Water Quality Assessment with Water Quality Indices

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ABSTRACT

A water quality index provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters. Water quality index (WQI) is valuable and unique rating to depict the overall water quality status in a single term that is helpful for the selection of appropriate treatment technique to meet the concerned issues. These indices utilize various physico-chemical and biological parameters and have been resulted as an outcome of efforts and research and development carried out by different government agencies and experts in this area globally. This review paper includes the water quality assessment with water quality indices being used globally.

Keywords: Water Quality, Water Quality Indices.

Water, a prime natural resource and precious national asset, forms the chief constituent of ecosystem. Water sources may be mainly in the form of rivers, lakes, glaciers, rain water, ground water etc. Besides the need of water for drinking, water resources play a vital role in various sectors of economy such as agriculture, livestock production, forestry, industrial activities, hydropower generation, fisheries and other creative activities. The availability and quality of water either surface or ground, have been deteriorated due to some important factors like increasing population, industrialization, urbanization etc.

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The degradation of water quality in a water body creates adverse condition so that water cannot be used for intended beneficial uses including bathing, recreation and as a source of raw water supply. According to Central Pollution Control Board, 90% of the water supplied in India to the town and cities are polluted, out of which only 1.6% gets treated (2007-2008). Therefore, water quality management is fundamental for the human welfare.

Water Quality Assessment

Water quality is determined by assessing three classes of attributes: biological, chemical, and physical. There are standards of water quality set for each of these three classes of attributes. Some attributes are considered of primary importance to the quality of drinking water,

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while others are of secondary importance. Primary water standards regulate organic and inorganic chemicals, microbial pathogens, and radioactive elements that may affect the safety of drinking water. These standards set a limit--the Maximum Contaminant Level (MCL)--on the highest concentrations of certain chemicals allowed in the drinking water supplied by a public water system.

Biological attributes of a waterway can be important indicators of water quality. Biological attributes refer to the number and types of organisms that inhabit a waterway. The poorer the quality of water, the fewer the number and types of organisms that can live in it.When assessing water quality, it is also important to look at the quality of organisms that live in a waterway. Some species are more sensitive to chemical and physical changes in their habitat than other species. If species that tend to be sensitive to pollution are present in a waterway, then that waterway most likely has good water quality.

To assess the biological attributes of water quality, scientists generally examine benthic macroinvertebrates. These organisms are abundant, easier to capture than fish, and easier to identify than algae or protozoa. Benthic macroinvertebrates include crustaceans, mollusks, worms, and many species of insect larva such as mayflies, stoneflies, caddisflies, and beetles. Samples of macroinvertebrates can be collected over areas of uniform size using a Hess sampler in large streams. A Surber sampler usually used in smaller streams. Generally, three samples are collected from one riffle per study site. Macroinvertebrates from each sample are identified and counted. The density of organisms per square meter of stream bottom at each site is estimated from the average of the samples collected there. A calculation of species diversity such as the Shannon Index of Species Diversity can be performed on this data. The Shannon Index of Species Diversity is often performed on macroinvertebrate order data rather than species data. The abundance of macroinvertebrates belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera should be noted. These three orders constitute the EPT Index of a stream. Since these orders of macroinvertebrates are highly sensitive to pollution, they are often used as water quality indicators. Their presence indicates a high quality of water, while their absence suggests water may be polluted. The EPT Index is calculated as the sum of the number of Ephemeroptera, Plecoptera, and Trichoptera divided by the total number of midges. Midges (Diptera: Chironomidae) are a species of fly that are present in large numbers in nearly all streams.

Chemical attributes of a waterway can be important indicators of water quality. Chemical attributes of water can affect aesthetic qualities such as how water looks, smells, and tastes. Chemical attributes of water can also affect its toxicity and whether or not it is safe to use. Since the chemical quality of water is important to the health of humans as well as the plants and animals that live in and around streams, it is necessary to assess the chemical attributes of water. Assessment of water quality by its chemistry includes measures of many elements and molecules dissolved or suspended in the water. Chemical measures can be used to directly detect pollutants such as lead or mercury. Chemical measures can also be used to detect imbalances within the ecosystem. Such imbalances may indicate the presence of certain pollutants. For example, elevated acidity levels may indicate the presence of acid mine drainage. Commonly measured chemical parameters include pH, alkalinity , hardness, nitrates, nitrites and ammonia, ortho- and total phosphates, and dissolved oxygen and biochemical oxygen demand. The presence of fecal coli form, a bacteria, is also determined using a chemical test. This microscopic organism is too small to detect during the biological assessment of macroinvertebrate populations. In addition, some “chemical” measurements actually indicate the physical presence of pollutants in water. These include measurements such as conductivity and density.

Physical attributes of a waterway can be important indicators of water quality. The most basic physical attribute of a stream is the path along which it flows. Most streams are classified as “meandering” or S-shaped. Meandering streams have many bends. The bends are characterized by deep pools of cold water along the outside banks where faster-moving water scours the bank. Meandering streams also have riffles along the straight stretches between pools. The riffles appear as humps in a longitudinal stream profile.

The S-shaped path of meandering streams prevents water from moving too quickly and flooding downstream ecosystems. The deep, cold pools of water provide ideal habitat for many species of fish — even when overall stream-flow is reduced. The riffles help to hold water upstream during times of low stream-flow. Also, turbulence in the riffles mixes oxygen into the water. Natural stream-channel patterns, with their bends, pools, and riffles, are essential to decreasing flooding as well as providing a suitable habitat for certain aquatic plants and animals. For these reasons, it is important to assess the physical attributes of a stream when examining its water quality.Measurements of a stream's physical attributes are used to describe the structure of a sampling site. This allows for the comparison of the biota and chemistry of similarly-structured streams at different locations. Measurements of a stream's physical attributes can also serve as indicators of some forms of pollution. For example, changes in temperature may indicate the presence of certain effluents, while changes in stream width, depth, and velocity, turbidity, and rock size may indicate dredging in the area. Other commonly measured physical characteristics of a stream include: elevation and catchment area, stream order, forest canopy , and total solids.

Water quality of any specific area or specific source can be assessed using physical, chemical and biological parameters. The values of these parameters are harmful for human health if they occurred more than defined limits(WHO, 2012; BIS, 2012; Central Pollution Control Board, 2013). Therefore, the suitability of water sources for human consumption has been described in terms of WQI, which is one of the most effective ways to describe the quality of water. WQI utilizes the water quality data and helps in the modification of the policies, which are formulated by various environmental monitoring agencies. It has been realized that the use of individual water quality variable in order to describe the water quality for common public is not easily understandable (Bharti and Katyal, 2011; Akoteyon *et al.,* 2011). That's why, WQI has the capability to reduce the bulk of the information into a single value to express the data in a simplified and logical form (Babaei *et al.,* F,2011). It takes information from a number of sources and combines them to develop an overall status of a water system (Karbassi *et al.,* 2011). They increase the understanding ability of highlighted water quality issues by the policy makers as well as for the general public as users of the water resources (Nasirian, 2007). The present study reviews some of the important water quality indices used in water quality assessment and provides their mathematical structure, set of parameters and calculations along with their merits and demerits, which are being used worldwide.

Water Quality Index

Initially, WQI was developed by Horton (1965) in United States by selecting 10 most commonly used water quality variables like dissolved oxygen (DO), pH, coliforms, specific conductance, alkalinity and chloride etc. and has been widely applied and accepted in European, African and Asian countries. The assigned weight reflected significance of a parameter for a particular use and has considerable impact on the index. Furthermore, a new WQI similar to Horton's index has also been developed by the group of Brown in 1970 (Brown *et al.,*1970) , which was based on weights to individual parameter. Recently, many modifications have been considered for WQI concept through various scientists and experts (Bhargava *et al.,*1998; Dwivedi *et al.,*1997).

WQI is defined as, a rating reflecting the composite influence of different water quality parameters. It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers (Ramakrishnaiah *et al.,* 2009).

A Water Quality Index (WQI) is a means by which water quality data is summarized for reporting to the public in a consistent manner. It is similar to the UV index or an air quality index, and it tells us, in simple terms, what the quality of drinking water is from a drinking water supply. Generally from literature reviews it is pertinent that a 100 point water quality index scale can be divided into several ranges corresponding to the general descriptive terms shown in the table below (Table 1).

Table 1: Water Quality Index Legend

Concentration	Quality	E.I.A.
90 – 100	Excellent	Excellent
80 – 90	Good	Healthy
50 – 80	Medium	Alarming
25 – 50	Bad	Badly Affected
0 – 25	Very bad	Very Badly Affected

Essentially the WQI is calculated by comparing the water quality data to any specific guidelines of water quality.

The WQI measures the scope, frequency, and amplitude of water quality exceedances and then combines the three measures into one score. This calculation produces a score between 0 and 100. The higher the score the better the quality of water. The scores are then ranked into one of the five categories described below:

- **Excellent:** (WQI Value 95-100) - Water quality is protected with a virtual absence of impairment; conditions are very close to pristine levels. These index values can only be obtained if all measurements meet recommended guidelines virtually all of the time.
- **Very Good:** (WQI Value 89-94) - Water quality is protected with a slight presence of impairment; conditions are close to pristine levels.
- **Good:** (WQI Value 80-88) - Water quality is protected with only a minor degree of impairment; conditions rarely depart from desirable levels.
- **Fair:** (WQI Value 65-79) - Water quality is usually protected but occasionally impaired; conditions sometimes depart from desirable levels.
- **Marginal:** (WQI Value 45-64) - Water quality is frequently impaired; conditions often depart from desirable levels.
- **Poor:** (WQI Value 0-44) - Water quality is almost always impaired; conditions usually depart from desirable levels.

WQI scores are computed for each public water supply system that has been sampled in a sampling season. The same variables are used in the computation of the WQI for all public water supply systems and only the six most recent samples are used. Various approaches have been used to estimate WQI using the existing approaches rigorously consideringphysical and geochemical processes that ultimately determine water quality. These approaches have been used to estimate water quality, including the use of historical data, geomorphology, chemistry of toxicants , geochemical modeling, and mass balance. There are different approaches for water quality estimation that have been summarized in the following table (Table 2).

Table 2. Different approaches for water quality estimation

Approaches	Principle	Analyte	References
Statistical approach	Maximum likelihood estimation (MLE) and regression on order statistics (ROS).performed better in simulations involving the gamma as the underlying distribution.	Copper, aluminium, arsenic, chromium, nickel, and lead.	Scha_alitzky, F. *et al.*,(2001)
Sparrow	Spatially Referenced Regressions.	Contaminant sources and factors influencing terrestrial and stream transport.	United States Geological Survey (USGS), (2000).
Interval clustering approach (ICA)	Interval samples can be analyzed with a view to delineating the important attributes via the interval weights.	Analysis of poorly measured data, poorly collected data and imprecise hydrological data.	Journal of Hydrology (2014)
Chemometric analysis	Principal component analysis (PCA), Discriminate analysis (DA) and Partial least squares (PLS),	Trilinear plots of major ions showed that the groundwater in this region is mainly of Na/K-bicarbonate type.	Bro, R.(1997)
Bayesian approach	Load and parameter estimation. statistics and to contrast it with the frequentist approach	Biological oxygen demand (BOD) and ammonia (NH_4^+)	Howson, C., (1993)
Support vector machine (SVM)	Water quality mapping based on remote-sensed images.	Chlorophyll density of water body.	IC-MED

Agricultural Water Supply Use Assessment Method	Use Total Dissolved Solids (TDS) as the indicator of agricultural use support because of its adverse and immediate detrimental effects on agricultural practices.	Total Dissolved Solids (TDS)	National Research Council. (2001)
TMDL approach	Total maximum daily loads of parameters.	Nutrients, Pathogens, and Acid load.	Amin Elshorbagy *et al.*, (1995)
Bio-Monitoring Approach	The use of living organisms for monitoring of water quality	phytoplankton, periphyton, microphytobenthos and aquatic macrophytes have physicochemical Factors like water temperature, pH, alkalinity, free CO_2, Do, nitrate, phosphate and calcium.	Singh, N.K. (1993)
Projection pursuit cluster (PPC) model	Multifactor problem can be converted to one factor problem.	All the effect factors associated with water quality must be used.	P. J. Huber (1985)
Stochastic approach	Random characteristics of many parameters, Based on Kalman-filtering and self-adaptive techniques	Organic pollutants and suspended solids, DO and BOD	R. G. Ghanem (1991)
Material flow analysis	Law of matter conservation	Nitrogen, phosphorus, carbon,	Daniel B (2006)
Principal component analysis (PCA)	Linear regression	pH, Conductivity, UV absorbance at 254 nm and permanganate index for raw water)	Rusbult, C.E. (1980)
Watershed approach	Watershed approach follows the principle of adoptive management, which uses the best information available to take action on immediate problems.	Watershed to take action on immediate problems. Landscape diversity, and geographic complexity.	Mitchell, B. (1990)
Water quality index approach	Overall water quality express in single value	pH,TDS, Total hardness Nitrate, Fluoride and Iron.	International Journal of Environmental Sciences and Research (2011)
Bayesian Maximum Entropy approach	Space/Time Geostatistical Exposure Assessment	Means of estimating seasonal chlorophyll a concentration.	Water Resources Research, (2007)
Geostatistical Approach	Geostatistics.	PH, Electrical conductivity, Sulphate, Nitrate, Hardness.	Polish Journal of Environmental Studies. (2009)
Q-PCR approach	Development of molecular tools to assess water quality using diatoms as the biological model.	Toxicity of Cd.	Sandra Kim Tiam *et al* (2006).,
Multiagent Dynamic Assessment Approach	Q-Learning Algorithm.	COD, Total Nitrogen (TN), and Total Phosphorus (TP),	Jaffray, J *et al.* (2007)
Fuzzy logic approach	"Fuzzy" analysis is based on using approximations in the calculations rather than precise values to give a broad and potentially more useful response,	pH, DO, BOD, Suspended solids, and Chlorides, Phosphates, Nitrates and Sodium.	Goranson H. T. (1992)

Mass balance approach	Source contributions of pollutant loads into the Receiving water bodies.	Conductivity, pH, Temperature, Dissolved solids, Nitrates, Phosphates and silicates.	Onstad, C. A., *et al.* (1991)
MODIS approach	Static landuse/land-cover (LULC) classifications derived from remote sensing imagery.	Nitrate and Dissolved Phosphorus.	Ackerman, S. A. *et al.* (1998)
Pattern recognition techniques	Principal component analysis (PCA) and hierarchical cluster analysis (CA),	EC, pH, TDS, NH_4, NO_3, NO_2, Turbidity, Total Hardness, Ca, Mg, Na, K, Cl, SO_4, SiO_2 as physicochemical and TC, FC,	Girolami, M. *et al.*, (2003)
Geospatial Approach	Geospatial data sets and their sources used in the ArcGIS module to summarize water quality issues.	Bacteria, Dissolved oxygen, pH, Phosphorus, Temperature, Total dissolved	Allsopp, R. (1998)
Fuzzy Synthetic Evaluation approach	It was designed to supplement the interpretation of linguistic or measured uncertainties for real-world random phenomena.	DO, BOD_5, NH_3-N, pH, and SS	N. Chang *et al.*, (2001).;

Using these diversified approaches various water quality index method was developed by paying utmost attention in integrating selecting parameters, developing a common scale and assigning weights (Table 3). The purpose of using these indices is to provide a simple and concise method for expressing the ambient water quality of streams for general recreational use, including fishing and swimming. Further the indices allow users to easily interpret data and relate overall water quality variation to variations in specific categories of impairment. The method for comparing the water quality indices to convey the water quality information for both management and the public based on diversified principles is relied upon water quality parameters such as temperature, pH, turbidity, fecal coliform, dissolved oxygen, biochemical oxygen demand, total phosphates, ammonia+nitrate nitrogen, nitrates ,fecal coliform and total solids. The parameters related with various measurements may vary from one station to the other and sampling protocol followed.

Table 3: Different water quality indices

Water quality index	Parameters involved	Validate location	purpose	References
Multimetric Benthic Macroinvertebrae Index	DO, BOD, pH, EC, TN, TP, Turbidity, Altitude,	Korea	Assessment of Stream Biotic Integrity	Gabriels, W. et al., (2010)
Fuzzy Logic Water Quality Index	DO, BOD, COD, AN, SS and pH.	Kuala Lumpur	Water quality of a river	Goranson H.T. (1992)
WQM-Water Quality Index	pH, EC, DO, BOD, Total Coliform, FC,	India	Water Quality Monitoring In India	WQD (1990)
Dairy cattle drinking water quality index	DO, BOD, Temp, TDS, Turbidity, Fecal Coliforms, Heterotrophic plate count, Hardness, Alkalinity, Arsenic, Lead, Mercury, Nickel, Cadmium, Chromium, Total phosphorous, H2S, Nitrate, and Fluoride,	Iran	Water quality	NRC (1974)
Drinking water quality index	pH, Total dissolved solids, Electrical conductivity, Turbidity, Total hardness, Suspended solids,	Mzuzu City, Northern Malawi	Ascertain the quality of water for domestic purposes	Johnson, D.L. *et al.*, (1997)

Modified water quality index	(COD and BOD5), Natural condition group (pH and T), and Nutrient group (TAN, Chl-a and DIP)	Shrimp ponds of Litopenaeus vannamei.	Water quality	CCME. (2001)
Water quality index for biodiversity	Temperature, Dissolved oxygen, pH, Electrical Conductivity, Total nitrogen, and Total phosphorus.	Upper Mississippi U.S.A.	River Water quality	Brazil. (1986)
Index of Aquifer Water Quality	Cd, Mn, Pb, Fe, NO_3^-, Total Alkalinity, TDS and Ca_{2+}) as against n=2 (chloride and nitrate	Indo Gangetic Plain in India	Groundwater water quality	Couillard, D., *et al.*, (1985)
CCME Water Quality Index	Do, pH, EC, carbonate, bicarbonate, COD, BOD , Total phosphate, Nitrate, Sulphate, Chloride, Calcium, Sodium, Magnesium, Turbidity and Total dissolved solids.	Lakes Of Mandya, Karnataka State, India	Water quality	Rocchini, R., et al., (1995)
Overall water quality index	pH, EC,DO, Colours, Turbidity, Ammonia Nitrogen, Fluorides, Chlorides, Sulphates, Total Solids, and P,	State of Chihuahua in northern Mexico.	Water quality of river	Harilal C C., *et al.*, (2004)
San Francisco Bay Water Quality Index	Sediment Contamination, Trace elements, Pesticides, PCBs, PAHs, Dissolved oxygen.	San Francisco Bay	Water quality in the Bay,	U. S. Geological Survey,
Trophic Diatom Index	Water temperature, pH, Conductivity, Ammonium ion, Nitrates, Nitrites, Silica and Phosphates	Nisava River, southern Serbia.	water quality of river	Jelena Z. Andrejic *et al.*, (1997)
Oregen water quality index	Temperature, DO, BOD, Ph, Total solids, Nitrogen, Fecal Coliforms,	Tualatin river at road bridge.	Water quality of river,	WQD(1920)
Pollution-index	COD and Phosphate concentrations,	Hebei in Bohai sea, china	Assessment of coastal pollution.	Marine pollution bulletin volume 62,(2011).
An aesthetic quality index	Taste and Odour, Turbidity and Colour.	Barcelona, Spain	Flavour profile analysis, odour, taste.	Water science and technology volume 40, (1999)
Canadian Water Quality Index (CWQI)	pH, EC, TSS, TDS, HCO_3, Cl, SO_4, Ca, Mg, Na, Mn, Hg, Fe, As, Cd, DO, COD, BOD, NO_3, Fecal Coliforms, Total Coliforms, Helminthus egg.	Shiraz wastewater, Iran.	Irrigation water quality,	Mohammad A Baghapour et al., (2006).
Chemical water quality index	Total nitrogen, Dissolved lead, Dissolved oxygen, pH, and Total particulate and Dissolved P,	Lake basin in northern Alabama.	Water quality of lake.	Tsegaye *et al.* (2006)
Index of river water quality	Temperature, pH, toxic substances, Organics Dissolved oxygen, BOD, Ammonia, Turbidity, Suspended solids, and Faecal Coliforms.	Taiwan	river water quality	Liou *et al.* (2004)
Overall Index of Pollution (OIP	pH, Turbidity, Dissolved oxygen, BOD, Hardness, Total dissolved solids, Total Coliforms, Arsenic, and Fluoride.	India	river water quality	Sargaonkar and Deshpande (2003)

NSFWQI	Temperature, pH, DO, TDS, Total hardness, Calcium, Magnesium, Chloride, Fluoride.	Kopargaon, maharastra	Ground water quality	I. j.of Advanced Technology in Civil Engineering, (2013)
Serbian water quality index	SS, TDS, pH, DO, BOD, E.Coli, COD, Colour, smell, Oxygen saturation,	Republic of Serbia	river water quality	Nebojsa Veljkovic et al. (1997)
Water Quality Index for Biodiversity (WQIB)	Temperature, Dissolved oxygen, pH, Electrical conductivity (salinity), Nitrogen and Phosphorus,	Vaal Rivers in South Africa.	Water quality of freshwater ecosystems	UNEP-GEMS
Iowa Water Quality Index	DO, E. coli, BOD, Total phosphorus, Nitrate + nitrite as N, Total detected pesticides, pH, Total dissolved solids, and Total suspended solids,	Iowa	Water quality of Iowa	Lowa DNR/IGS the Iowa department of natural resources.
DOE water quality index	DO, BOD, COD, AN, SS, and pH.	Malaysia	River water quality	Susilo et al(2006).
Statistical Water Quality Index (SWQI)	Dissolved oxygen (DO), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), and Total dissolved solid	Egypt.	Assessment of Surface Water Quality	Journal of Applied Sciences Research, (2012)
Source Water Quality Index (SWQI)	Arsenic, Boron, Cadmium, Nitrate chromium, Copper, Fluoride, Lead, Manganese, Mercury, f. coliform,	Republic of Korea.	Drinking water quality	WQI(1976)
Heavy metal pollution index (HPI)	Iron, Manganese, Lead, Copper, Cadmium, Chromium and Zinc,	Jharia coalfields Dhanbad, India.	Ground water quality	APHA (2002)
Trophic Index (TRIX)	Oxygen, Chlorophyll a, Dissolved inorganic Nitrogen and Total phosphorus,	Gulfs of Erdek and Bandırma in the Marmara Sea.	Evaluation of Coastal water quality	Giovanardi, F.*et al.*, (2004)
Fresh water quality index	Sediments, DO, Nutrient,Tematature,	Salish sea in British Columbia, Canada,	To evaluate fresh water ecosystem,	CCME-WQI,
Acceptability Water Quality Index (AWQI)	Ammonia, Chloride, Iron, pH, Sodium, Sulphate, Zinc,	Russian Federation	Drinking water quality	UNEP GEMS/Water Programme,

CONCLUSION

The aim of the water quality assessment with water quality indices is to study about the various water body and in turn to compute indices for various water such as drinking water, aquatic life and recreation purposes. From this the water can be used for different purposes in the future that includes the water can be used for aquaculture and agriculture purposes. So after study of different water quality indices, it may be inferred the aim of WQI is to give a single value to water quality of a source alon with reducing higher number of parameters into a simple expression resulting into easy interpretation of water quality. This review is an updated account of coomonly used indices used in water quality vulnerability assessment and also provides information about indices composistion and mathematical forms. These indices utilize various physico-chemical and biological parameters and have been resulted as an outcome of efforts and research and development carried out by different government agencies and experts in this area globally. In spite of all the efforts and different discussed indices being used globally, no index has so far been universally accepted and search for more useful and universal water quality index is still going on, so that water agencies, users and water managers in different countries may use and adopted it with little modifications.

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