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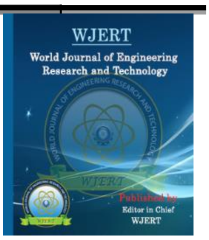

INVESTIGATING AND ANALYZING OF WATER QUALITY STATUS OF TIKUR WUHA RIVER FOR SUITABILITY OF DRINKING AND IRRIGATION BY USING WQI AND MULTIVARIATE ANALYSIS (HAWASSA, ETHIOPIA)

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ABSTRACT

The analysis of physical, chemical, and biological characteristics of water is referred to as water quality assessment. Water quality indices aim to assign a single value to a source's water quality, reducing many parameters to a single expression and making monitoring data easier to interpret. Various water quality indices (WQI) used for monitoring surface water quality are discussed in this review paper. There are multiple WQI specific to any location or area since different National and International Agencies involved in water quality assessment and pollution control specify water quality criteria for different uses of water using different indicator parameters. Here, we've attempted to cover all the different water quality indices developed around the world, as well as their history and application areas. In this respect, this review presents a comparative analysis of several indices and identifies eight WQIs that are basic indices for water quality assessment. Their statistical structure, parameter set, calculation, aggregation algorithm, and defects have all been described in depth.

KEYWORDS: Surface water quality; parameters; water quality index; Multivariate Analysis.

Abbreviations

WQI - Water Quality Index

WAWQI - Weighted Arithmetic Water Quality Index

CCMEWQI - Canadian Council of Ministers of Environment

1. INTRODUCTION

Water is necessary for life and covers approximately 71% of the earth's surface. Seas and oceans are expected to cover 96.5 percent of the world's water. While 1.7 percent is in groundwater, and 1.7 percent is fixed in Arctic and Antarctic glaciers and icecaps. A large amount of water is found in bodies of water, and about 0.001% of it is suspended in the air as vapors and clouds, which fall as precipitation.

Thus, only 2.5 percent of the earth's water is freshwater, with the remaining 98.8 percent stored as ice and groundwater. Rivers, lakes, and the atmosphere contain less than 0.3 percent of freshwater (Khatri & Tyagi, 2015). Among freshwater resources, rivers are the primary source of water for domestic, agricultural, recreational, transportation, energy production, and other human needs.

Rivers are the primary source of freshwater for human needs such as domestic, agriculture, recreation, transportation, energy production, and as a rich source of fish (Kumar & Dua, 2010). Furthermore, it transports a large amount of municipal sewage, industrial wastewater, and agricultural runoff water to coastal areas (Leta & Dibaba, 2019). River water quality, on the other hand, is highly sensitive to natural processes (changes in precipitation inputs, erosion, and crustal material weathering) as well as anthropogenic influences (urban, industrial, and agricultural activities) that degrade surface water quality and limit its potential use (Hussain et al., 2020).

Heavy rainfall causes soil erosion, and as a result, many different substances, as well as nutrient elements, drain to the surface water. Heavy metals, such as zinc and cadmium, are the most common substances.

Found in natural soils that drain to bodies of water. Cadmium exists in unpolluted natural soils in quantities ranging from 0.01 to 2.7 mg/kg, whereas in polluted soils the range exceeds 10.5 mg/kg due to their abundance in the parent rock (Scaccabarozzi et al., 2020). In addition, zinc is found in natural soils in an estimated amount of 70 mg/kg (Wuana

& Okieimen, 2011). A significant amount of this constituent enters the receiving water bodies during erosion. The number of constituents added with suspended solids into surface water, on the other hand, is determined by erosion rate, which is solely determined by soil texture, vegetation cover, and intensity of erosion. For example, a catchment area with forest cover protects soil erosion better than grassland areas (Prokop & Poreba, 2012). Population growth, because of factors such as urbanization, agricultural activities, and industrialization, has resulted in the accumulation of waste and pollutants, which end up in rivers and other bodies of water (Mustapha et al., 2013). The ecological values of water ecosystems, as well as the availability of good quality water for all socioeconomic functions in the community, are significantly impacted by urban surface runoff water and untreated wastewater (Sarkar et al., 2007). More specifically, the discharge of untreated domestic sewage from urban areas contributes significantly to the accumulation of heavy metals in the environment. According to (Chen et al., 2007), heavy metals such as copper, lead, and zinc are components of household waste and account for approximately 50 to 80 percent of total waste. The source of 50 to 80 percent of these heavy metals in urban sewage.

Increased use of fertilizers and pesticides, as well as other livestock activities, degrades water quality. The three most common agricultural water contaminants are nitrates, phosphorus, and pesticides. Increased pesticide use significantly contributes to indirect harmful chemical emissions, while rising nitrate concentrations endanger drinking water quality. As nitrate and phosphorus levels rise, surface waters' ability to support plant and animal life suffers (Bhateria & Jain, 2016). Excessive use of fertilizers and pesticides in agricultural fields, on the other hand, can lead to an increase in the introduction of heavy metals into water bodies (Showqi et al., 2018).

Phosphate-containing fertilizers, for example, contain cadmium as an environmental contaminant in concentrations ranging from trace amounts to 300 ppm on a dry weight basis (Robertsa, 2014). The majority of the contaminants emitted by agrochemical applications are harmful to human health and animal life, as well as accelerating soil degradation (Uddin et al., 2014).

Large amounts of inorganic and organic chemicals, as well as their byproducts, are found in industrial waste. Many industries operate on a small scale and do not have sewage lines. Even today, most of them lack adequate wastewater treatment plants and dump toxic waste into unlined channels and waterways, causing massive air, water, and soil pollution (Bougherira et al., 2014). According to Tadesse et al. (2018), approximately 90 to 96 percent of total industries in Ethiopia discharge their waste directly without treatment.

In general, poor water quality endangers human and environmental health, raises treatment costs, reduces access to safe drinking water, destabilizes socioeconomic conditions, and causes water scarcity and drought. Heavy metals are carcinogenic and toxic, and because they are non- degradable, they will accumulate in the human body, animals, and plants via the food chain (Marara & Palamuleni, 2019).

Most Ethiopia's rivers have deteriorated in water quality as a result of receiving urban, industrial, and agricultural wastes. On the other hand, most people in rural Ethiopia rely on unregulated sources of water, such as rivers.

As a result, each year, more than 500,000 people, primarily babies and teenagers die because of waterborne diseases (Amare et al., 2017). The quality of Wabe River water is specifically degraded because of the combined effect of natural and anthropogenic activities. Naturally, watershed soil erosion and sediment load from the upper catchment contribute significantly to river water pollution (Sahle et al., 2019). Whereas the discharge of domestic, municipal, and agricultural wastes into the river water, along with runoff, is also a source of river water contamination (Terfasa et al., 2019).

River water is used for a variety of purposes, including domestic, irrigation, and aquatic life, depending on the physicochemical and biological quality of the water (Uddin et al.,2014). As a result, periodic evaluation of the water quality status is required to identify contaminants, categorize water usage, and plan corrective action to preserve ecological health and restore the water body's carrying capacity (Vadde et al., 2018).

The two methods for monitoring river water quality that have been developed are conventional and water quality index. The traditional river water quality monitoring method focuses on comparing the determined variable to local norms, which provides only a partial picture of the state of water quality. A water quality index has been widely used in recent years to track the quality of river water to conveniently and effectively collect information on the quality of river water from a global perspective (Sun et al., 2016). The Water Quality Index would make policy recommendations while also developing methods to assess the suitability of water supplies for their intended use and to advocate for more effective management of water resources and river basins through the development of pollution control strategies (Amare et al., 2017).

The purpose of this review paper is to examine the physicochemical parameters in selected Tikur Wuha River sampling points. The study also assessed the water quality for drinking, irrigation, and aquatic life. Furthermore, the risk of heavy metals on aquatic ecosystems was determined at each sampling point using a potential ecological risk assessment index.

The deterioration of water quality in any body of water is the result of both natural and anthropogenic influences. Pollutants will naturally be introduced into the water because of soil erosion, as well as various contaminants from the rock that will dissolve into it as it passes on and through the surface. Furthermore, anthropogenic factors such as municipal garbage discharge, industrial effluent, and fertilizer, pesticide, and herbicide runoff from agricultural land can all have an impact on water quality (Akhtar et al., 2021).

Analyzing a wide range of physical, chemical, and bacterial water quality variables can help you determine the level of pollution in any body of water. The indicators, on the other hand, will be chosen by international and national water quality guidelines (Tadesse et al., 2018). The weighted arithmetic water quality index, which combines the individual influences of water quality indicators, is useful in informing concerned individuals and policymakers about the overall water quality state of any waterbody. It is also critical for assessing and managing water quality (Tyagi et al., 2020).

Irrigation water from any body of water contains varying amounts of dissolved salts that are produced either naturally (Precipitation rate, rock weathering, and dissolving of other salt sources) or anthropologically (Domestic and industrial sources).

Irrigation water containing dissolved salts can have an impact on soil salinity, crop growth, and yield (Mohammed Saleh, 2016). As a result, determining irrigation water quality indices such as SAR, MR, PI, PS, KI, RSC, and percent Na is critical to have complete information about the salinity, sodium, and magnesium hazard of irrigation water and its impact on crops (Berhe, 2020; Kundu & Ara, 2019).

Heavy metal pollution on aquatic ecosystems is now recognized as a serious environmental problem because it endangers public health and harms aquatic life (Dinku et al., 2016). The application of PERI is required to determine the threat level of heavy metals on the environment by combining the ecological toxicity of each element (Tian et al., 2020).

Furthermore, the use of MI is required to understand the additive impact of heavy metals on human health and to quickly evaluate the potential use of water (Calmuc et al., 2020).

GIS is the most powerful tool for determining the spatial pattern of pollution status because it can perform geo- statistical analysis. The IDW was the most used interpolation method in GIS to show the spatial pattern of water quality status at the watershed level (Oke & Ogedengbe, 2013).

Terfasa et al., (2019) previously determined the water pollution status of the Wabe River by analyzing river water from four sample sites, including Angie, Kokir, Chancho, and the Wabe bridge. The study's scope was limited to determining the total heterotrophic bacterial density, pH, and temperature at each site. Other physicochemical water quality parameters, however, have not yet been investigated.

Furthermore, the suitability of river water for multipurpose use was not emphasized using water quality indices. This motivates researchers to fill gaps in knowledge by analyzing physicochemical water quality parameters and assessing water quality status for domestic, irrigation, and aquatic life. In addition, PERI will be used to assess the risk of heavy metals on aquatic ecosystems.

2. River water quality parameters

2.1. Water quality parameters

The health of a river is defined by the quality of its water, which is altered by contaminants. To evaluate water quality, a range of measures that express the physical, chemical, and biological content of water is used (Journal et al., 2011). pH, temperature, dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), electrical conductivity (EC), and lead, chromium, ammonia nitrogen, and phosphate phosphorus concentrations are among the water quality characteristics studied in this study. The selection of these water quality criteria, which were assessed in connection to water consumption and pollution sources, was supported by the guidelines offered in the literature (Chapman and Kimstach 1992); Liston and Maher 1997).

2.2 Significance of selected water quality parameters

2.2.1 Temperature

Water temperature has a significant impact on the physical, chemical, and biological processes in water bodies (including flowing waters such as rivers), and thus many variables are concentrated (ANZECC 1992). High water temperatures accelerate the rate of chemical reactions, which has an impact on the evaporation and volatilization of substances from water. The solubility rate of gases in water, such as oxygen (O2), decreases as the water temperature rises. Furthermore, in warm water, aquatic organisms' respiration rates increase, resulting in higher O2 consumption and a faster rate of decomposition (Chapman and Kimstach 1992). A sudden change in water temperature can cause more damage to aquatic life. Excessive water temperature, on the other hand, may result in the unwanted growth of water plants and wastewater fungus (Metcalf and Eddy 1991).

Surface water temperature can be affected by factors such as geographical location, seasonality, diurnal period, air circulation, cloud cover quantity, depth of water, and flow rate. In general, the temperature of surface water ranges from 0 ^{0}C to 30 ^{0}C; however, unusually high temperatures can occur. From industrial effluent and sewage treatment plant discharges (Chapman and Kimstach (Kimstach, 1992).

2.2.2 PH

The pH is defined as "the negative of the logarithm to the base 10 of the hydrogen ion concentration" and is used to determine a solution's acid balance (Chapman and Kimstach 1992, p.62). The pH scale runs from 0 to 14 (Extremely acidic to extreme alkaline), with 7 indicating neutrality. The pH of natural water stays between 6.0 and 8.5 but could be affected by chemicals entering the waterways (Chapman and Kimstach 1992). This is a significant parameter to assess water quality as it influences ‘many biological and chemical processes within a water body and all processes associated with a water supply and treatment’ (Chapman and Kimstach 1992, p.62). This parameter can be used to determine the amount of effluent plume in a water body while assessing the effects of a discharge (Chapman and Kimstach 1992).

2.2.3 Dissolved oxygen

Dissolved oxygen (DO) analysis is used to determine the amount of gaseous oxygen dissolved in water, which is essential for all aquatic life. Diffusion from the atmosphere and photosynthesis by aquatic plants are the main sources of DO in water. Because O2 is involved in "virtually all chemical and biological activities within water bodies," determining this parameter is an important part of assessing water quality (Chapman and Kimstach 1992, p.65).

At sea level, DO ranges from 15 mg/L at 0 ^{0}C to 8 mg/L at 25 ^{0}C in freshwater. DO can also be expressed as a percentage of saturation, with saturation levels below 80% in drinking water being detectable by taste and smell (Chapman and Kimstach 1992). Because turbulence creates more opportunities for O2 circulation across the air-water interface, stagnant water usually has lower DO levels than flowing water (Xu-2006).

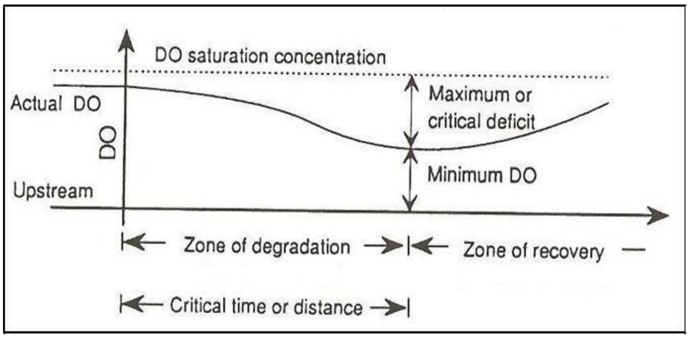

Figure 2.1: Typical changes in DO downstream of a wastewater input to a river.

Adapted from: Arceivala 1981

2.2.4 Biochemical oxygen demand

The biochemical oxygen demand (BOD) is used to read the level of biochemically degradable organic matter or carbon loading in the water. It is usually defined by the amount of O2 consumed by the aerobic micro-organisms present in the water sample to oxidize the organic matter and to convert it to a stable inorganic form (Chapman and Kimstach 1992); (Liston and Maher 1997). Hence, in water quality analysis this parameter is used to determine the biodegradable organic content of the waste in terms of O2 which is required when the wastes are discharged into natural water where aerobic condition prevails.

Organic matter + O2 micro-organisms CO2 + H2O + New cells + Stable products

2.2.5 Chemical oxygen demand

The chemical oxygen demand (COD) is a standard method for determining the oxidation susceptibility of organic and inorganic compounds found in water bodies, as well as sewage and industrial effluents. It determines the amount of organic matter in a water sample that can be oxidized by a strong chemical oxidant like dichromate or permanganate in terms of O2 equivalent (Chapman and Kimstach 1992). The COD laboratory tests take 2 to 4 hours to complete and determine the amount of oxygen required for the chemical oxidation of organic and inorganic substances in the water sample to convert to CO_2 and water. The purpose of the COD test is not to identify oxidizable material or to distinguish between organic and inorganic material in the water. However, for the past several decades, it has been an extensively utilized measure for water quality analysis. COD concentrations in unpolluted surface water are typically less than 20 mg/L, whereas effluents typically have values larger than 200 mg/L. (Chapman and Kimstach 1992). COD values are frequently greater than BOD5 measurements, it should be noted (Master's 2004).

2.2.6 Electrical conductivity

Electrical conductivity in water (ECw) is a metric for salinity and the ability of water to conduct electricity. It refers to the concentrations of total dissolved solids (TDS) or salts in a specific water body and is measured in micro-Siemens per centimeter (S/cm) (Chapman and Kimstach 1992); (Taylor 1993); (Liston and Maher 1997). Sodium, calcium, magnesium, and potassium are examples of cations, while chloride, sulfate, and bicarbonate are examples of anions (Masters 2004).

By multiplying the conductance (in S/cm) by a factor of 0.68, the salinity or TDS in mg/L of water can be computed. Al Bakri and Chowdhury (Al Bakri and Chowdhury, 2002).

2.2.7 Heavy metals: Lead and Chromium

Due to their toxicity, the presence of heavy metals in freshwater (beyond permitted levels) causes major ecological concerns. Because heavy metals cannot be eliminated naturally from water bodies, they travel from one region of the aquatic environment to another, including the biota, via food chain transfers (Chapman and Kimstach 1992). This heavy metal phenomenon frequently has negative effects on the ecosystem and increases the toxicological risk to humans. Heavy metals have a variety of negative impacts on the human body, including damage to the brain system and kidneys, mutations, and tumor induction (master's 2004). As a result, heavy metal contamination measurement has become an important feature of most water quality assessment programs.

2.2.8 Nutrients: Ammonia Nitrogen and Phosphate phosphorus

The availability of nitrogen and phosphorus, two important nutrients for plant and animal growth, is critical (Gundersen and Bashkin 1994). Nutrients in the water, on the other hand, are frequently labeled as pollutants and are harmful to water quality, especially when a high concentration of nutrients promotes the growth of undesirable aquatic plants, like algae. Eutrophication in aquatic habitats is caused by a variety of reasons, including these nutrients (Metcalf and Eddy 1991; Liston and Maher 1997). As the algae mature and die, their decomposition reduces the amount of oxygen in the water, potentially lowering DO levels. Furthermore, algae and other decomposing organic debris impart color, turbidity, aromas, and unpleasant tastes to water that are difficult to remove and may significantly impair its desirability as a supply of domestic water (Master's 2004). Municipal wastewater discharges, sewage, urban and agricultural runoff, animal feedlots, and industrial wastes are all major contributors of nitrogen and phosphorus in the water. The main sources of phosphorus in water are detergents and other laundry items (Welch 1980; Masters 2004).

3. DISCUSSION

3.1. Weighted Arithmetic Water Quality Index for Water Resource Evaluation (WAWQI)

In developing countries where the data collection process for the water quality database is not extensive, researchers such as Goher et al., (2014); Kalagbor et al., (2019); Menberu et al., (2021) Oni & Fasakin, (2016) employ the weighted arithmetic water quality index (WAWQI). It's also beneficial for estimating the water quality at a location where data has been collected over time for the goal of determining the water quality (Ali & Mekonin,n.d.). WAWQI is also crucial for water quality management in addition to water quality assessment (Khatri et al., 2020).

Bhateria & Jain, (2016) used WAWQI to evaluate the water quality status of water bodies in India such as Channarayapatna, Bagura, Janivara, and Anker. For drinking water evaluations, indicators such as pH, turbidity, conductivity, total alkalinity, total solids, TDS, DO, BOD5, COD, total hardness, calcium, magnesium, free CO2, and chloride were evaluated. The measured parameters' unit weights were assigned according to WHO guidelines. As a result, the investigation discovered that the water quality has decreased in all drinking water sample stations. As previously stated, all the water quality parameters have exceeded the guideline value, necessitating the implementation of certain practical measures to improve the water quality.

Goher et al., (2014) also used WAWQI to assess the water quality of the Ismailia canal,

Nile River in Egypt, for drinking, irrigation, and aquatic life. Water samples were gathered from eleven stations during the study period, and variables such as TDS, pH, DO, BOD5, COD, NH3-N, NO3$^-$N, TP, chloride, sulfate, Na$^+$, Ca^{2+}, Mg^{2+}, and total hardness for drinking purposes were examined. TDS, pH, DO, NH3$^-$N, NO3$^-$N, bicarbonate, and other parameters are used to assess irrigation appropriateness. The researchers used chloride, sulfate, Na$^+$, Ca^{2+}, Mg^{2+3}, and K^{+3}. Variables such as TDS, pH, DO, BOD5, COD, NH $^-$N, NO $^-$N, and chloride was also included in the water quality index.
for aquatic life appropriateness assessment.

Four stations were classified as poor for drinking purposes based on WAWQI values, while the rest were classified as good. In addition, all the stations were in outstanding condition for irrigation. Six stations received an excellent water quality rating, while four stations received a bad water quality grade for aquatic life use. (Menberu et al., 2021) used WAWQI to assess the suitability of Ethiopia's Lake Hawassa for multipurpose usage by collecting water samples from eleven different places. water quality indicators such as Temperature, turbidity, total alkalinity, chloride, EC, TDS, pH, DO, BOD5, COD, TSS, TS, NO $^-$N, TP, and chloride are examples of indicators. The lake water was deemed unfit for multipurpose use based on the value of the weighted arithmetic water quality index (120.06-228.29).

Kalagbor et al. (2019) used a weighted arithmetic water quality index to assess the water quality of the Kaani and Kpean Rivers in Nigeria. During the study period, water samples were collected from three sample points in each river using sterilized 150 ml plastic bottles. During July, August, and September 2018, pH, temperature, turbidity, conductivity, dissolved oxygen, BOD5, COD, nitrate, chloride, phosphate, total solid, TDS, magnesium, calcium, and fecal coliform were all measured. The WAWQI ratings for both rivers ranged from 1.68 to 6.04, suggesting that the rivers' water quality was outstanding, indicating that they were suitable for multipurpose usage.

Furthermore, Oni & Fasakin (2016) examined the pollution status of streams in Ado Ekiti, Nigeria, using WAWQI. During the study period, samples were taken from two different locations in the stream, and variables like pH, sulfate, iron, nitrate, chloride, nitrate, lead, zinc, copper and total coliforms were measured. The stream water quality was bad, according to the WAWQI result, as the computed value of the index ranged from 496 to 811.

WAWQI is one of the methods being used by many researchers this day. because of its capacity to incorporate the effects of many water quality variables to evaluate the water quality status for the intended use and its applicability in data-scarce locations.

WQI classifies WQ such as good, bad, and worst, based on the criteria established by the research area's governing organizations; the results are numerical but given in a simplified format (Tiyasha et al., 2020). In the assessment, monitoring, and control of river water quality, research is critical. The number of scientific ways to obtain, manage and comprehend WQ data has risen dramatically in recent years.

3.2.Canadian Council of Ministers of Environment (CCMEWQI)

Instead of normalizing observed values to subjective rating curves, the CCMEWQI compares observations to a benchmark, which might be a water quality standard or a site-specific background concentration (Lumb et al., 2006). So, this is a benefit of the index, as it may be used by water authorities in a variety of situations.

Countries that have had little change Four categories have been established to categorize water quality in this context. Excellent, Good, Fair, and Poor have all been mentioned. To calculate index scores (Khan et al.2004)

4. CONCLUSIONS

After a thorough examination of the above water quality indices. All the water quality parameters were analyzed by WAWQI for drinking purposes and by applying Multivariate Analysis the parameters were analyzed for irrigation purposes. The Analysis includes the indices, sub-indices, aggregation formula, and defects. The NSF, Bhargava, OIP, Oregon, and Ved Prakash indices, which use the weighted arithmetic average (Stojda & Dojlido, 1983) and the modified weighted sum (Couillard & Lefebvre, 1985) to index general water quality, were shown to produce the best results. Similarly, the weighted geometrical average has been frequently utilized, particularly where sample variability is high.

Finally, the software applied for interpretation of the results obtained from WQI, GIS, and Grapher 16 were applied.

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