Evaluation of Groundwater Quality Using Water Quality Index and GIS, The Case of Debre Tabor Town, Ethiopia

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Abstract

Assessing the quality of groundwater for better management of the water sources is essential. This study is aimed at evaluating the groundwater quality of Debre Tabor town. Twelve groundwater samples were collected at hand dung wells during the wet season (Mid July-Mid August 2020) and dry season (1st February –Mid-March 2021). Various Physico-chemical parameters (pH, electrical conductivity (EC), Total dissolved solids (TDS), Temperature, Turbidity, Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^{-}), Nitrate (No_3^{-}), and microbiological parameters (Total coliform and Feacal coliform)) were analyzed and compared with the standard guidelines recommended by WHO. GIS was used to show the distribution of groundwater quality throughout the study area. WQI created by Canadian Council of Minster of the Environment (CCME) was applied to evaluate the suitability of the groundwater for drinking purposes. Also, the result shows that total coliform and faecal coliform at all groundwater wells were not suitable for drinking purpose. The result shows that Electrical conductivity, Temperature, Nitrate, Chloride and Magnesium at all groundwater wells were suitable for drinking purpose for both dry and wet season whereas Turbidity, pH, Calcium and Total Dissolved Solids are suitable for drinking purpose at some groundwater wells but not suitable at some wells. The water quality analysis result shows that spatial and seasonal variations of the parameters are significant throughout the study area($p < 0.05$). According to CCMEWQI result seven groundwater samples show poor water quality status of 40.53-44 while, five groundwater samples show marginal water quality status of 44.19–55.82. Based on the information provided by the study, it is recommended to identify the source of contamination, provide properly designed sanitation systems and to monitor water quality at least once per year for effective and proper management of the groundwater quality.

Introduction

Groundwater can become contaminated naturally or because of numerous types of human activities; residential, municipal, commercial, industrial, and agricultural activities (Kumar et al., 2009). It is also contaminated from waste disposal sites, animal wastes, leaking underground storage tanks, industrial chemical wastes by pesticides and fertilizers. Contaminated groundwater can be unsuitable for various purposes and its remediation is difficult, time consuming and expensive. Once groundwater is contaminated, its quality cannot be restored by just stopping the pollutants from source, this is because groundwater contamination may continue years after the waste source is in place (Ramakrishnaiah et al.,2009). As groundwater has a huge potential to ensure the supply of future demand for water, it is important that human activities on the surface do not negatively affect the precious resource.

To evaluate the status of groundwater for human consumption, it is essential to determine and assess its quality. Different researchers have used different methods to express water resource quality. The Canadian Council of Ministers of the Environment (CCME) Water Quality Index (WQI) was developed for simplifying the reporting of water quality data(Cash and Saffran 2001). It is a tool for generating meaningful summaries of water quality data that are useful to technical and policy individuals, as well as the general public interested in water quality results. Water Quality Index (WQI) is defined as a technique of rating that provides the composite influence of individual water quality parameter on the overall quality of water. Water Quality Indixe is a simple mathematical tool that can provide a distinct picture of overall water quality status over an area based on important water quality parameters (Li, 2014). In this regard, WQI assumes a prominent place in the water quality management and it offers a useful representation of the overall quality of water for public use or for any intended use. It is simple and easy to understand for decision makers about quality and possible uses of any water bodies (Ambiga and Annadurai 2013).

Ethiopia as a developing country has failed to provide appropriate sanitation facilities and potable water from protected sources to its population. Citizens heavily rely on unprotected water sources like hand-dug wells, streams, borehole rivers and springs. They also use open sources like drainage and dry wells for dumping refuses. These lead to contamination of human by pollutants. Most of hand dug wells in Ethiopia requires frequent monitoring and protection. This may result from inappropriate location of wells, shallow depth, land use, low construction standards and vulnerability to multiple pollution sources. Due to insufficient water supply for municipal, hand dug wells have been the sources of water in Debre Tabor town for many residents.

Expanding in population, poor sanitation system, expansion of urbanization and attitudes towards environmental protection in Debre Tabor town led to the outbreak of waterborne disease. Consequently, disease will continue to spread among the consumers until adequate wastewater disposal accompanies the provision of safe drinking water (Khan et al., 2013). In this study area hand dug wells were exposed to some pollution sources like dumping of domestic waste, uncontrolled industrial and commercial activities, sewerage and effluent leakage. However, the groundwater quality has not been prioritized, as this hand dug wells are used for consumption and other purposes without water quality test analysis. Therefore, this study seeks to evaluate the groundwater quality of Debre Tabor town using water quality index based on physico-chemical and bacteriological parameters. It also evaluates the seasonal and spatial variation on the concentration of the parameters

Materials And Methods

Description of the Study Area

The study was conducted at Debre Tabor town which is the capital city of south Gondar administrative zone of Ethiopia. Geographically the town is located at 38 ^{0} 00’17.016” E and 11 ^{0} 51’29.309” N with an average altitude of 2717m. It is 66% mountainous, 20% plain, and 14% rocky (Alubel 2018). The town had a moderate climate with 13 to 18^{o}C average annual temperature and having a mean annual rainfall of 1589.7 mm (Debre Tabor Water Supply Design Report, 2019). It has 6 general primary schools, 5 secondary and preparatory schools, 7 colleges and one university (DTU) in the education sector, and three health centers and one referral hospital in the health sector. The town has 8 Orthodox and 1 kale-hiowt Churches and 1mosque. It has 16832 households, 100992 total numbers of people out of these 45739 males, and 55253 females with an average family size of 6 people. The town has 9 underground water sources with two booster reservoirs. According to water agency of the town and health extension office of each kebele the population of the town is using hand dung well (392), hand pump (6) and spring water (13) taken in February 2019.

Figure 1 : Map of the study area

Research Design and Methods of Data Collection

The study has been conducted at Debre Tabor town to evaluate the groundwater quality. The parameters of determined in water sample includes physico-chemical and bacteriological characteristics. A total of 12 sampling points were selected to take the sample of water that can cover the entire study area. The sampling was done for dry season (1st February –Mid March 2021) and wet season (Mid July-Mid August 2020). Sampling bottles used for sample collection were first washed with the water being sampled and then filled. The sampling bottles were labeled for each particular sampling location and the samples are preserved and stored in the laboratory at 4^{o}c until analysis.

Table 1
Materials used in the study

Materials	Functions
Sampling bottle	To take sample from sampling location in laboratory
Incubator	To grow the microbes
Spectrophotometer	For measuring water quality parameters NO_3, Cl, Ca^{2+}, mg^{2+}
SPSS	For statistical analysis of water quality parameters
Arc GIS 10.8	Used for description of study area spatial distribution of water quality
AQUAROPRO AP700	To measure pH, EC, temperature and TDS
GPS	To locate sampling points
Ice box	For preserving the sample
Turbidimeter	To measure turbidity

Sampling location and frequency

Samples were taken from selected locations of private hand dung wells. A purposive sampling technique was adopted in selecting 12 hand dung wells for sampling. These selected sampling points were commonly used by most residents for different purposes like drinking, washing and its spatial representativeness to the study area as observed during field study. For each sampling station, 3 samples for dry season and 3 samples for wet season with a total of 6 samples were taken for each sampling station to analysis of water quality. The location of 12 sampling station was obtained using a handled GPS instrument and represented as follows. W01, W02 W03, W04, W05, W06, W07, W08, W09, W10, W11and W12 where W, stand for hand dung well.

Sampling techniques

Sampling water for physicochemical and biological examination was collected in conformity with the international sampling procedure of water and wastewater(APHA, 1998). All water samples for physico-chemical analysis were collected in one-liter polyethylene bottle separately without any air bubbles and the collection bottles were thoroughly washed and rinsed with a sample to avoid any possible contamination. The collected samples from each point were labeled. All water samples were collected in properly washed sampling bottles and were taken to Bahir Dar institute water quality and treatment laboratory. All water samples were stored in an icebox and delivered on the same day to the laboratory and all samples were kept at a constant temperature of 4^{o}C to avoid samples deterioration due to the effects of light and temperature until laboratory analysis was taken (APHA, 1998). But temperature, pH and electrical conductivity were measured onsite using multi parameter water quality checker (model: YSI Pro 30). Water samples for bacteriological analysis were collected in a 250 ml capacity glass bottle but not full. All glass bottles used for sampling were thoroughly cleaned and preferably sterilized before use.

Sample analysis methods

The physico-chemical parameters analysis was carried out using various methods. The calcium (Ca^{2+}) magnesium (Mg^{2+}), chloride (Cl^{-}), nitrate (NO_3^{-}) were measured following standard procedures using Spectro photometer. The turbidity of the sample was measured using turbidity meter. A chemical reagent was dissolved in 10ml of water in a cylindrical sample cell test and allowed to react. Color develops with intensity proportional to the amount of the target element was measured. Each element has a unique maximum absorption wavelength at which the spectrophotometer was adjusted. The light was allowed to pass through the sample cell so that light is absorbed in the required wavelength. The result was displayed on the LCD screen in mg/l proportion to the amount of light absorbed at that particular wavelength.

The bacteriological test was undertaken within 6 hours after collection to avoid the growth or death of micro-organisms in the sample. Total coliform and faecal coliforms were assessed in all station of sampling. Introduce the growth absorbent pads into the base of Petri dishes, and the growth pads were saturated with the Lauryl Sulphate Broth then after 100ml water sample was filtered using a membrane filter (0.45μm) in a vacuum filtration apparatus, and all the filters were Transferred to the absorbent pad which was saturated the Broth, finally the filters were incubated at 37^{o}c and 44^{o}c for total coliforms and faecal coliform respectively for 24hours, after which the filter is direct read counted, recorded and the result was compared with WHO guideline value.

Data Analysis

Statistical analysis variance of groundwater quality has been carried out in this study by considering the space of the sample point and the time to collect samples from individual sample sites. The mean values, two independent factors (space and time), twelve water sampling points and three replications has been considered for each sample. SPSS ANOVA version 20 was used to determine the significant differences in the mean values of the water quality parameter at the various sampled sites and also correlation was employed to see statistical significance relation between all parameters. Microsoft excel was also used for statistical analysis of data. Finally, the result of the water quality parameter was analyzed and compared set by WHO drinking water guideline value.

Water quality index determination (CCME WQI)

Water quality index is one of the most effective tools to express the water quality and used as an important parameter for the assessment and management of the water source. It is a mathematical expression that combine the unique effects of water quality parameters with a single number to measure the overall water quality. The CCME WQI model consists of three measures of variance from selected water quality objectives (Scope, Frequency and Amplitude) (Khan,et al,.2005). The “Scope (F1)” the number of variables not meeting water quality objectives. The “Frequency (F2)” the number of times these objectives are not met (“failed tests”). The “Amplitude (F3)” represents the amount by which failed tests do not meet their objectives. These three factors combine to produce an index value between 0 and 100 that represents the overall water quality. This index doesn’t give any weighted numbers but treats the values of parameters in mathematical way to ensure that all parameters contribute adequately in the final number of the index. Depending on the index value, the water quality is characterized as excellent (95–100), very good (89–94), good (80–88), fair (65–79), marginal (45–64) and poor (0–44). The formulation of the WQI as described in the Canadian Water Quality Index 2001 technical Report is as follows.

The measure for scope F_1 is calculated as % of variables that exceed the guideline.

$$F_1 = \left(\frac{\text{Numberoffailedvaiabbles}}{\text{Totalnumberofvariables}}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The measure for frequency F_2 is calculated as % individual tests within each variable that exceeds the guideline.

$$F_2 = \left(\frac{\text{Numberoffailedtests}}{\text{Totalnumberoftests}}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The measure for amplitude, F_3 is calculated as the extent to which failed test exceeds the guideline.

Excursion is the number of times by which an individual concentration is greater than or less than the objective.

$$\text{Excursion}_i = \left[\frac{\text{failedtestvalue}}{\text{objective}}\right] - 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

The collective amount by which individual tests are out of compliance is calculated by summing the excursions of individual tests from their objectives and dividing by the total number of tests (both those meeting objectives and those not meeting objectives). This variable, referred to as the normalized sum of excursions (nse) is calculated as:

$nse = \sum_{i=1}^{\infty} \frac{[Excursions]}{numberoftests} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$

F_3 is then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a range between 0 and 100.

F_3 =

$$\left(\frac{nse}{0.01*nse+0.01}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

The water quality index (CCME WQI) is then calculated as:

$$\mathrm{CCMEWQI} = 100 - \left[\frac{\sqrt{F_1^2 + F_1^2 + F_3^2}}{1.732}\right]$$

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1. 732 is a scaling factor to ensure the index is between 0 and 100.

Results And Discussion

Spatial and temporal variation of physical characteristics of ground water

Turbidity

In the dry season the value of turbidity at all wells of groundwater were between 1.313 ± 0.065 to 8.937 ± 0.406 NTU with a mean value of 5.140 ± 2.255 NTU while in the wet season ranged from 2.983 ± 0.624 to 23.617 ± 2.003 NTU with a mean value 10.589 ± 5.961 NTU. The mean values of turbidity recorded in the wet season (10.589 ± 5.961 NTU) were higher than WHO’s (2011) permissible limits of 5 NTU as well as from the mean value of dry season (5.140 ± 2.255 NTU) shown in the appendix.

This may be due to high concentrations of small clay mineral particles, dissolved compounds and colloids, coagulation of dissolved substances in the boreholes, particles from weathering activities in the underground waterways and surface runoff from agricultural fields around the ground water sources, dissolved clay and mud materials into the groundwater through infiltration. This means during a rainfall, particles from the waste and surrounding land are washed into the water sample points and leaching into groundwater making the water a muddy brown color, indicating water that has higher turbidity values. Also, during rainy season, water velocities are faster and water volumes are higher, which can more easily stir up and suspend material from the stream bed, causing higher turbidities. The reason for lower turbidity in dry season may be the reduction in runoff material, precipitates, and suspended solids during the dry season which contributed to turbidity. The lower value of turbidity in dry season resembles with the work of (Hannington et al.,2016) who have done on effects of seasonal variation in physical parameters on quality of gravity flow in Uganda. In the case of spatial variation in the dry season the maximum values of turbidity were observed at W10 and a minimum value at W08.Also in the wet season the maximum value was recorded at W07 and minimum value at W08. The statistical result of one-way ANOVA in the appendix shows that the mean value of turbidity was significantly affected by season and location which is less than the significant level value of ($p < 0.05$). Generally, high turbidity can provide hiding places for harmful micro-organisms and thereby shield them from disinfection process, raises water temperature in high and consequently, the concentration of dissolved oxygen can be decreased.

From the variability map of turbidity shown in Fig. 3(a), it was observed the value of turbidity recorded in the range of (1.32–8.94). This indicates that high value of turbidity was observed in the central region and south western region of the study area while the minimum value occurred in the south western and south eastern region of the study area. As shown map of turbidity in Fig. 3(b), its recorded value was (2.99–23.61). One can see from this high value of turbidity were observed in the central and northern region while the minimum value observed in the southern region of the study area.

Total dissolved solid

In this study the amount of dissolved solid in the groundwater were from 255.767 ± 13.136 to 533.01 ± 13.005 mg/l during dry season with a mean value of 373.681 ± 98.427 mg/l while in a wet season from 217.467 ± 12.314 to 366.123 ± 11.917 mg/l with a mean value of 280.386 ± 45.595 mg/l. Findings of the study indicated that the measured mean values of total dissolved solid during dry season (373.681 ± 98.427mg/l) and wet season (280.386 ± 45.595 mg/l) were within the WHO’s permissible limit (500mg/l) (WHO, 2011).

On the base of spatial variation in both dry and wet season the maximum values of total dissolved solid were observed at W09, W08, W06 and a minimum value were observed at W11 in dry season while at W03 in wet season as shown in the Fig. 4. The high concentration value in the groundwater sample may be due to water flow from domestic sewage and leaching of salts from soils at that location. On the base of seasonal variation all values of total dissolved solid during the dry season were higher than the values of the wet season. The reason for this higher value is total dissolved solids are introduced into the borehole from rocks and soil through which water percolates (WHO, 2006). This could have been due to the higher temperatures observed during the dry season which facilitated dissolution, ion exchange capacity, desorption and weathering processes. Also, during the dry season borehole water evaporated and ionic concentrations increased. This higher TDS value during the dry season was in line with the study of Adnani et al. (2020) who have done on assessment of seasonal and spatial variation of groundwater quality in the coastal Sahel of dole Kala Morocco. The statistical result of one-way ANOVA shows that the mean value of TDS was significantly affected by season and location which is less than the significant level of ($p < 0.05$). Generally, this higher values of TDS in ground water are generally not harmful to human beings, but high concentration of these may affect persons who are suffering from kidney and heart diseases. Water containing high solid may cause laxative or constipation effects according to (Sasikaran et al., 2012).

From the variability map of TDS shown in Fig. 5(a), it was observed that the value of TDS recorded in the range of (255.8-532.95). From this we can see that high value were observed southern and central region of the study area while the minimum value observed in the southern and south eastern region. The variability map of TDS in Fig. 5(b) shows that the value was recorded in the range from (217.49–366.10). This indicates that high value was observed in the eastern and southwestern region of the study area while the minimum value observed in the southeastern region of the study area.

Electrical conductivity

In this study the dry season value of electrical conductivity at all samples of groundwater were between 365.467 ± 13.196 to 665.600 ± 24.950 µS/cm with a mean value of 493.533 ± 102.459 µS/cm while in the wet season from 322.600 ± 16.064 to 462.367 ± 20.134 µS/cm with a mean value 386.594 ± 57.469 µS/cm. The result indicates that the mean value of electrical conductivity for both dry and wet season is within the permissible limit of 1000µS/cm for drinking purpose. This result indicated that the water in the system is characterized by low ionized and has a low level of ionic concentration activity due to the low concentration of dissolved solids. As shown in Fig. 6, the mean value of electrical conductivity in dry season is higher than the mean value recorded during wet season.

This parameter could be influenced by temperature and the presence of inorganic solids. Temperature affects conductivity by increasing ionic mobility as well as the solubility of many salts and minerals. The increase in electrical conductivity was due to evaporation of water in underground water channels which increased the concentrations of dissolved salts or conducting substances in the borehole water systems and in the wet season there is dilution of the ions due to rainwater increasing underground water volumes resulting in a decrease in electrical conductivity (Hannington et al., 2016). The result are in agreement with the findings of (Wilberforce et al. 2016) who showed that the electrical conductivity value recorded in the dry season were generally higher than the rainy season. On the base of spatial variation in dry season the maximum values of electrical conductivity were observed at W08 & W06 while the minimum value at W11 and in wet season the maximum value was observed at W09 while a minimum value at W03 as shown in Fig. 6. The statistical result of one-way ANOVA shows that the mean value of TDS was significantly affected by season and location which is less than the significant level.

From the variability map of electrical conductivity shown in Fig. 7(a), it was observed that the value of electrical conductivity recorded in the range of (365.50-665.53). This indicates that high value of electrical conductivity was observed in the central and western region of the study area while the minimum value occurred in the southern and south eastern region of the study area. As shown map of electrical conductivity in Fig. 7(b), its recorded value was ranged from (322.62-462.34). One can see from this high value of electrical conductivity were observed in the central and south eastern region while the minimum value observed in the northern and western region of the study area.

Temperature

In this study the dry season value of temperature at all wells of groundwater were ranged between 18.400 ± 0.400°C to 23.333 ± 0.764°C with a mean value of 20.625 ± 1.491°C while in the wet season ranged from 17.367 ± 0.503°C to 20.433 ± 0.551°C with a mean value of 18.525 ± 0.945°C. As shown in Figure the mean value of temperature value during both dry and wet season were within the standard limit of (WHO, 2011) which indicates that the temperature of water should not exceed 30°C for drinking purpose. Seasonally, the mean value of temperature during dry season was higher than wet season due to prevailing of atmospheric conditions as shown in Fig. 8.

The impact of temperature increase on groundwater during dry season may include mineral weathering, water flow, chemical adsorption and desorption, gas solubility and microbial redox processes. Also, increase in temperature decreases the amount of dissolved oxygen, accelerates nitrification and oxidation of ammonia to nitrates and leading to oxygen deficient water environment. As shown in the (appendix), the temperature values varied significantly according to both seasonal and spatial variation ($p < 0.05$). Generally, temperature changes could trigger changes in physical, chemical and microbial process in the subsurface environment, resulting in ground water quality changes (Saito et al., 2016). Generally, as shown the ANOVA result, the temperature value varied significantly for both seasonal and spatial variation.

The variability map of temperature in Fig. 9(a), show that observed value of temperature was recorded in the range of (18.40-23.33). This indicates that high value was observed in the eastern region of the study area while the minimum value occurred in the northern and south eastern region of the study area. The variability map of temperature in Fig. 9(b) shown the value was recorded in the range from (17.37–20.43). This indicates that high value was observed in the eastern region of the study area while the minimum value observed in the south eastern and northern region of the study area.

Spatial and temporal variation of chemical characteristics of ground water

pH

In this study the pH value in the dry season were recorded in the range from 6.343 ± 0.135 to 8.160 ± 0.0387 with a mean value of 7.341 ± 0.764 while in wet season ranged from 5.917 ± 0.317 to 7.237 ± 0.301 with a mean value of 6.400 ± 0. 171. The result analysis mean value of water samples shows pH of wells were within the WHO allowable limit of 6.5–8.5 for dry season while less than the recommended minimum WHO standard limit in wet season. pH of less than 7 indicates that the water is acidic while it has become alkaline if the value is more than 7. The acidity may have been due to high carbon dioxide concentrations from eutrophication processes of organic matter, adsorption of metal anions and presence of some non-metallic compounds in the ground water sources. In aquatic ecosystem pH influence the solubility of toxic metals which have a negative effect on the aquatic living organisms and human health. As shown in the figure below the maximum pH value were recorded at W05 and a minimum value were observed at W02 in the dry season while in the wet season the maximum value was observed at W10 and a minimum value at W02. On the base of seasonal variation, the mean value of pH in groundwater was higher in the dry season than in the wet season as shown in Fig. 10.

This observation may be due to increased infiltration of aquifers with water containing chemical fertilizers, herbicides, pesticides and municipal and industrial wastes. Also in the wet season rainfall could be combines with carbon dioxide can influence the water toward acidity, lower temperature and lower ion exchange capacity taking place (Nwaeze and Ehiri, 2017). Photosynthesis, respiration and decomposition all contribute to pH fluctuations due to their influences on CO2 levels. The findings of higher value pH in a dry season during the study period was similar with the work of (Nienie et al., 2017) who investigates seasonal variability of water quality by physico-chemical index and traceable metals in the suburban area in kikwit, democratic republic of Congo and found out lower value of pH during wet season. The pH values varied significantly according to both seasonal and spatial variations.

From the variability map of pH shown in Fig. 11(a), it was observed that the value of pH recorded in the range of (6.34–8.16). This indicates that high value of pH was observed in the central and south western region of the study area while the minimum value occurred in the south western, central and northern region of the study area. As shown map of pH in Fig. 11(b), its recorded value was ranged from (5.92–7.24). One can see from this high value of pH were observed in the central region while the minimum value observed in the south eastern and south western region of the study area.

Nitrate (NO_3)

Nitrate concentration in the groundwater wells were in the range from (0.148 ± 0.025) to (2.537 ± 0.471) with a mean value of (0.543 ± 0.688) mg/L and from 0.770 ± 0.161 to 4.557 ± 0.162 with a mean value of 2.921 ± 1.514 mg/L at dry season and wet season respectively. On the base of seasonal variation, the mean value of nitrate observed in the wet season were higher than that of the dry season. The higher content of nitrate during rainy season period could be due to anthropogenic factors such as the application of nitrogen-rich fertilizers to plants and agricultural processes leading to the leaching of nitrate through porous soil into groundwater.

Waste materials such as human wastes from septic tanks and animal sewage disposal as well as proximity to cultivated fields may be possible sources of nitrate in some of the well water containing high concentration of nitrate. Soil biochemical processes also affect the availability of NO_3^- in groundwater (Stigter and Dill, 2006). Also this might have been due to high nitrate concentration in wet season suggested that increased flush of nitrate causing components such as ,decaying plant or animal material, agricultural fertilizers, manure, compost, human or animal waste and domestic sewage derived from waste disposal site and the areas around during storm event resulted in nitrate concentration or the increased nitrate level was due to fresh water inflow and terrestrial run-off during the wet season (Karuppasamy and Perumal, 2000). The disclosures of high value of nitrate in a wet season during the study period was similar with the research of (Adnani et al. 2020) who studies assessment of seasonal and spatial variation of groundwater quality in the coastal Sahel of doukkala, Morocco. Although nitrate content in the samples during both wet and dry season were below standard recommended maximum permissible level of 50.0 mg/L (WHO, 2011). The finding of the value of nitrate below the recommended WHO standard during the study period was similar with the work of (Nwankwoala et al., 2009) who have done Seasonal Distribution of Nitrate and Nitrite Levels in Eleme Abattoir Environment, Rivers State, Nigeria. On the base of spatial variation, the maximum value was recorded at W03 with a minimum value at W11 during dry season while in the wet season the maximum value was recorded at W06 and a minimum value at W01 as shown in Fig. 12. The reason for high value at this sampling location may be improper disposal of human and animal wastes, plant decaying, chemical fertilizers run off from grazing and agricultural lands near to the sampling location. As shown the statistical result of ANOVA in the (appendix), the value of nitrate was significantly varied both sampling location and season. Generally, nitrates that enter the body by eating or drinking leave the body without harm. Sometimes, though, conditions such as diarrhea and dehydration (not enough fluids in the body) can make nitrates change to nitrites in greater amounts. These nitrites in the blood cause changes in hemoglobin, or the molecules that help move oxygen in the body and can make it so that less oxygen is available for the body to function properly

As shown the variability map of nitrate in Fig. 13(a), the value of nitrate was recorded in the range from (0.14–2.54). This indicates the high value were observed southern region of the study area while the minimum value observed in central, south western and eastern region of the study area where as in the variability map of nitrate in Fig. 13(b) the value of nitrate was recorded in the range from (0.77–4.56). From this one can see that high value of nitrate were observed in the central, western region of the study area.

Chloride

In this study the result of chloride concentration was ranges from (6.423 ± 1.735) mg/l to (29.500 ± 4.258) mg/l with a mean value of (17.233 ± 6.556) mg/l during the dry period while ranges from (15.967 ± 2.695) mg/l to (34.490 ± 3.815) mg/l with a mean value of (24.848 ± 6.733) mg/l in the wet season. According to the (WHO, 2011) the permissible concentration of chloride for drinking water is 250 mg/l. The mean concentration value for the study area is much less than the permissible limit set by world health organization for drinking water at both dry and wet season. The finding of the value of chloride below the recommended WHO standard during the study period was similar with the work of (Vyas and Sawant, 2008) who have done seasonal variations in drinking water quality of some borewell waters in urban area of Kolhapur city and the recorded value during the study period were below the recommended standards. On the base of seasonal variation, the mean value of chloride observed in the wet season were higher than that of the dry season.

This may be due to sodium chloride is added to many processed foods to delay spoilage while bring out flavor. However, chlorides are not removed from wastes by septic tank treatment processes and enter the leach field with the rest of the effluent. from there, chlorides could be entered groundwater through septic systems. Another anthropogenic source of chloride in groundwater is fertilizer made with potash that are added to increase soil fertility on farms and home gardens and could leach from fertilized soils into the groundwater during rainy season (Chlorides in Fresh Water). The finding of high mean chloride value in the dry season is similar with the work of (Aladejana et al., 2020) who have done assessing the impact of climate change on groundwater quality of the shallow coastal aquifer of eastern Dahomey basin, southwestern Nigeria and recorded higher chloride value during dry season. On the base of spatial variation shown in Fig. 14, the maximum chloride value was observed at W08 and a minimum value at W03 during dry season while the maximum value observed at W03 and a minimum value recorded at W09 during wet season as shown in Fig. 14. The reason for recording higher value at these sampling locations could be the dissolution of halite (Nacl) or the presence of a salt intrusion could eventually lead to high level of chlorides and geological formations (conglomerate, clay, limestone, carbonate) present in the catchment may explain the presence of the ion's chloride according to (Benhamiche et al., 2016). As shown in the (appendix), the mean chloride values varied significantly according to both the seasonal and spatial variations.

As shown the variability map of Fig. 15(a), the value of chloride ranges from (6.43–29.49). This indicates the high value of chloride were observed in the south eastern and southern region of the study area while the minimum values were observed in the central and eastern region of the study area. From the variability map of chloride in Fig. 15(b) the value of chloride was recorded in the range from (915.97–34.49). This indicates the high value of chloride were observed in the eastern and southwestern region of the study area while the minimum value was observed in the central, southern and western region of the study area.

Calcium

In this study the result of calcium concentration was ranges from (17.783 ± 1.108) mg/l to (103.223 ± 6.542) mg/l with a mean value of (63.203 ± 6.556) mg/l during the dry period while ranges from (15.947 ± 3.210) mg/l to (80.917 ± 3.526) mg/l with a mean value of (41.603 ± 20.462) mg/l in the wet season. The result analysis mean value of water sample show calcium of wells were within the WHO allowable limit of 75 mg/l for both dry season and wet season while in some sampling location of the study area the value of calcium concentration were above the WHO permissible limit. On the base of seasonal variation, the mean value of Calcium in groundwater was higher during the dry season than in the wet season.

The finding of high mean calcium value in the dry season is similar with the work of (Vyas and Sawant, 2008) who have done seasonal variations in drinking water quality of some borewell waters in urban area of Kolhapur city and recorded higher calcium value during the dry season. The reason could be during the wet season, the precipitation in the form of snow will have relatively low concentration of salts of marine origin.as both substratum and plants are frozen for long periods during wet, mineral-ion uptake must be minimal or non-existent. Although, plants may be release of nutrients into the film of melt water adhering to the plants and reducing the level of certain mineral elements (Smith, 1999). On the base of spatial variation shown in Fig. 16, the maximum calcium value was observed at W07 and a minimum value at W08 during dry season while the maximum value observed at W05 and a minimum value recorded at W03 during wet season shown in Fig. 16. The basic sources of calcium are carbonate rocks, i.e., limestone's and dolomites, which are dissolved by carbonic acid in groundwater. The chemical breakdown of calcic-plagioclase feldspars and pyroxenes may be responsible for calcium in the groundwater (Ganyaglo et al., 2010). Generally, Calcium is the principal cause of the formation of scale in boilers, water heaters, and pipes, and to the objectionable curd in the presence of soap. These mineral constituents and hardness greatly affect the value of water for public and industrial uses. As shown the statistical result of ANOVA, the value of calcium was significantly varied both sampling location and seasonal as the value of($p < 0.05$).

From the variability map of calcium shown in Fig. 17(a), it was observed that the value of calcium recorded in the range of (17.5-103.2). This indicates that high value of calcium was observed in the central region and northern region of the study area while the minimum value occurred in the south western and eastern region of the study area. As shown map of calcium in Fig. 17(b), its recorded value was ranged from (15.95–80.90). One can see from this high value of calcium were observed in the central and western region while the minimum value observed in the eastern and southwestern region of the study area.

Magnesium

The concentration of magnesium in the study area ranged from (14.807 ± 2.176) mg/l to (30.893 ± 3.128) mg/l with a mean value of (22.367 ± 5.406) mg/l during the dry period while ranges from (6.663 ± 0.313) mg/l to (23.063 ± 2.653) mg/l with a mean value of (17.186 ± 5.981) mg/l in the wet season. According to the (WHO, 2011) the permissible concentration of Magnesium for drinking water is 50 mg/l. The mean concentration value for the study area is much less than the permissible limit set by world health organization for drinking water at both dry and wet season. The finding of the value of magnesium below the recommended WHO standard during the study period was similar with the work of (Ojekunle et al., 2020) who have done assessment of physicochemical characteristics of groundwater within selected industrial areas in Ogun State, Nigeria and the recorded value during the study period were below the recommended standards. On the base of seasonal variation, the mean value of magnesium in groundwater was higher during the wet season than in the dry season as shown in Fig. 18.

The finding of recording higher magnesium value in wet season is similar with the work of (Tlili-Zrelli et al., 2018) who have done on spatial and temporal variations of water quality of mateur aquifer and observed higher magnesium value during the wet season. On the base of spatial variation shown in Figure (4.17), the maximum magnesium value was observed at W02 and a minimum value at W11 during dry season while the maximum value observed at W09 and a minimum value recorded at W06 during wet season as shown in Fig. 18. This could be Magnesium occurs in limestone and dolostone in significant amounts and the dissolution of limestone causes magnesium to be brought into solution. Magnesium can also be released into groundwater by weathering of igneous rocks, and precipitates from marine deposits. As shown the statistical result of ANOVA, the value of Magnesium was significantly varied both spatial and seasonal as the value of ($p < 0.05$).

The variability map of magnesium in Fig. 19(a), show that observed value of magnesium was recorded in the range of (14.81–30.89). This indicates that high value was observed in the eastern and central region of the study area while the minimum value occurred in the northern, southern and central region of the study area. The variability map of magnesium in Fig. 19(b) shows the value of was recorded in the range from (6.67–23.06). This indicates that high value was observed in the western and southern region of the study area while the minimum value observed in the southern and eastern region of the study area.

Spatial and temporal variation of biological characteristics of Groundwater

Total coliform

The value of total coliform in the study area was from (8 ± 2) CFU/100ml to (305 ± 13) CFU/100ml with a mean value of (115 ± 89) CFU/100ml during the dry period while ranges from (20 ± 7) CFU/100ml to (336 ± 22) CFU/100ml mg/l with a mean value of (171 ± 102) CFU/100ml in the wet season. This result indicates that the bacterial colony counts were all above the WHO guide line limit of 0 CFU/100ml for drinking purposes. The reason for the contaminated water by total coliform could be agricultural runoff, effluent from septic systems or sewage discharges, infiltration of domestic or wild animal fecal matter, poor well maintenance and construction can also increase, the risk of bacteria and other harmful organisms getting into a well water supply. Total coliform does not necessarily indicate recent water contamination by fecal waste, however the presence or absence of these bacteria in treated water is often used to determine whether water disinfection is working properly. The measured mean value of total coliform during wet season was higher than that of dry season as shown in Fig. 20.

Similar increasing in groundwater quality parameters in wet seasons have been identified in Nepal (Shrestha et al., 2014) who have done Seasonal variation in the microbial quality of shallow groundwater in the Kathmandu Valley, Nepal and reported increased total coliform concentrations in the shallow groundwater during the wet season. This could be due to the discharged human wastes or fecal matters are flushed/washed/ away by the actions of rainfall from its source to the different water bodies. Then during its flow, it joins surface waters and open boreholes besides to leaching in to ground water through percolation and infiltration. The transport of bare soil contaminated with faeces by the wind/rain/ into open bores as well as surface runoff could also have accounted for the high bacterial load during the wet season as compared to the dry season. On the base of spatial variation shown in Fig. 20, the maximum total coliform value was observed at W06 during both dry and wet season of the study period while the minimum value recorded at W02. The total coliform values varied significantly according to both the seasonal and spatial variations.

As shown the variability map of Fig. 21(a) the value of total coliform ranges from (8.03-304.89). This indicates the high value of total coliform were observed in the central and eastern region of the study area while the minimum values were observed in the south eastern and northern region of the study area. From the variability map of total coliform in Fig. 21(b), the value of total coliform was recorded in the range from (20.38–335.90). This indicates the high value were observed in the eastern and central region of the study area while the minimum value was observed in the south eastern and northern region of the study area.

Faecal coliform

In this study the result of faecal coliform was ranged from (3 ± 1) CFU/100ml to (213 ± 13) CFU/100ml with a mean value of (67 ± 63) CFU/100ml during the dry period while ranges from (9 ± 2) CFU/100ml to (266 ± 9) CFU/100ml with a mean value of (108 ± 74) CFU/100ml in the wet season. The mean value of the faecal coliform in the study area were above the WHO limit of zero. This may be due to sewage generated from homes which are not properly stored in septic tank and find their way into groundwater sources and causes contamination. The liquid that leaves the septic tank or pit latrine contains quite high level of bacteria which have the potential to contaminate groundwater. The mean faecal coliform value in the wet season is higher than dry season as shown in Fig. 22.

This may be due to; pit latrine is still in use in the study area, it is likely that a huge amount of wastewater is being leaked into the subsurface and also there is poor solid waste management in the study area results in contamination of the land surface. So, during the wet season, these highly contaminated increase the pollutant load in the groundwater. Also change in water level below the ground surface could be the reason for increasing coliform in wet season than dry season. So as the water level roses, the groundwater may have reached the point of pollution in the subsurface and filtration of micro-organisms by soil layers may have been reduced. The high amount of these coliform during the wet season could be due to the fact that water availability favors the movement and reproduction of the organisms. On the base of spatial variation shown in Fig. 22, the maximum total coliform value was observed at W06 during both dry and wet season of the study period while the minimum value recorded at W02 as shown in Fig. 22.

The variability map of faecal coliform in Fig. 23(a), show that observed value of faecal coliform was recorded in the range of (3.35–213.60). This indicates that high value was observed in the eastern and central region of the study area while the minimum value occurred in the northern and southeastern region of the study area. The variability map of faecal coliform in Fig. 23(b), shown the value was recorded in the range (9.36-266.24). This indicates that high value was observed in the central and eastern region of the study area while the minimum value observed in the southeastern and northern region of the study area.

4.2 Correlation Matrix of physico-chemical and bacteriological parameters

The correlation coefficient analysis was done using SPSS version 20 statistical tools and the correlations among the physico-chemical and bacteriological parameters are presented below.

Table 2
Correlation matrix of physio-chemical and bacteriological parameters

	pH	Turbidity	Mg	Ca	No3	Cl	EC	Temp	TDS	FC	TC
pH	1										
Turbidity	-0.026	1									
Mg	0.159	-0.309	1								
Ca	0.509	0.027	0.208	1							
No3	-0.176	0.404	-0.44	-0.148	1						
Cl	-0.59	0.224	-0.011	-0.449	0.205	1					
EC	0.321	-0.319	0.189	0.179	-0.448	0.056	1				
Temp	0.52	-0.466	0.184	0.223	-0.406	-0.461	0.457	1			
TDS	0.365	-0.283	0.266	0.202	-0.435	0.074	0.923	0.532	1		
FC	0.123	0.131	-0.338	-0.033	0.398	-0.034	0.039	0.319	0.102	1	
TC	0.129	0.052	-0.326	-0.056	0.362	-0.074	0.033	0.345	0.102	0.969	1

Pearson's correlation coefficient measures the statistical relationship or association between two continuous variables. It gives information about the magnitude of the association or correlation, as well as the direction of the relationship. The Pearson coefficient value can range from + 1 to -1 where − 1 indicates a perfect negative relationship, + 1 indicates a perfect positive relationship whereas 0 value indicates no relationship exists and 0.7 are considered to be strongly correlated whereas (r) has a value in between 0.5 to 0.7 a moderate correlation is showing be present (Helena et al. 2000).The analysis suggested that some of the parameters have weak or strong positive correlations or weak and strong negative correlations. In the physico-chemical and bacteriological analysis of the ground water quality the temperature, calcium and chloride were moderately correlated (r = 0.5 to 0.7) with PH value. The turbidity, magnesium nitrate electrical conductivity, total dissolved solid, fecal and total coliform were weakly correlated (r < 0.5) with pH value as shown in the above table. The pH, temperature, calcium and chloride, magnesium nitrate, electrical conductivity, total dissolved solid, fecal and total coliform were weakly correlated with turbidity. There was a poor negative correlation of magnesium with nitrate, chloride, fecal, total coliform and also poor positive correlation with temperature, calcium electrical conductivity and total dissolved solid. There was strong positive correlation value (r = 0.923) of total dissolved solid with electrical conductivity. There was also a moderate positive correlation (r = 0.5 to 0.7) of temperature with pH and total dissolved solids. Temperature pH turbidity, nitrate, electrical conductivity and total dissolved solids were poor positively correlated with fecal and total coliforms. There is no almost correlation between chloride and magnesium, electrical conductivity, total dissolved solids, feacal, total coliform with (r < 0.01). Electrical conductivity forms positive correlation with almost all the physico-chemical parameters except nitrate and turbidity.

4.3 Water quality index for evaluating groundwater quality in the study area

In order to evaluate the groundwater quality, the CCME WQI value for all sampling location with respect to physico-chemical characteristics were determined. The calculated results of WQI for all groundwater samples of the study area were presented in Table 3

Table 3
CCME WQI value for all sampling locations

Sampling location	CCME WQI value	water quality Status
W01	44.00	Poor
W02	43.23	Poor
W03	50.54	Marginal
W04	43.36	Poor
W05	55.82	Marginal
W06	40.99	Poor
W07	40.99	Poor
W08	44.19	Marginal
W09	41.44	Poor
W10	46.30	Marginal
W11	48.39	Marginal
W12	40.53	Poor

Analysis of groundwater in Table 3 shows the variation of WQI with CCME standard level to evaluate the status of existing water quality of the study area. The index ranges from 0 to 100 and depending on the value; the water quality is characterized as excellent, good, fair, marginal and poor. The value of three factors (scope, frequency and amplitude) were available in the appendix part. The result shows the maximum number of variables whose objectives are not met lie in the range between 10 to 35. The frequency with which objectives are not met lie in the range between 5 to 23 and the amount by which the objectives are not met (amplitude) lie in the range between 84 to 96. This amplitude index helps to identify the critical parameters after quantifying the amount by which failed test values do not meet the objective. The results from table showing seven sample points as poor and five sample points as marginal throughout the study time. The marginal status sample points were found in W03, W05, W08, W10 and W11. This indicates that Water quality is frequently endangered or deteriorated; conditions often deviate from natural or desirable levels. poor status of sample points was found in W01, W02, W04, W06, W07, W09 and W12. This indicates that water quality of this sampling points is always endangered or deteriorated; conditions usually deviate from natural or desirable levels.

As shown the variability map of WQI in Fig. 24, the value recorded in the study area were ranged from (40.53–55.81). this indicates that high poor water quality status was observed in western and central region while high marginal water quality status was observed in the central and eastern region of the study area.

Conclusions

In this study, the physicochemical and bacteriological quality of groundwater samples from different sampling locations of Debre Tabor town were analyzed in both dry and wet seasons. The result of analyses shows that Turbidity, Nitrate, Chloride, Magnesium, Total coliform and Feacal coliform have higher mean values during the wet season while pH, Calcium, Total dissolved solid, Electrical conductivity and Temperature have higher mean values during dry season. This indicates that assessing the quality of groundwater considering different season is important due to its significant change on the contents of certain parameters. The analysis of physico-chemical properties recorded values shows that nitrates, chlorides, magnesium, electrical conductivity and temperatures were within the accepted limit of WHO standards throughout the study time while other fluctuates within the season. The feacal coliform and total coliform counts detected were above the recommended limit of WHO standards for drinking water in all hand dug wells throughout the study time. This indicates that the wells are not suitable for human consumption without further treatments like boiling. The result of statistical analysis of variances (ANOVA) shows that all the measured physico-chemical and bacteriological parameters were varied significantly among the sampling locations and temporal variations during the study period($p\text{-value} < 0.05$). Spatial distribution map of certain prepared parameters using GIS is important in identifying the best groundwater quality zone in the study area. The CCME WQI is an effective tool to evaluate groundwater quality. The resulting scores for the water quality index indicate that, all hand dug wells classify from poor water quality to marginal water quality. This indicates that the hand dug wells in the study area is not suitable for human consumption. Therefore, authorities concerned in Debre Tabor town closely monitor the continued deterioration of hand dug wells, take necessary precaution to prevent use of contaminated water for human consumption.

Declarations

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Author contribution

A.S.T collected and analyzed data, Z.F.B developed a GIS map, Software and wrote the main manuscript text and D.A.Y visualization, editing and reviewing the manuscript

Data Availability

The data that support the findings of this study are available from the author (Adugnaw Shega Tasew, adugnew8072@gmail.com), upon reasonable request.

Ethics Approval: Not applicable

Consent to Participant: Not applicable

Consent for publication: Not applicable

Compering interests: The authors declare no competing interests

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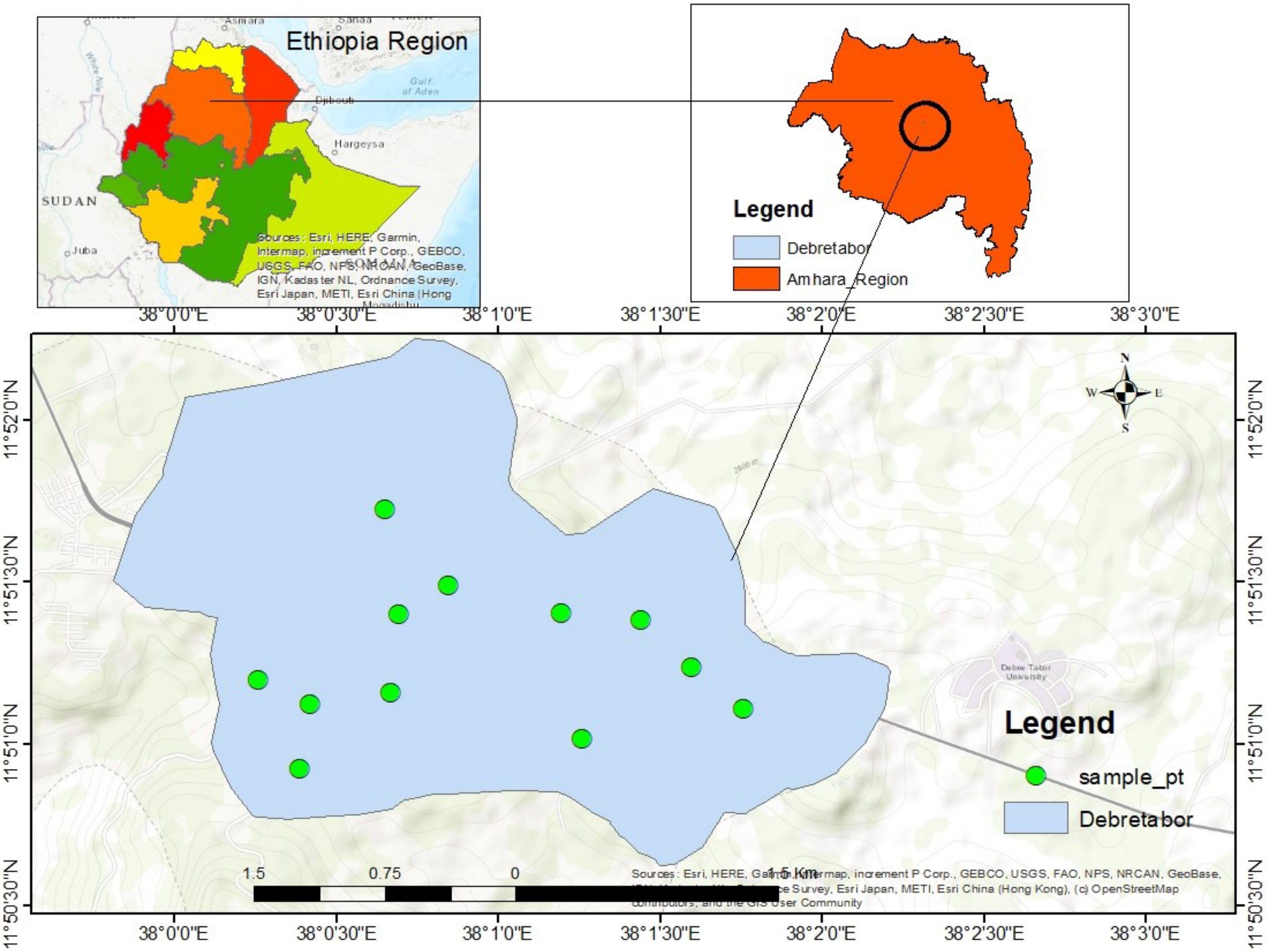
Figures



Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 1

Map of the study area

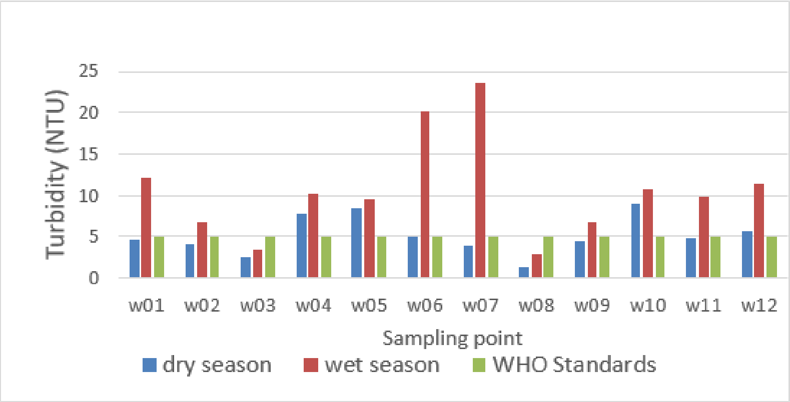
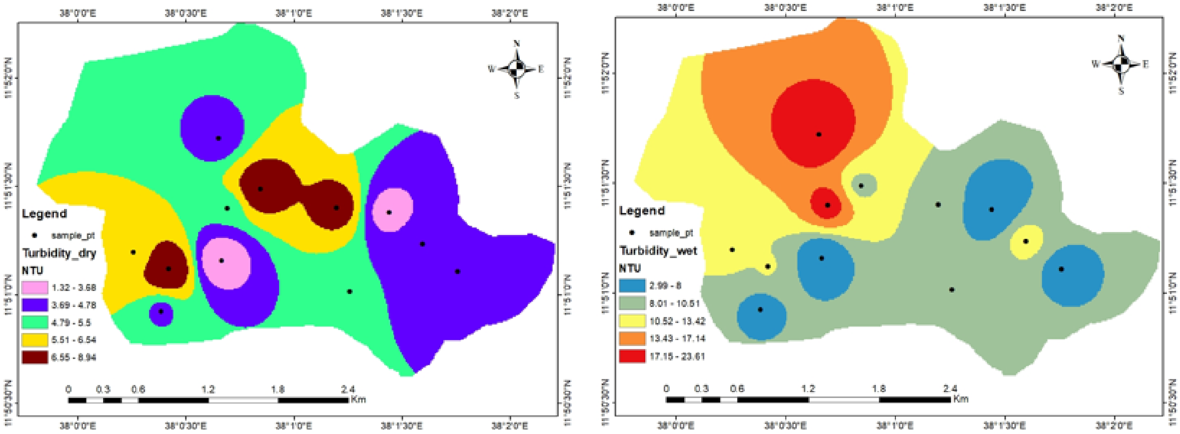


Figure 2

Temporal and Spatial variation of turbidity



a

b

Figure 3

Spatial distribution map of turbidity (a) Dry Season and (b) Wet Season

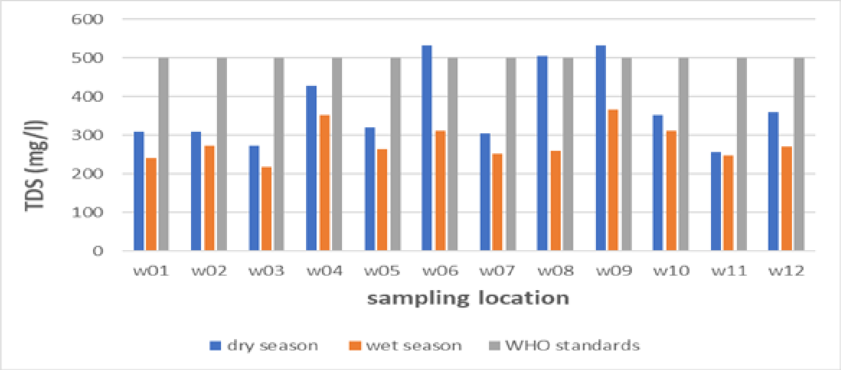
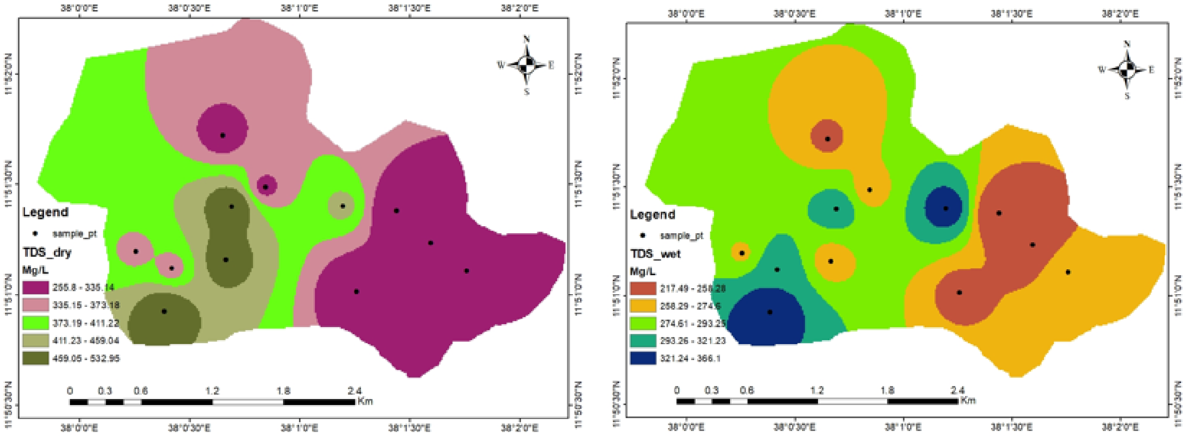


Figure 4

Temporal and Spatial variation of TDS



a

b

Figure 5

Spatial distribution map of Total dissolved solid (a) Dry Season and (b) Wet Season

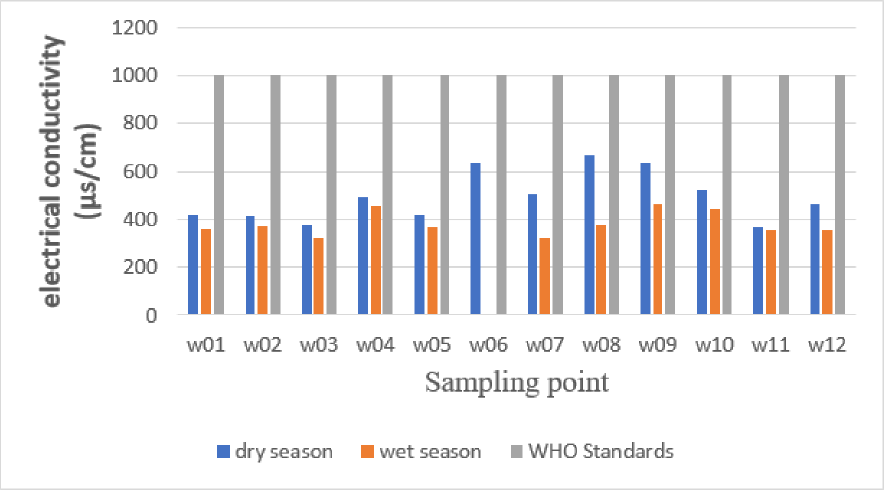
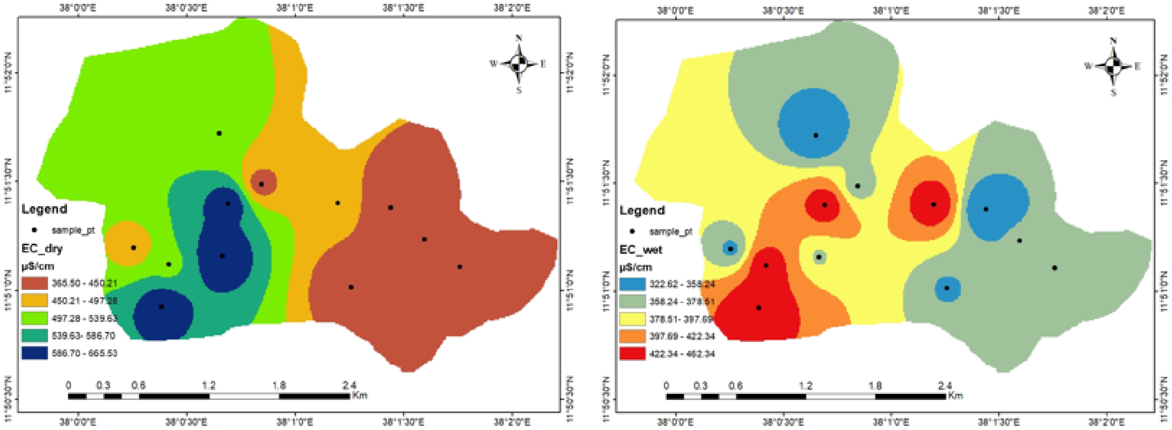


Figure 6

Temporal and Spatial variation of Electrical conductivity



a

b

Figure 7

Spatial distribution map of electrical conductivity (a) Dry Season and (b) Wet Season

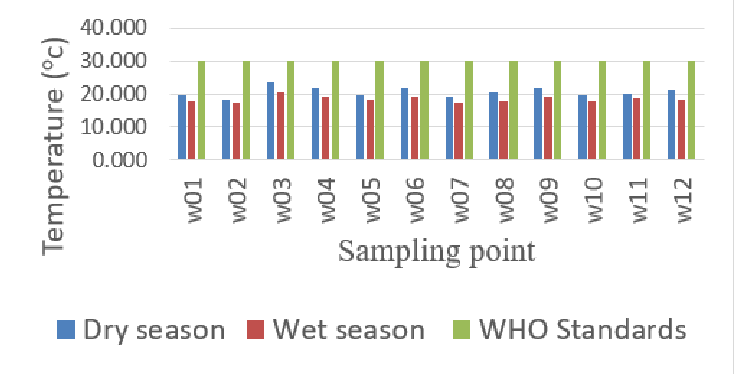
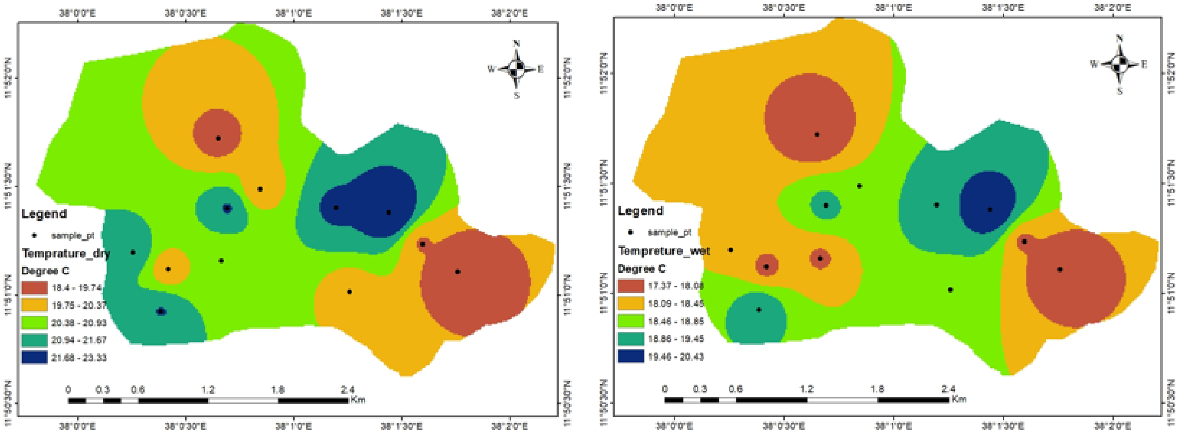


Figure 8

Temporal and Spatial variation of Temperature



a **b**

Figure 9

Spatial distribution map of temperature(a) Dry Season and (b) Wet Season

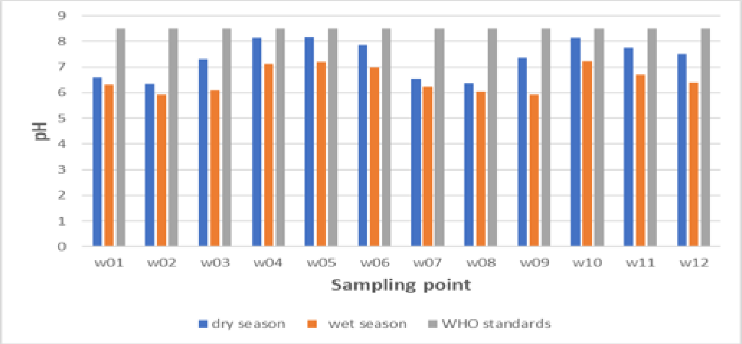
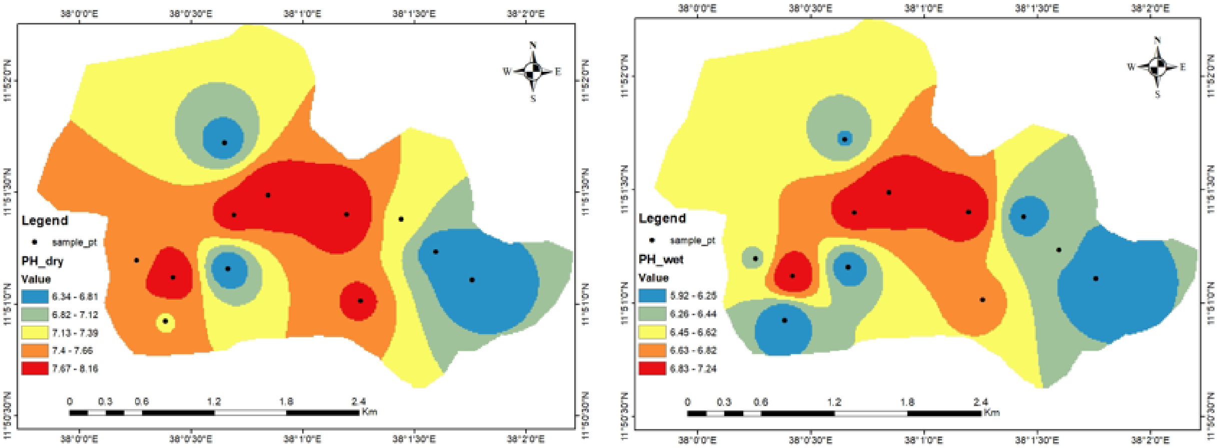


Figure 10

Temporal and Spatial variation of pH



a **b**

Figure 11

Spatial distribution map of pH (a) Dry Season and (b) Wet Season

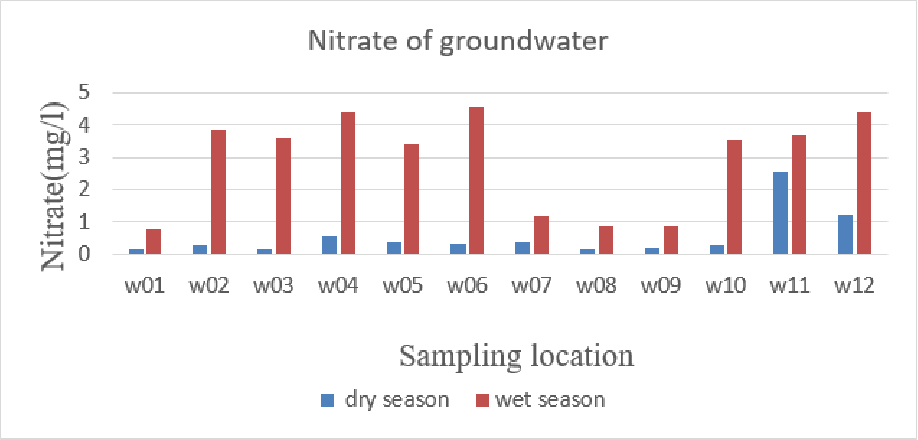
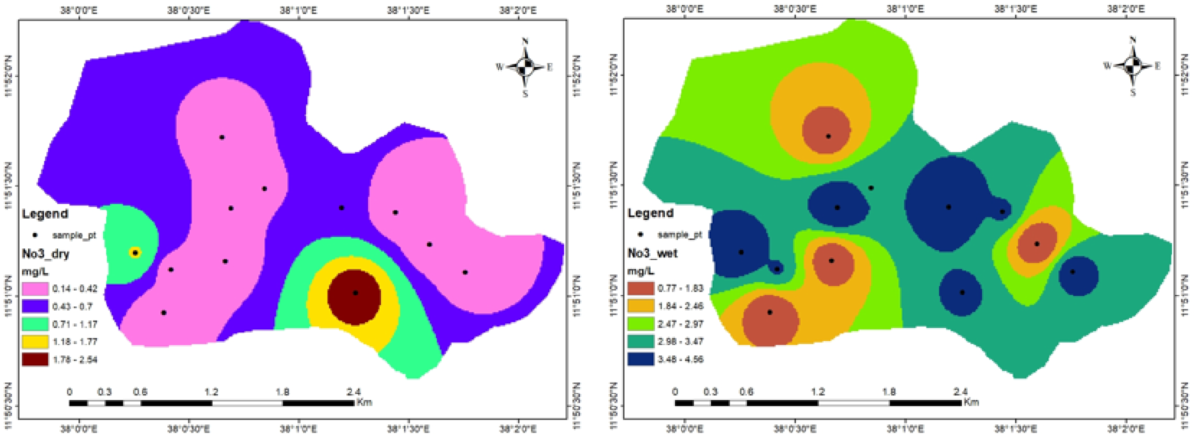


Figure 12

Temporal and Spatial variation of nitrate



a

b

Figure 13

Spatial distribution map of nitrate (a) Dry Season and (b) Wet Season

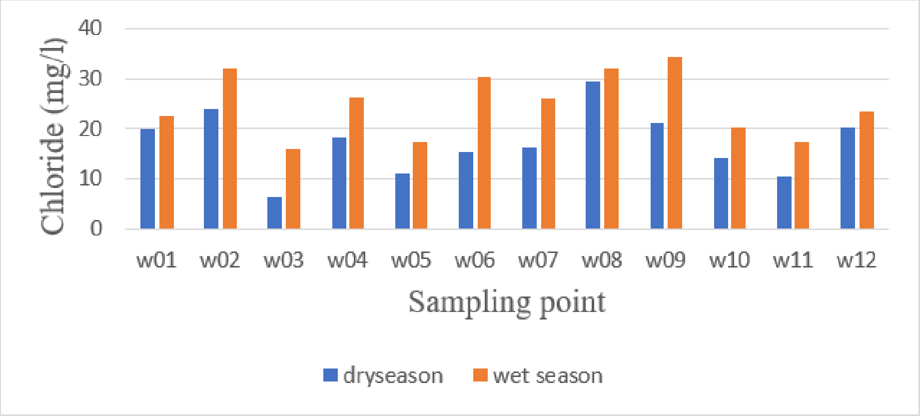


Figure 14

Temporal and Spatial variation of chloride

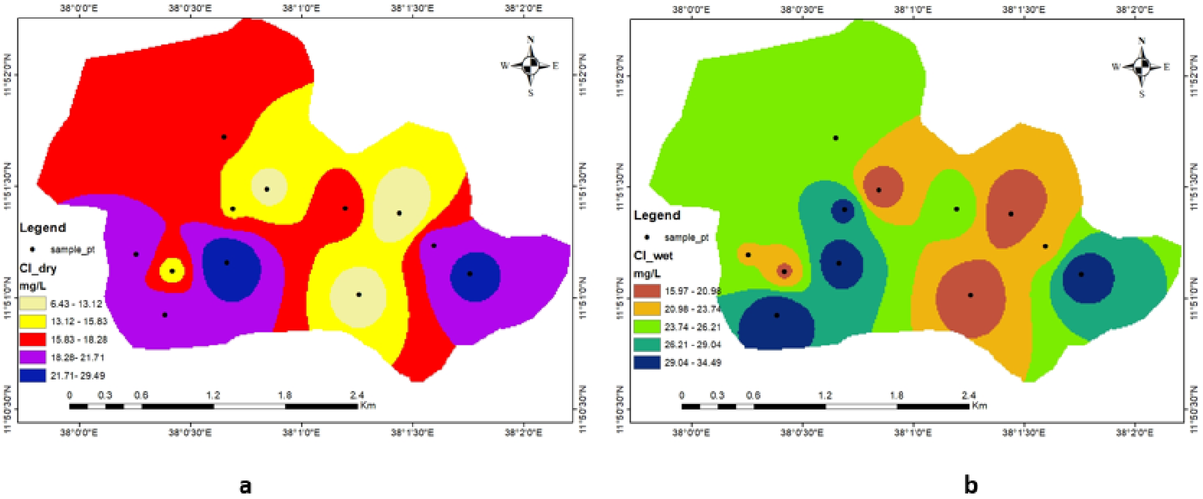


Figure 15

Spatial distribution map of chloride (a) Dry Season and (b) Wet Season

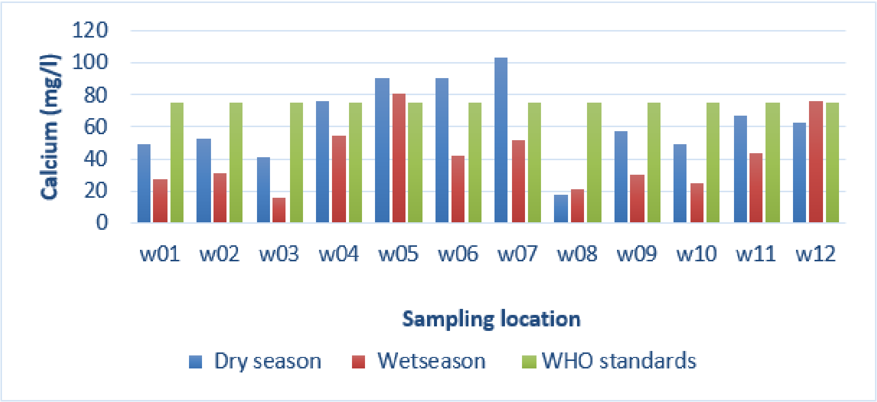


Figure 16

Temporal and Spatial variation of calcium

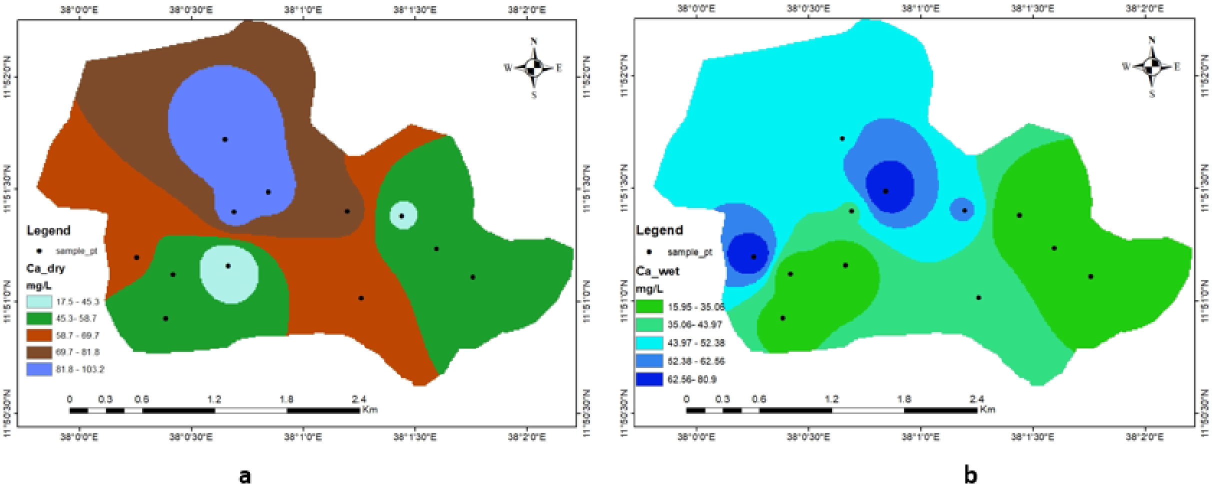


Figure 17

Spatial distribution map of calcium (a) Dry Season and (b) Wet Season

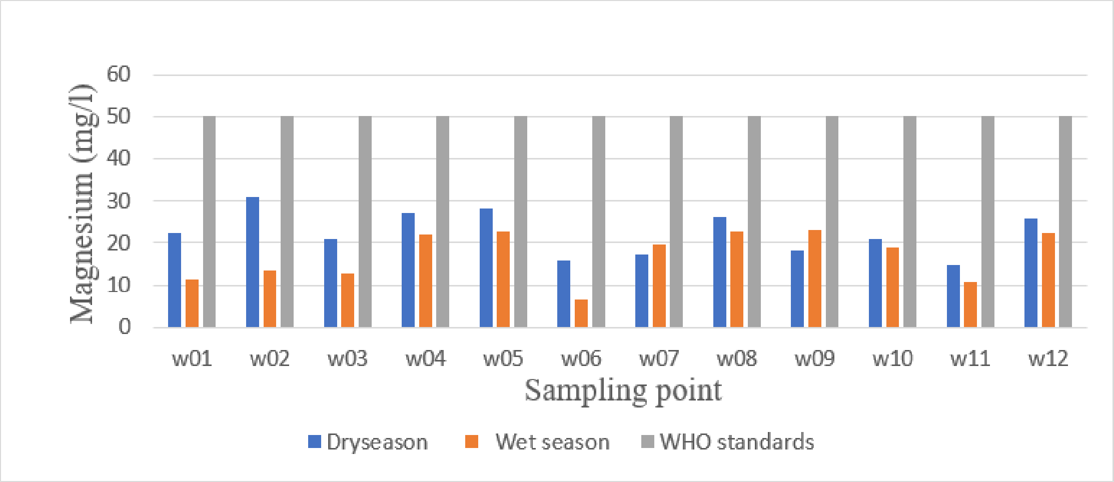
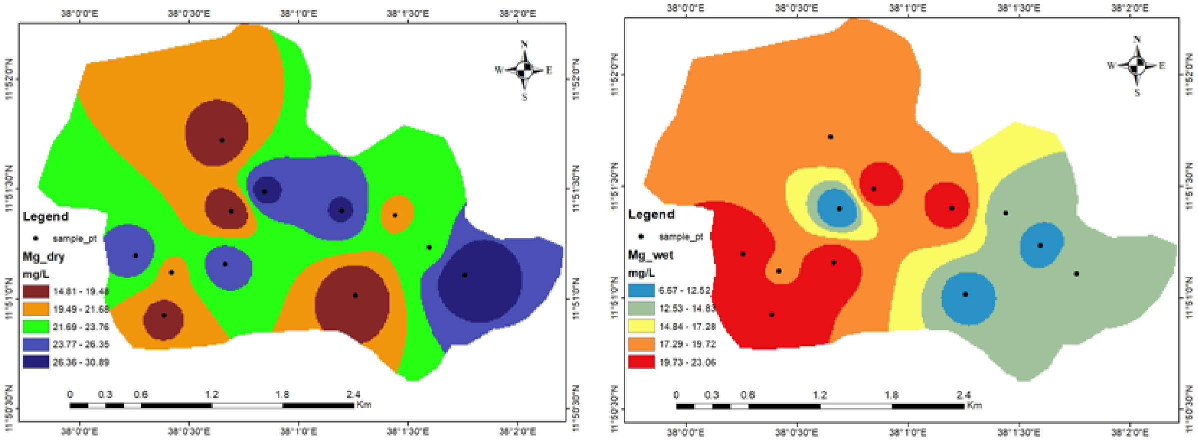


Figure 18

Temporal and Spatial variation of magnesium



a

b

Figure 19

Spatial distribution map of magnesium (a) Dry Season and (b) Wet Season

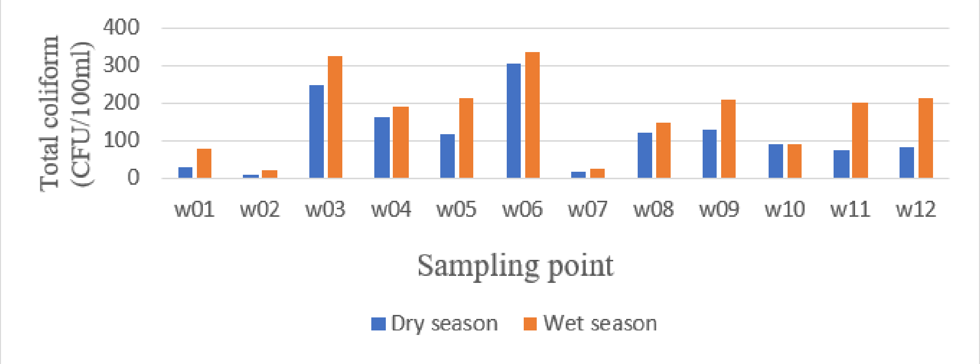


Figure 20

Temporal and Spatial variation of total coliform

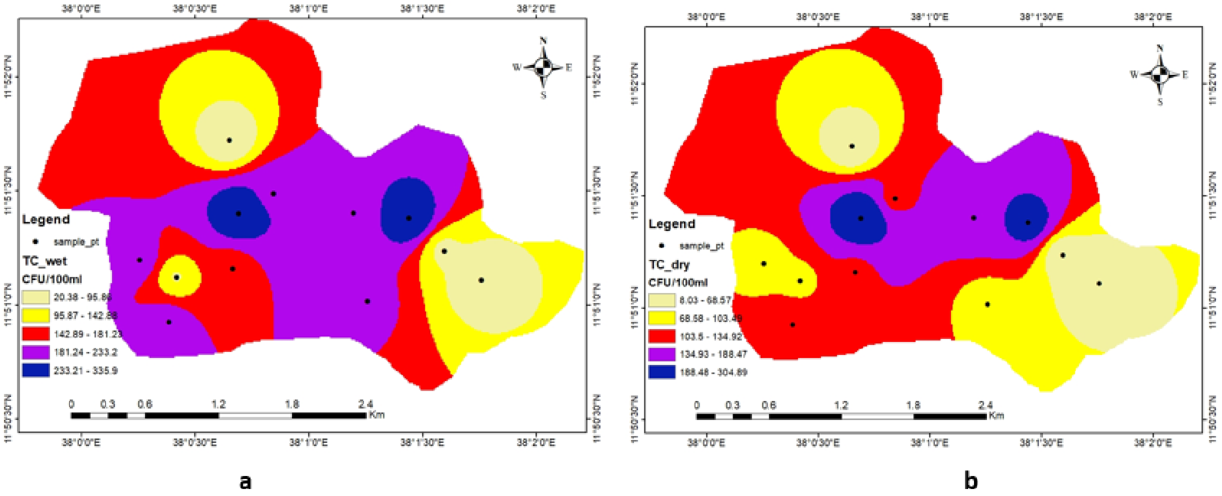


Figure 21

Spatial distribution map of total coliform (a) Dry Season and (b) Wet Season

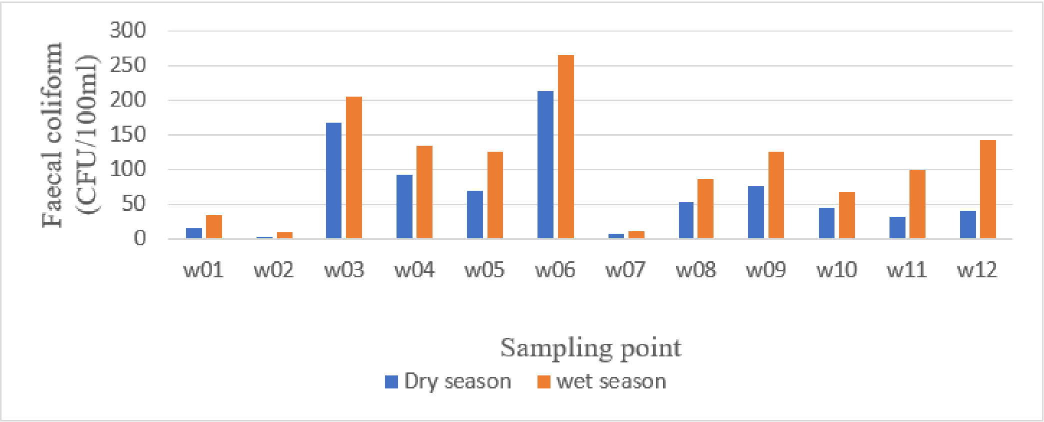


Figure 22

Temporal and Spatial variation of faecal coliform

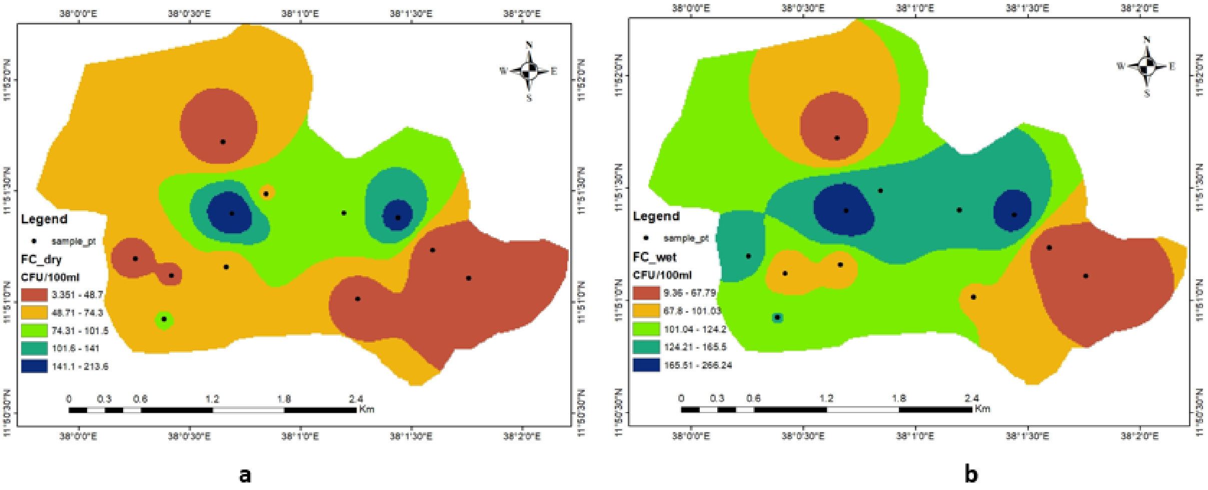


Figure 23

Spatial distribution map of faecal coliform (a) Dry Season and (b) Wet Season

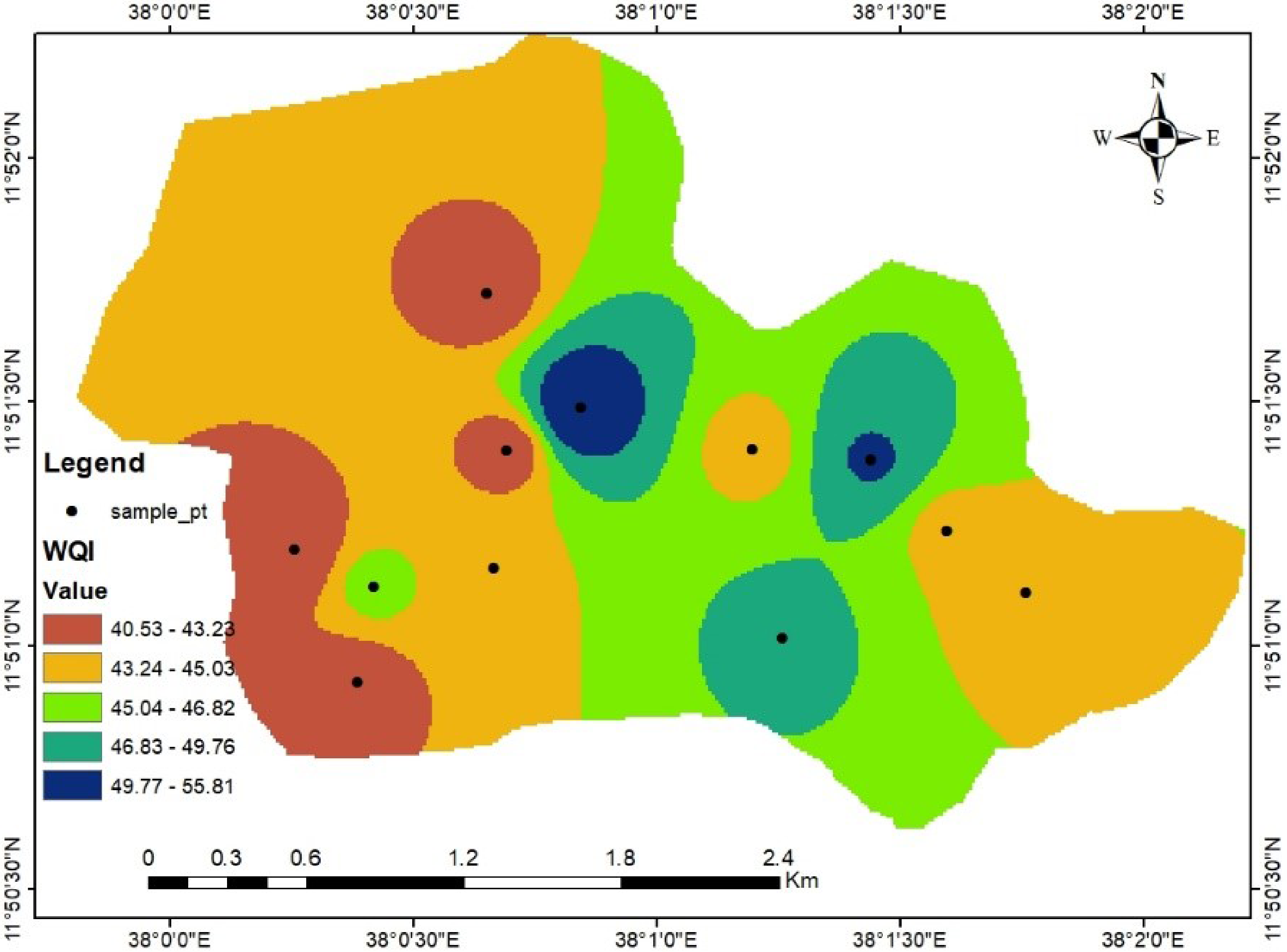


Figure 24

Spatial distribution map of WQI