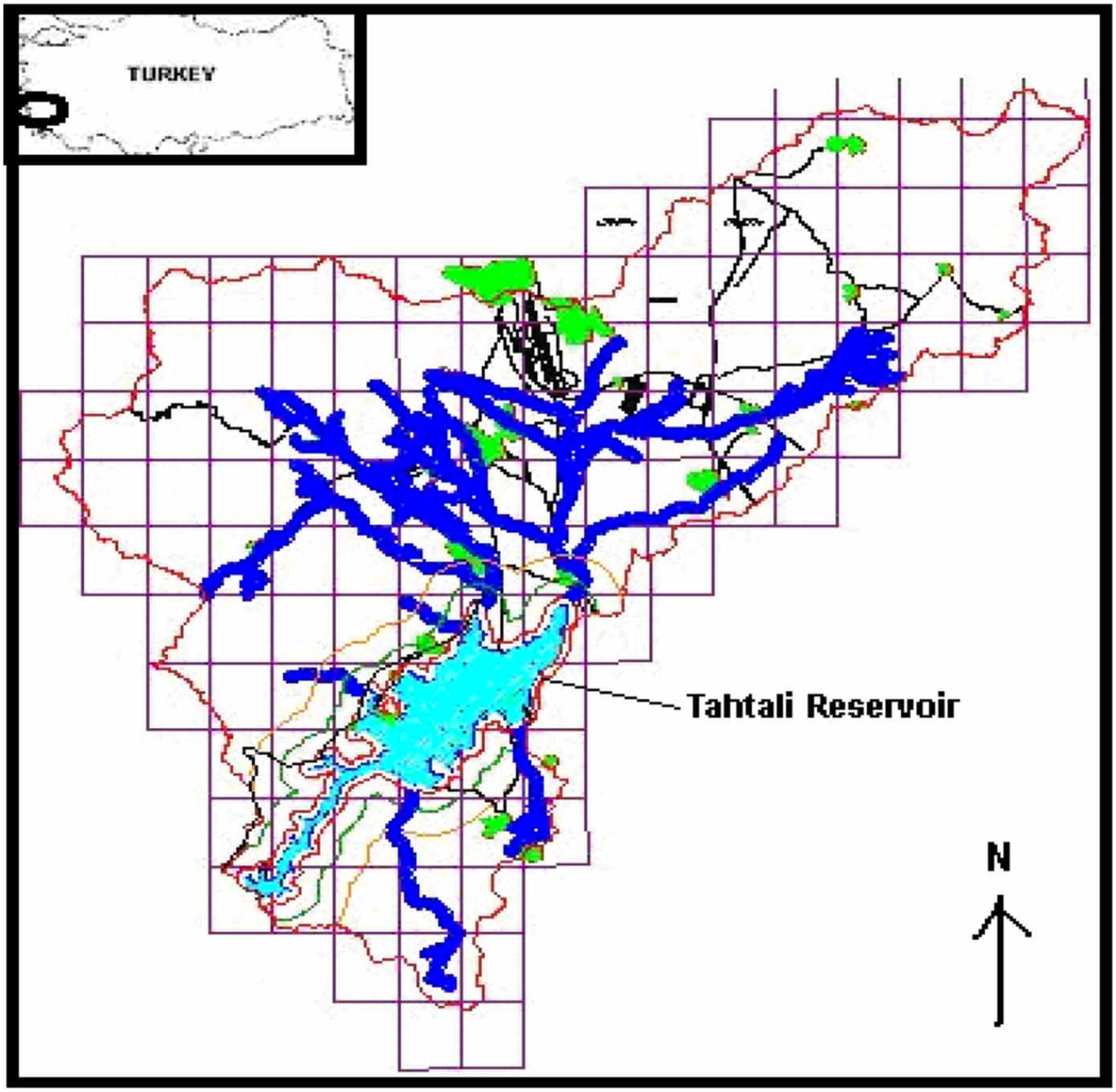

Figure 2 | Location of the Tahtalı Reservoir.

Therefore, all the pollutants in the surface water could be considered to be found naturally.

In the study, water quality was observed at a unique monitoring site in the Tahtalı Dam Reservoir for a two-year period on a monthly basis and the data set was considered for the calculation of EWQI. Water quality samples were analysed at the laboratory for DO, Cl^-, SO_4^{2-}, NO_3^--N and NO_2^--N according to procedures described in *Standard Methods for the Examination of Water and Wastewater* (APHA 2005). Descriptive statistics of the data sets comprising these five index components are presented in Table 5.

A factor analysis was applied to every data set and a correlation matrix was generated. Furthermore factors extracted by the centroid method were rotated by varimax rotation. The results of factor analysis including factor loading matrix, eigenvalues and total and cumulative variance values are given in Table 6. Chloride (Cl^-) and sulfate (SO_4^{2-}) marked factor 1 (F1) and factor 2 (F2) had a high positive loading on nitrite-nitrogen (NO_2^--N) and nitrate nitrogen (NO_3^--N). These two factors explained 70% of the total variance.

Table 5 | Descriptive statistics of Tahtalı Reservoir water-quality data set (concentrations are in mg/L)

Tahtalı Reservoir		Cl^-	NO_3^--N	NO_2^--N	DO	SO_4^{2-}
Mean		26.9	0.4	0.01	5.7	29.4
Median		27.0	0.2	0.01	6.7	29.3
Mode		25.5	0.2	0.00	1.9	27.8
Std. deviation		2.3	0.3	0.01	2.5	2.9
Percentiles	90	30.7	0.8	0.01	8.9	34.8

Table 6 | Factor loading matrix and total variance explained for Tahtalı Reservoir water-quality data set

	Component	
Tahtalı Reservoir	1	2
Cl^-	**0.938**	−0.125
SO_4^{2-}	**0.901**	0.219
NO_3^--N	−0.122	**0.812**
NO_2^--N	0.352	**0.805**
DO	0.385	−0.405
% variance explained	40	30
Total variance explained	70	

Chlorides, sulfates, carbonates, calcium bicarbonates and magnesium are commonly found in subsurface drainage water (Tanji & Kielen 2002; Boyacioglu 2006). Nitrites (NO_2^-) and nitrates (NO_3^-) are signs of organic contamination of water. Based on the sources of these variables in surface waters, two factors representing two different processes can be represented as:

F1: salt content,

F2: nitrogen content of water.

Due to the low factor loading for DO, it was not grouped under factors F1 and F2. It was considered as a separate factor representing the oxygen content of water in this case.

In the following step, using the mathematical formulations that are presented in Table 2, sub-index values were calculated and each parameter was assigned a value between 0 and 100. Sub-indices were calculated using a characteristic value representing the 90th percentile of the data set for each index component. The calculated sub-indices are presented in Table 7.

A weighted-sum method was applied in order to obtain overall index values using the weights indicated in Table 3. An index score including all sub-indices was calculated as 96 (nearly-no-pollution class). Furthermore, based on the factor analysis, some index components were excluded from the calculations. The main approach was to include at least one variable from each factor (salinity content, nitrogen content) and also represent the whole quality with at least one variable from each group. Results revealed that excluding some variables that were selected based on the factor analysis did not cause loss of information and a similar overall EWQI was obtained. These results are presented in Table 8.

Table 7 | EWQI component sub-index scores for Tahtalı Reservoir

EWQI component	Sub-index score
Cl^-	94.1
NO_3^--N	100.0
NO_2^--N	99.0
DO	100.0
SO_4^{2-}	90.5

Table 8 | Tahtalı Reservoir EWQI scores

Index components	Weighted index score
Cl^-, NO_3^--N, NO_2^--N, DO, SO_4^{2-}	96,0
Cl^-, NO_3^--N, DO	97.6
SO_4^{2-}, NO_3^--N, DO	96.2
SO_4^{2-}, NO_2^--N, DO	95.0
Cl^-, NO_2^--N, DO	96.8

Application of EWQI to classify surface water quality in the Küçük Menderes River Basin

The Küçük Menderes River Basin is located in western Turkey. The catchment area is 3,225 km^2 (Figure 3). The total population of the basin was about 3.8 million inhabitants in 2015. Agricultural lands occupy about 290,000 ha in the basin and constitute approximately 41% of its surface area. Industrial sites are concentrated in the west part. The Küçük Menderes River and its tributaries constitute an annual average discharge rate of 11.45 m^3/s. The basin has hot and dry summers with mild and rainy winters. The mean annual precipitation calculated for the study area is 622 mm. The surface-water-quality class of the basin is not adequate for many purposes in the region and the main reason is the uncontrolled industrial and agricultural discharges (Boyacioglu & Boyacioglu 2018; GDWM 2018).

In this study, the water-quality data set representing Küçük Menderes River surface water quality was processed using factor analysis and the index method as described before. Water samples, which were taken from six sampling locations on a semi-monthly basis for a one-year period and analysed for Cl^-, SO_4^{2-}, TOC, TP, TN and NO_3^--N, were processed. Locations of the sampling sites, which were determined based on accessibility and considering the impact of point discharges on water quality, are depicted in Figure 3. Data sets were merged to apply factor analysis to determine underlying factors in the whole basin. Descriptive statistics of the merged data set are presented in Table 9. It should be noted that index scores were calculated for each monitoring site individually.

Factor analysis created three factors explained 78% of the variance and the results are given in Table 10. The three factors and factor components are as follows:

Factor 1: Cl^-, SO_4^{2-},

Factor 2: TP,

Factor 3: TN, NO_3^--N.

Based on the results and considering the characteristics of the water-quality variables, three groups of factors were assigned as:

F1: salinity content,

F2: phosphorus content,

F3: nitrogen content.

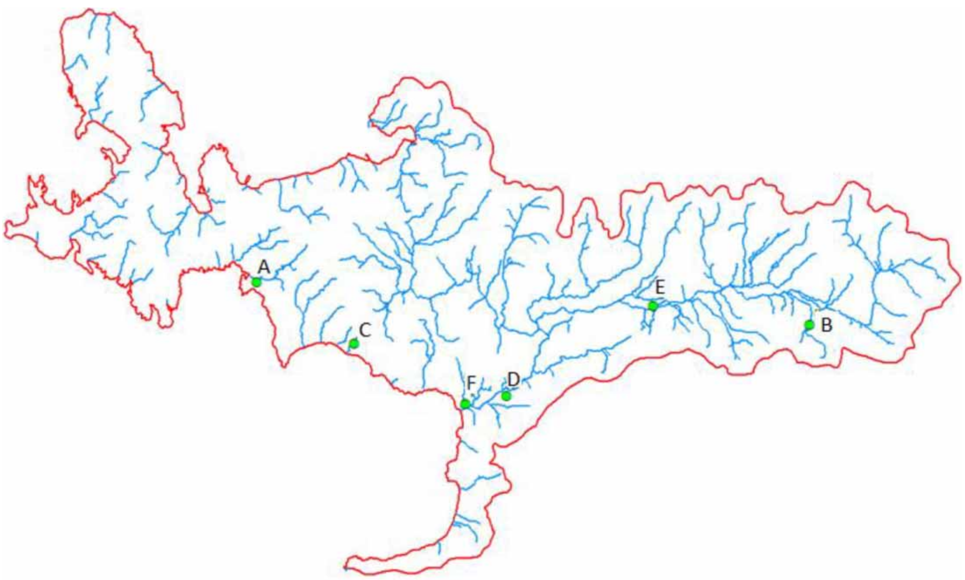

Figure 3 | Küçük Menderes Basin water quality monitoring stations.

Table 9 | Descriptive statistics of Küçük Menderes River water-quality data set (concentrations are in mg/L)

Küçük Menderes Basin		Cl^-	SO_4^{2-}	TOC	TP	TN	NO_3-N
Mean		22.4	39.8	2.2	0.12	2.0	1.7
Median		18.0	42.5	2.2	0.15	1.9	1.4
Mode		9.2	47.3	2.2	0.17	0.9	0.5
Std. deviation		11.4	10.3	0.7	0.06	0.8	0.7
Percentiles	90	43.3	51.5	3.2	0.20	3.6	2.9

Table 10 | Factor loading matrix and total variance explained for Küçük Menderes River water-quality data set

	Component		
Küçük Menderes Basin	1	2	3
Cl^-	**0.869**	0.236	0.103
SO_4^{2-}	**0.773**	−0.204	−0.130
TOC	−0.753	0.207	−0.096
TP	−0.045	**0.945**	0.017
TN	−0.061	0.053	**0.944**
NO_3-N	0.473	−0.486	**0.557**
% variance explained	40	20	18
Total variance explained	78		

TOC was negatively correlated with F1 and was not included in any factor. It was considered as a separate factor component in index calculations. Sub-index values for six variables at each monitoring site are presented in Table 11.

In the last step, water quality was examined at five monitoring stations separately. Five scenario alternatives were created and then tested by including/excluding some index components. Results including overall index scores for each scenario at each station are presented in Table 12. Index scores (represented on the *Y*-axis) calculated for five alternatives (e.g. I, II) at each monitoring station (A, B, C, D and E) are also depicted in Figure 4. Water quality classes representing each index score range are also seen in the same figure. Based on the index values, it was concluded that: Stations A, B and C can be considered as 'moderately polluted' and Stations E and F as 'heavily polluted' water quality classes. There were slight differences between index scores at stations based on the comprised index components. These differences did not cause misclassification of water quality. In other words, excluding a variable from the calculations did not cause misinterpretation (water quality class was not changed by excluding selected variables from calculations).

Table 11 | EWQI component sub-index scores for the Küçük Menderes River

Monitoring station	Cl^-	SO_4^{2-}	TOC	TP	TN	NO_3-N
A	95.3	100.0	88.4	40.3	61.3	70.2
B	83.2	78.4	93.9	40.9	47.7	41.6
C	75.2	86.2	92.3	75.5	63.5	89.3
D	9.1	65.3	86.3	0.0	0.0	39.1
E	36.9	69.1	61.5	0.0	0.0	51.1
F	0.9	55.5	83.5	0.0	0.0	39.8

RESULTS AND DISCUSSION

In this study, an Ecological Water Quality Index (EWQI) was developed. The objective was to determine the ecological status of surface water based on chemical variables. The legislation which is still in use in Germany was selected as reference. Total nitrogen (TN), nitrate nitrogen (NO_3^--N), nitrite nitrogen (NO_2^--N), ammonium nitrogen (NH_4^+-N), total phosphorus (TP), orthophosphate phosphorus (PO_4^{3-}-P), oxygen (DO), chloride (Cl^-), sulphate (SO_4^{2-}), total organic carbon (TOC) and adsorbable organohalogens (AOX) were selected as index components. Seven quality-class threshold values were used to develop mathematical equations to convert observed values to index scores (sub-indices). Ecologists were asked to assign weights to index variables considering ecological importance. Finally, an overall index was formulated using a weighted-sum method. The applicability of the method was demonstrated in two basins located in Turkey. In order to reduce the number of index components in calculations, factor analysis was applied. This could be considered as a variable selection process. The objective was to reduce the number of index components in calculations without losing information. Factor groups and variables comprised by these groups

Table 12 | Küçük Menderes River water quality monitoring station EWQI scores

	EWQI scores for scenarios including different index components				
Stations	Scenario I SO_4^{2-}, TOC, TP, TN, NO_3-N	Scenario II Cl^-, TOC, TP, TN, NO_3-N	Scenario III Cl^-, SO_4^{2-}, TOC, TP, TN	Scenario IV Cl^-,SO_4^{2-}, TOC, TP, NO_3-N	Scenario V All index components included
A	71.1	70.2	75.6	78.8	74.8
B	59.3	60.2	66.9	67.6	63.0
C	79.7	77.7	77.2	83.7	79.0
D	34.7	24.5	29.2	40.0	30.7
E	33.0	27.2	30.5	43.7	33.6
F	32.5	22.6	25.4	35.9	27.6

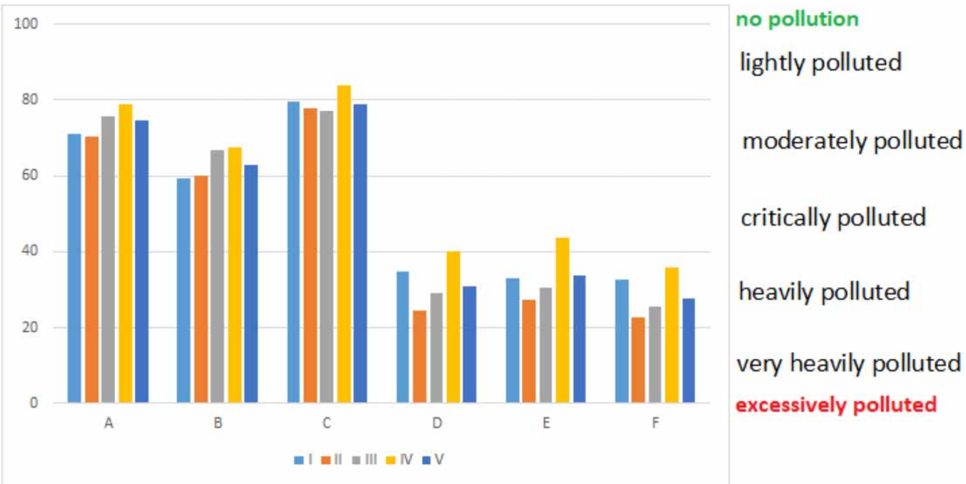

Figure 4 | EWQI values, and ecological status classification at monitoring stations in Kücük Menderes Basin.

were determined for both case study areas. Then, various alternatives were tested by including/excluding water quality variables (index components). The main approach was to include at least one variable from each quality group (e.g. salinity content, nitrogen content) and also represent whole water quality by including at least one variable from each group. Results showed that there were slight differences between index scores of tested various alternatives. These differences did not cause misclassification of surface waters.

CONCLUSION

The object of this study was to develop a new water quality index based on German legislation. Federal Government and Länder in Germany developed a water quality classification scheme prior to the Water Framework Directive's entry into force. In Germany for nutrients and some variables there are no binding values for classification of a good ecological status and chemical water quality classification will be used in the future. Since the legislation can be applicable at a European scale and also in many countries in the world, it was referenced in development of an Ecological Water Quality Index (EWQI). This approach will provide assignment of overall water quality into pre-defined ecological water quality classes in the studied areas. EWQI was developed in four steps: (a) water-quality variable (index component) selection, (b) formulation of sub-index equations, (c) assignment of weights to index components and (d) formulation of overall index equations. The applicability of the index was tested in two different sites in Turkey. Water-quality variable selection was optimized using factor analysis. Study results revealed that (a) EWQI can assist decision makers (a) to assess the status of water quality, (b) investigate water quality class and (c) evaluate spatial and temporal changes in the quality of surface waters. Moreover factor analysis is proposed as a usefull method to optimize the number of index components.

REFERENCES

Abbasi, T. & Abbasi, S. A. 2012 *Water Quality Indices*. Elsevier, Oxford, UK.

APHA (American Public Health Association) 2005 *Standard Methods for the Examination of Water and Wastewater*, 21st edn. American Public Health Association, Washington DC, USA, p. 20.

Boyacioglu, H. 2006 Surface water quality assessment using factor analysis. *Water SA (ISI)* **32** (3), 389–393.

Boyacioglu, H. 2007 Development of a water quality index based on a European classification scheme. *Water SA (ISI)* **33** (1), 101–106.

Boyacioglu, H. & Boyacioglu, H. 2018 Environmental determinants of surface water quality based on environmetric methods. *Environment and Ecology Research* **6** (2), 120–124.

El Najjar, P., Kassouf, A., Probst, A., Probst, J. L., Ouaini, N., Daou, C. & El Azzi, D. 2019 High-frequency monitoring of surface water quality at the outlet of the Ibrahim River (Lebanon): a multivariate assessment. *Ecological Indicators* **104**, 13–23.

GDWM (Republic of Turkey Ministry of Agriculture and Forestry General Directorate of Water Management) 2018 *Küçük Menderes Basin Drought Management Plan*. GDWM, Ankara, Turkey.

Gupta, A. K., Gupta, S. K. & Patil, R. S. 2005 Statistical analyses of coastal water quality for a port and harbour region in India. *Environmental Monitoring and Assessment* **102**, 179–200.

Horton, R. K. 1965 An Index number system for rating water quality. *Journal of the Water Pollution Control Federation* **37** (3), 300–306.

Mukate, S., Wagh, V., Panaskar, D., Jacobs, J. A. & Sawant, A. 2019 Development of new integrated water quality index (IWQI) model to evaluate the drinking suitability of water. *Ecological Indicators* **101**, 348–354.

Poikane, S., Phillips, G., Birk, S., Free, G., Kelly, M. G. & Willby, N. J. 2019 Deriving nutrient criteria to support 'good' ecological status in European lakes: an empirically based approach to linking ecology and management. *Science of The Total Environment* **650** (Part 2), 2074–2084.

Schuwirth, N., Honti, M., Logar, I. & Stamm, C. 2018 Multi-criteria decision analysis for integrated water quality assessment and management support. *Water Research X* **1**, 100010.

Sharma, S., Reddy, A. S. & Dalwani, R. R. 2015 Ecological water quality index development and evaluation of water quality of the Satluj River. *Indian Journal of Environmental Protection* **35** (6), 477–489.

Simeonov, V., Stratis, J. A., Samara, C., Zachariadis, G., Voutsa, D., Anthemidis, A., Sofoniou, M. & Kouimtzis, Th. 2003 Assessment of the surface water quality in Northern Greece. *Water Research* **37**, 4119–4124.

SPSS-20 2011 *IBM SPSS Statistics 20.0*.

Sutadian, A. D., Muttil, N., Yilmaz, A. G. & Perera, B. J. C. 2016 Development of river water quality indices – a review. *Environmental Monitoring and Assessment* **188** (1), 58.

Tanji, K. K. & Kielen, N. C. 2002 *Agricultural Drainage Water Management in Arid and Semi-Arid Areas*. FAO Irrigation and Drainage Paper 61, FAO, Rome, Italy.

Tyagi, S., Sharma, B., Singh, P. & Dobhal, R. 2013 Water quality assessment in terms of water quality index. *American Journal of Water Resources* **1** (3), 34–38.

Umwelt Bundesamt–BMU 2019 *Chemical Water Quality Classification*. Available from: https://www.umweltbundesamt.de/en/topics/water/rivers/assessment-of-watercourses/chemical-quality-standards-assessment#textpart-4 (accessed 13 August 2019).

UNEP 2007 *Global Drinking Water Quality Index Development and Sensitivity Analysis Report*. United Nations Environment Programme (UNEP), Global Environment Monitoring System (GEMS), Burlington, ON, Canada.

Yu, S., Shang, J., Zhao, J. & Guo, H. 2003 Factor analysis and dynamics of water quality of the Songhua River, Northeast China. *Water, Air, and Soil Pollution* **144**, 159–169.

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