

Water quality index for assessment and mapping of groundwater quality in Webuye municipality, Kenya

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Abstract

Promotion of access to water as a human right has gained a lot of emphasis from various stakeholders in the recent past. This is well articulated in UN human Rights works, the goal number 6 of Sustainable Development Goals and the Secretary-General's Call to Action for Human Rights. While trying to enforce this, it is important to consider the challenging dynamics in which water quality affects the realization of this goal. Determination of water quality therefore is a key measure to ensure that while promoting access to water its suitability for usage is enhanced. The objective for this study was to carry out an assessment and mapping of water quality index for groundwater in Webuye municipality. The water quality index for hand dug wells and springs in Webuye was evaluated using Weighted Arithmetic Water Quality Index Method. Mapping of water quality index was performed in ArcGIS 10.3 carrying out interpolation of Water quality indices of all groundwater samples using Inverse distance weighting (IDW) method. The water quality index was performed on chemical parameters of 53 groundwater sources sampled randomly from 46 hand dug wells and 7 springs. The water quality physiochemical parameters were; Turbidity, PH, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Salinity, Sulphates, Phosphate and Nitrates. The results show that 69% of water samples from the study area majorly fell in class >100 (Unfit for consumption), class 76-100 (Very poor) were 16%, class 51-75 (poor) were 11%, WQI class 26-50 (Good) 2% and WQI class 0-25 (Excellent). It is recommended that groundwater sources from the area should not be utilized for drinking unless if subjected to full water treatment. Water quality index gives important information for economic planning since per capita water demand is recently increasing while availability of freshwater continues to decline.

Key Words: hand dug wells, springs, water demand, Weighted Arithmetic, Inverse distance weighting

1. INTRODUCTION

Groundwater use has continuously been accessed to supporting human life in various aspects because of its reduced susceptibility to drought and contaminants. Groundwater is located in the zone of saturation which occupies the cracks in rock masses or pore spaces among mineral grains (Berhanu *et al.* 2014). Groundwater sources are buffered from short-term variability in weather patterns and is a stable and reliable resource (Jha *et al.* 2007). Groundwater usage has increased due to recent innovations that have improved pumping efficiency and increased electricity network extension. Groundwater extraction globally has increased from 312 km³/year in 1960s to 743 km³/year in the year 2000 (Wada *et al.* 2010). Groundwater satisfies the water demand for

approximately half of the domestic human needs in urban areas (Sun *et al.* 2009).

Several studies have reported that global increase in population and urbanization are the most significant trends of the 21st century. The trends affect global economic development, natural resource use and human well-being (Sun *et al.* 2009; Lederbogen *et al.* 2011; McDonald *et al.* 2013). It is also reported that 55% of the world's population currently live-in urban areas, and is projected to increase to 68% by 2050 (Dorling *et al.* 2021). Additionally, the report indicates that urbanization, combined growth of the world's population can add 2.5 billion people to urban areas by 2050, especially in Asia and Africa (Dorling, 2021). Population growth builds pressure on groundwater due to the increased demand for various uses. Use of

groundwater in Africa is on the rise because of its susceptibility to the ever-changing meteorological conditions as compared to surface water. Groundwater provides a natural buffer against climate change variability (Calow *et al.* 2010). Approximately 17 million people in Kenya live in Arid and Semi-Arid Lands (ASALs) where groundwater is the main water resource. Demand for groundwater is expected to rise, owing to population increase and continuous depletion of surface water resources.

Population increase is the key driver towards increased groundwater exploitation and reduced groundwater quality. Population grows along with industrialization, use of onsite sanitation systems, increased solid wastes and farming practices which either through point or non-point sources, leach contaminants into the groundwater (Deepnarain *et al.* 2020). This definitely makes groundwater unsuitable for direct consumption. Water quality has a significant impact on water supply sources and help to assess various options in water abstraction (Li *et al.* 2015). Water quality index (WQI) is the overall evaluation water quality to determine its suitability for specific purposes. This evaluation is carried out on water quality physical, chemical and biological parameters.

There are various methods that can be used to calculate Water Quality Index. The WQI index was developed by Horton in the USA in 1965 (Mădălina *et al.* 2019). Several methods have been developed using different approach and suggested for obtaining water quality index (WQI). The difference in these methods is approach used in selection of parameters and their influence on the calculation of the water quality index value (Uddin 2017). The

commonly used methods in water quality index calculations are: NSF-WQI (National Sanitation Foundation-Water Quality Index), The Canadian Council of Ministers of the Environment Index (CCME-WQI), OWQI (Oregon Water Quality Index) and Weighted Arithmetic Water Quality Index Method. Weighted Arithmetic Water Quality Index Method is the most preferred method because it covers various physicochemical parameters and gives accurate results. Water quality index is an effective way of communicating to the public about water trends, identification of contamination sources and development of a strategic water quality protection to minimize public health risks. The objective of this study was to carry out Water quality index for assessment of water quality of groundwater in Webuye municipality, Kenya.

2. METHODS

2.1. Study area

The study was carried out in Webuye town in Bungoma County. The GPS location for the area is latitude 00 45'0" N and 00 30'0" N of the Equator and longitude 340 40'0" E and 340 45'0" E of the Greenwich meridian. Webuye municipality totals up to 95.48 Km². The study area is in Webuye West Sub-County. The Sub-County is comprised of both rural and semi-urban areas, with approximate population of 151,654 and 32,839 households (KNBS 2019). The Webuye Local Physical Development Plan estimations that the current population of Webuye town is about 65,000, implying that 43% of the population in the study area live in the urban areas. population increase in Webuye township can be attributed to rural-urban migration and natural rate of increase.

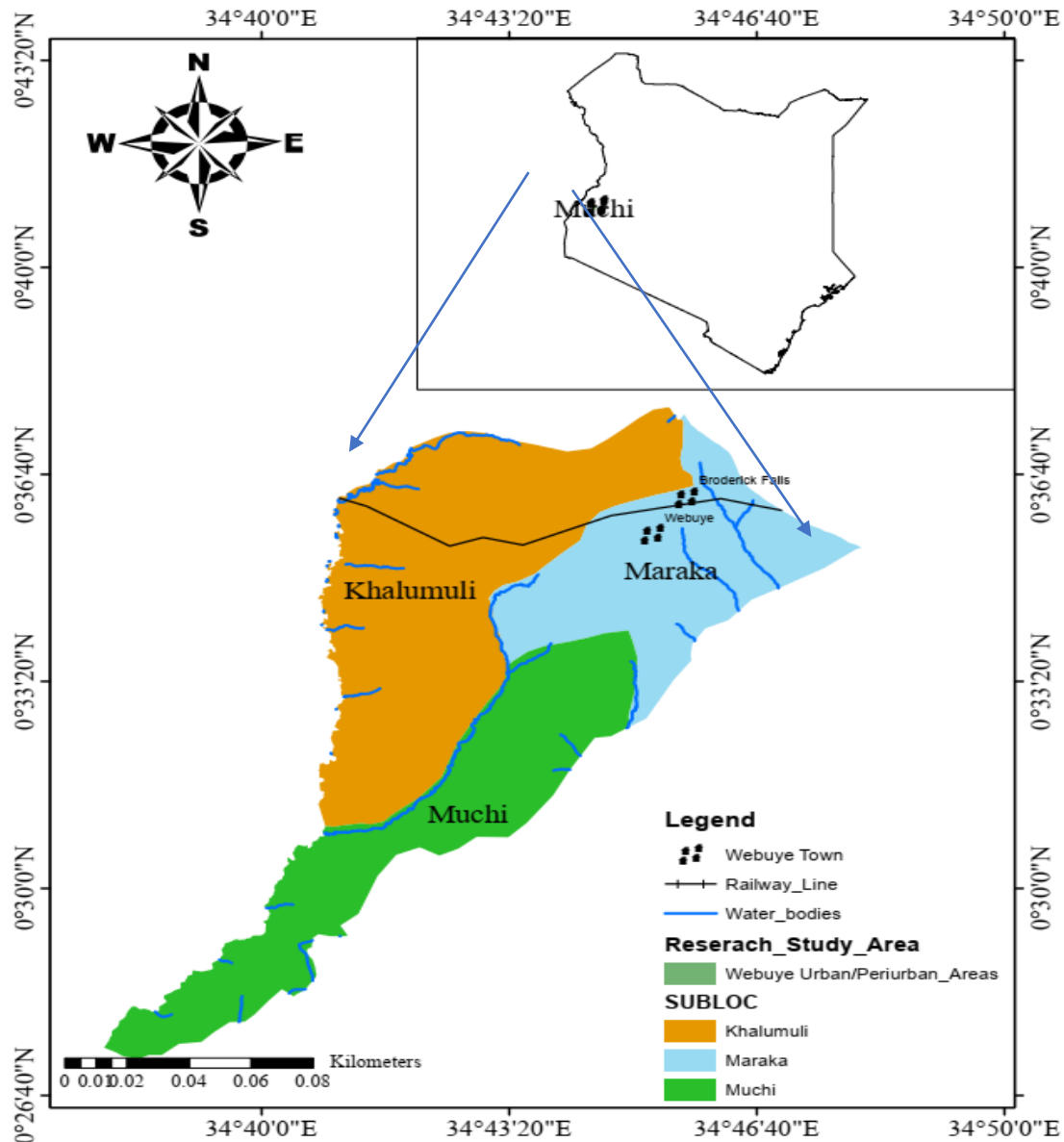


Figure 1: Map of the study area

2.2 Data Collection

The main data used in this survey was water quality data for groundwater samples collected from different water wells in Webuye urban and peri-urban areas. Samples collected in dry season were collected in February 2022 while samples collected in wet seasons were collected in November 2022. Water samples were collected from Wells, boreholes and springs using random sampling method. According to the sample size total of 74 water well and 8 spring samples were to be collected in both rainy and dry periods. However, the first data set was collected in February during dry periods and it was observed that 28 Hund dug wells and one spring had no water, they had dried up. The

water samples were then collected from 46 water wells and 7 springs making it a total of 53 water samples that were collected in dry season and also another set of 53 in wet season for comparison.

2.3 Water quality analysis

Water samples were analysed using standard procedures for physicochemical tests and assessed against the drinking water standards in Kenya (KEBS). Apart from turbidity tests that were done insitu, Samples were collected and transported to Matisi Water Laboratory operated by Nzoia Water Services Company Ltd. Analysed parameters and methods are as shown in Table 1.

Table 1: Water quality parameters and analytical methods

No.	Parameters	Analytical methods/Instrument
1	pH	Electrometric: pH Meter
2	Turbidity	Nephelometry
3	Total Suspended Solid (TSS)	Filtration, constant weight at 103°-105°C
4	Electrical Conductivity (EC)	Electromagnetic induction method
5	Salinity	Electrical conductivity meter
6	Sulphates	Spectrophotometer
7	Phosphate	Spectrophotometer
8	Nitrate	Spectrophotometer
9	Total Dissolved Solids (TDS)	Gravimetric, Dried at 180 degrees C

2.4 Water Quality Index (WQI) Calculation

In this study, WQI was calculated using weighted arithmetic water quality index which was originally proposed by (Horton & Hawkins 1965), and further developed by (Brown *et al.* 1972) in the following form:

$$WQI = \frac{\sum Q_n W_n}{\sum W_n} \dots\dots\dots (1)$$

The formula has been applied in several studies (Chowdhury *et al.* 2012; Tyagi *et al.* 2013; Olowe *et al.* 2016) on the common measured water

quality parameters. The steps followed in the calculation of urban and peri-urban areas of Webuye were guided by Brown *et al.* (1972). The WQI was calculated using physical and chemical parameters; Turbidity, PH, Total Suspended Solids, Total Dissolved Solids, Electrical Conductivity, Salinity, Sulphates, Phosphate and Nitrates. The results of WQI were presented in five categories depending on value of each groundwater water source as shown in Table 2.

Table 2: Water quality rating as per Weight Arithmetic WQI method

WQI Value	Rating of Water	Quality Grading
0-25	Excellent	A
26-50	Good	B
51-75	Bad	C
76-100	Very Bad	D
>100	Unfit	E

Source: Shweta e. al., 2013

2.4.1 Calculation of Unit Weight (W_n)

The calculation of unit weight (W_n) was done for each parameter using equation 2 below;

$$W_n = \frac{K}{S_n} \dots\dots\dots (2)$$

Where;

$$K = \frac{1}{\frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \dots + \frac{1}{S_n}} = \frac{1}{\sum \frac{1}{S_n}}$$

S_n = Standard desirable value of the nth parameters

On summation of all selected parameters unit weight factors W_n=1 (unity)

2.4.2 Calculation of sub-index of quality rating (Q_n)

Here, the calculation is based on the equation 3;

$$Q_{pH} = \left(\frac{V_{pH}-7}{8.5-7} \right) 100 \dots\dots\dots (3)$$

Let;

(n) there be the water quality parameters (q_n) the quality rating or sub-index corresponding to nth parameter is a number reflecting the relative value of this parameter in the polluted water with respect to its standards permissible value.

The Q_n value of is calculated using the following expression.

$$q_n = \left(\frac{V_n - V_0}{S_n - V_0} \right) 100$$

Where:

Q_n = quality rating for the nth water quality parameter;

V_n = estimated value of the nth parameter at a given sampling station;

S_n = standard permissible value of the nth parameter;

V_0 = actual value of nth parameter in pure water

Note: All actual (V_0) values are taken as zero (0) for pure water for all other parameters except the parameter pH, where it is 7.0 (Chowdhury *et al.* 2012).

2.5 WQI mapping

The water quality indices for each groundwater source was placed against their GPS points. The WQI were imported into the study area map in ArcGIS 10.7 and interpolated using Inverse distance weighting (IDW) method to develop spatial distribution of the water quality indices.

3. RESULTS AND DISCUSSIONS

3.1 water quality index

Water quality indices was calculated based on the results physiochemical analysis of water samples from 53 groundwater sources. Table 3 shows a sample water quality index of one groundwater source.

Table 3: WQI calculation for groundwater sources in Webuye urban and peri-urban

Parameter	Sn	1/Sn	∑1/Sn	K	Wn	Vn/Sn	Qn	WnQn
Turbidity	5	0.2000	0.9151	1.0928	0.2186	4.1174	411.74	88.06
PH	8.5	0.1176	0.9151	1.0928	0.1286	0.4670	46.70	5.88
TSS	30	0.0333	0.9151	1.0928	0.0364	0.6654	66.54	2.37
TDS	700	0.0014	0.9151	1.0928	0.0016	0.2659	26.59	0.04
EC	1500	0.0007	0.9151	1.0928	0.0007	0.2086	20.86	0.01
Salinity	200	0.0050	0.9151	1.0928	0.0055	0.1015	10.15	0.05
Sulphates	400	0.0025	0.9151	1.0928	0.0027	0.0507	5.07	0.01
Phosphate	2.2	0.4545	0.9151	1.0928	0.4967	3.2312	323.12	157.06
Nitrates	10	0.1000	0.9151	1.0928	0.1093	0.3800	38.00	4.06
		0.9151			∑Wn =1			∑Qn Wn =257.56

$$\begin{aligned}
 WQI &= \frac{\sum Q_n W_n}{\sum W_n} \\
 &= \frac{257.56}{1} \\
 &= 257.56
 \end{aligned}$$

The results show that the WQI for urban and peri-urban areas of Webuye town ranged from 4 - 429 as shown in the Figure 2.

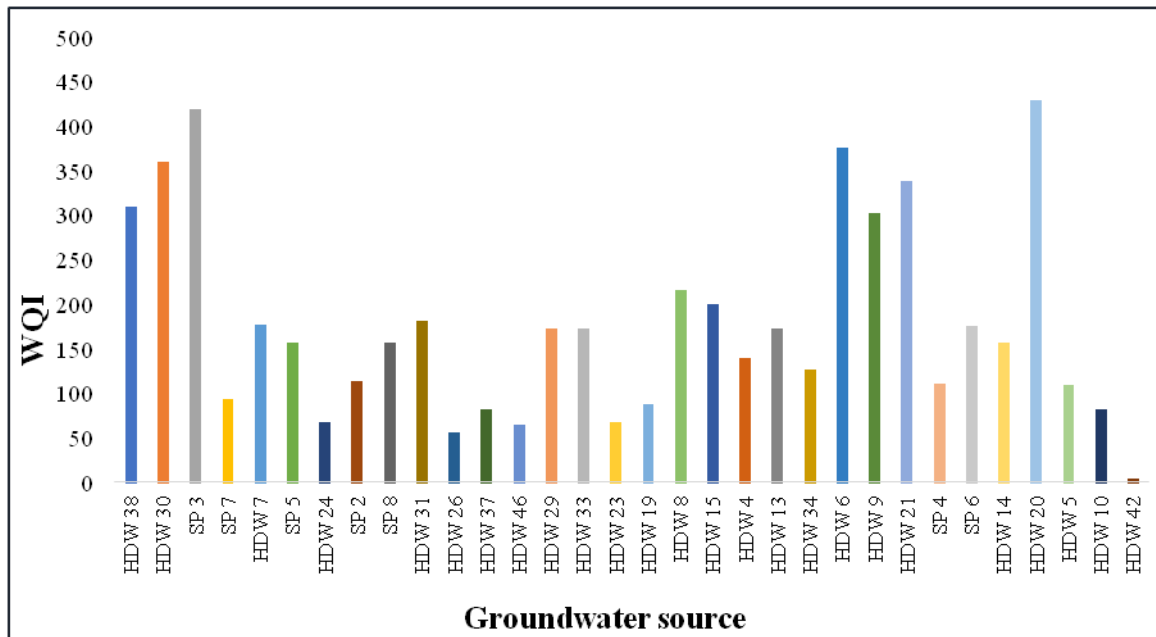


Figure 2: WQI results

The water quality indices were plotted on a curve to show how they are distributed in the study area. The curves shows that the lowest water quality index was well 42 which scored WQI of 15 representing excellent water quality. Water well 26 and 46 have scored WQI of 48 and 50 respectively falling in category 26–50

which represents good water quality. All other groundwater sources scored WQI above 51 implying poor water unfit for consumption (Brown *et al.* 1972; Yogendra & Puttaiah 2008). The results are further illustrated by computation of percentages in each WQI in Figure 3.

Range	Score	Percentage (%)	Water quality status	Rating
0–25	1	1%	Excellent	Green
26–50	2	3%	Good	Light Green
51–75	56 -71	11%	Poor	Brown
76–100	80 - 100	16%	Very Poor	Yellow
Above 100	> 100	69%	Unfit for Consumption	Red

Figure 3: Categories of Webuye urban and peri-urban areas

According to the classification as guided by (Brown *et al.* 1972; Yogendra & Puttaiah 2008), the results show that 69% of ground water samples were found to be Unfit for consumption with WQI >100, 16% of the groundwater sources were very poor with WQI within the range of 76-100, 11% of the samples were poor with WQI ranging between 50-75, 3% of the samples were good with WQI ranging between 26-50 while 1% of the groundwater sources was excellent with WQI of 15 ranging between 0-25. Further, based on the classification of WQI by

(Yogendra & Puttaiah 2008) the results imply that groundwater quality in Webuye urban and peri-urban areas of Webuye is fit for irrigation and Industrial use due to the observed high water quality index. However, this water requires treatment before being used for domestic and drinking purposes.

3.2 WQI mapping

The water quality indices of each well and the GPS location were inversely overlaid on the

study area map. The results are shown in Figure 3.

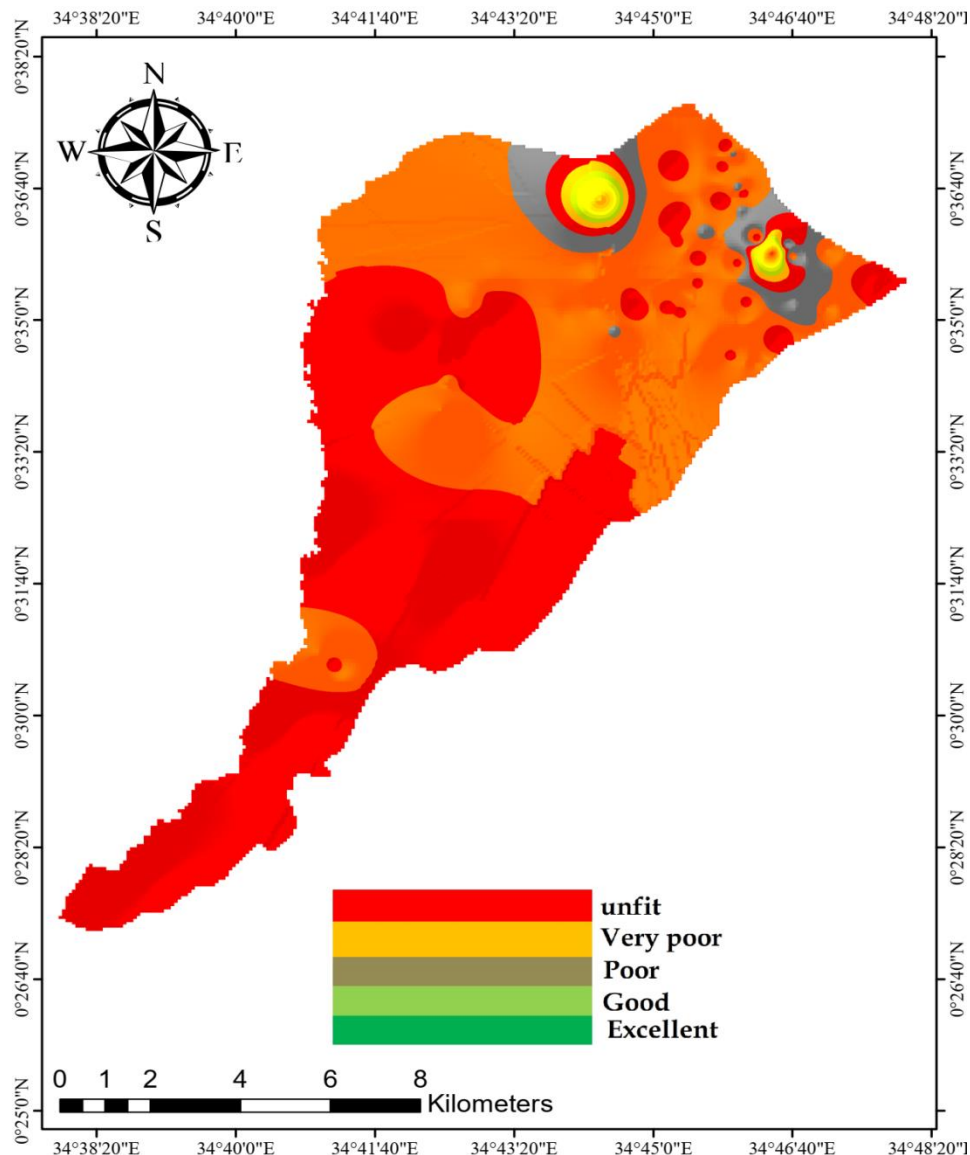


Figure 3: WQI distribution of groundwater sources in Webuye Town

The results show that major parts of the study area have high water quality index score >100 representing water that is unfit for consumption. It can also be observed that High risk areas majorly are in low areas, implying that that the urban area contribute highly to the pollution in peri-urban areas. High WQI is majorly contributed to by excessive flow of agricultural and domestic waste, due to various human activities like the inflow of unmaintained sewerage from residential and commercial establishments in the urban set up and lack of or inadequate sanitation system especially in areas of unplanned settlements. Urban agricultural

activities were also observed around water points to improve food production especially for vegetables, fruits and to some extent maize and beans with fertilizer application practiced this can be a great contributor of Phosphates and Nitrates as a result of observed agricultural runoff to unprotected water points. The results agree with (Feng *et al.* 2021), who reported that urbanization comes along with growth in population, social and economic status of an area. This existence leads to increased waste generation which if not controlled, find their ways into groundwater sources and cause gradual change water quality.

Groundwater pollution can be naturally caused or anthropogenic related activities (Uddin *et al.* 2021). Pollution related to natural factors are hydrological, geological and climatological (Riaz *et al.* 2018). This study focused more on human activities in urban and peri-urban set up which affect water quality. These activities are: livestock farming, human waste generation, disposal, sewer systems overflow and effluent discharge (Abbasnia *et al.* 2019).

CONCLUSIONS

The results on Water Quality Index show that 69% of water samples from the study area majorly fell in class >100 (Unfit for consumption), class 76-100 (Very poor) were 16%, class 51-75 (poor) were 11%, WQI class 26-50 (Good) 2% and WQI class 0-25 (Excellent). The water quality index revealed a strong significance relationship between the well and pollution risk factors. Farming activities, open defecation, sewer overflows and use of unlined pit latrines are attributed to undesirable water quality in Webuye municipality. Undesirable water quality index is a risk to economic and social development of an area. With unpredictable dynamics in terms of levels and quality, surface water is not dependable. Groundwater being a suitable option to cater for the rising demand, need to be protected against pollution. Assessment and mapping of water groundwater quality index is an informative way of depicting the status of groundwater, and also for general public and stakeholders, on the status of groundwater exploration and planning purposes respectively.

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