A SPATIAL STUDY OF GROUNDWATER QUALITY PARAMETERS IN ILESA WEST LOCAL GOVERNMENT, OSUN STATE, NIGERIA - GIS APPROACH

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Abstract
The study assessed the different groundwater resources to understand the quality and to develop spatial distribution maps of water quality parameters in Ilesa west local government area (LGA), Osun State, Nigeria. A total of 63 household's hand- dug wells, 5 boreholes and a spring water were selected from the 10 wards of the LGA. These different water sources were sampled and analyzed for iron, pH, Total dissolved solids, electrical conductivity and basic cations/anions for a period of one year using the standard methods. The results of the analysis were input into an Excel sheet and was linked with the geographical coordinates of all the groundwater sources using the ArcGIS 10.1 software. The Inverse distant weighting interpolation technique of the Analyst tool of the software was used to generate the spatial maps of the different water quality parameters. The spatial distribution maps revealed that the South East region of the study area has concentrations of pH, TDS, hardness, bicarbonate, alkalinity, potassium, iron, TDS and EC that were higher than the Nigeria Industrial Standard recommended and acceptable values. The concentration of sulphate, magnesium and nitrate is low, and it varied significantly for the different months. The results obtained in this study and the spatial database established in GIS will be helpful for site suitability information, monitoring and management of the groundwater resources. The land-use pattern of the study area should also be re-evaluated and the residents should be enlightened on the adequate treatment needed to reduce the concentrations of parameters that were the above recommended values.

Keywords: Spatial variation, water quality, Inverse distance weighting, Geographic Information, Groundwater resources

Introduction
Groundwater is the most important natural resource used for drinking by many people around the world, especially in arid and semi-arid areas. The resource cannot be optimally used and sustained unless the quality of groundwater is assessed. The measurement of water quality is an important part of water resources management as it gives a detailed picture of the spatial and temporal distribution/variation of the quality of water and of the changes that take place, either under the control of a man or nature (Fadipe *et al.*, 2020). Groundwater been one the most important resource is the most widely used for domestic purposes in the world and it cannot be optimally used or sustained unless the quality is assessed. One of the factors that influenced the quality of groundwater has to do with of the media from which the water moves to the saturation zone of the groundwater (Adeyemi *et al.*, 2007).

The quality of groundwater is closely connected to other environmental components such as changes in atmospheric precipitation, urbanization, land-use, season, geology/geochemistry and other anthropogenic influences (Ocheri *et al.,* 2014). The physical characteristics of an aquifer, such as the location, sediment or rock type and thickness are significant factors in deciding if groundwater can be penetrated by pollutants from the land surface. In deep aquifers, pumping of groundwater can remove mineralized groundwater that is not ideal for drinking and can also draw salty seawater from coastal areas. In unconfined (water-table) aquifers, the possibility of pollution is higher than for enclosed aquifers since they are generally lower to the surface of the land and lack an overlying layer to hinder contaminant movement. When quality of groundwater is affected, it threatens human health. A lot of models have been developed for water quality assessment; GIS approach (water quality index, Hybrid Fuzzy GIS-based water quality index, regression models and Artificial Neural Network (ANN), matter element extension method (Jing ,2013, Fadipe *et al*., 2019, Fadipe *et al*., 2020, Jha, 2020, Fadipe *et al.,* 2021).

The use of GIS based models has proved to be a useful tool and has simplified the assessment of water resources including groundwater (Sadat-Noori, 2013). The different models are widely used in groundwater studies for site suitability assessments, site inventory data management, and spatial data integration of groundwater quality assessment models to build spatial decision support systems (Balakrishnan *et al.,* 2011). GIS is a computer system which can compile, store, manipulate and display geographically referenced data. It is not possible to assess groundwater quality at all locations, but when laboratory analysis is carried out on water samples taken from geo-referenced locations, Geo-statistics can make it possible to estimate values for places where no measurements have been taken and also to determine the uncertainty of these estimates. The spatial autocorrelation among measured points is quantified by geostatistical techniques and accounts for the spatial arrangement of the sample points around the prediction site. Interpolation techniques are classified into two major groups: deterministic and geostatistical.

Based on either the degree of similarity (inverse distance weight (IDW)) or the degree of smoothing, deterministic interpolation techniques produce surfaces from measured points (radial basis functions). When interpolating using IDW, a weight is assigned to the point to be determined the quantity of this weight depends on the point's distance from another unknown point. Using variables from a nearby weighted location, the IDW technique computes an average value for the unsampled location. On the bases of the power of ten, these weights are regulated (10). With a power increase of ten (10), the impact of the more distant points decreases. The lower power distributes the weights more equally between neighboring points. The distance between the points counts in this technique, so the points with equal distance have equal weights (Lu & Wong., 2008).

To assess the safety of water for drinking and as a preventive indicator of possible environmental health issues, a groundwater quality map is essential for any city. The study area is a non- piped borne water community for over 3 decades, and has depended on groundwater as a significant drinking water source; for every 10 houses, there are 8 to 9 private hand- dug wells. The aim of the study is to assess the groundwater resources for drinking water quality and to develop spatial maps that will be useful for boreholes/hand-dug wells site suitability information, monitoring and management of the sources.

Materials and Methods

Area of study

In this work, Ilesa West Local Government Area (LGA) in Osun State, Nigeria is the area of study (Figure 1). The coordinates are 07^0 36′ N and 004^0 40′E and 07^0 42′N and 004^0 46′E and it has a total area of 63 km^2. The study area has a humid tropical climate and an average annual rainfall of 1600 mm/year. There are two dominant seasons; the rainy season is from May to October, while November to April is the dry season. In the study area, two periods of elevated temperatures are recorded annually. The first period is between March and April, and the second period is between November and December.

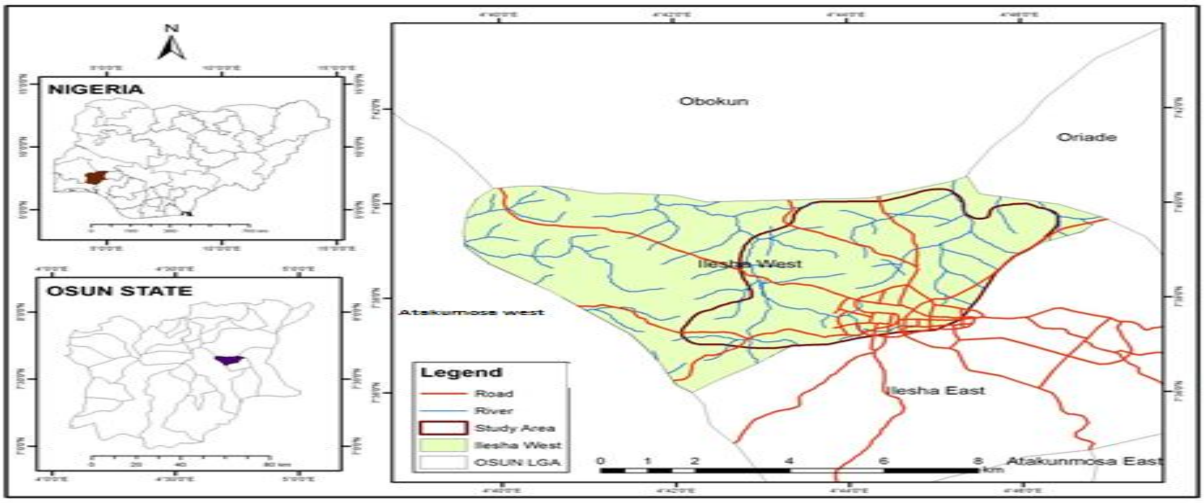


Figure 1: Map of the Nigeria, Osun State and the Study area

Data Requirements for the Research

The data set required for the study is spatial and non-spatial. The spatial data set is obtained using the various maps obtained from different authorities and google map. The administrative and Google map of the study area were used to identify the various streets. A field study was then conducted to obtain the GPS points (using the hand-held GARMIN GPS device) of the different groundwater resources. These points were imported into a gridded map using the fishnet of the ArcGIS 10.1. The final selection of the water sources map was based on the position of the sources on the grids (sources at the centres of each grid were picked for fair representation of the study area). The point features of each water source (dug wells, boreholes and spring) were made the spatial data used to develop the location study area map (Figure 2). A total number of 66

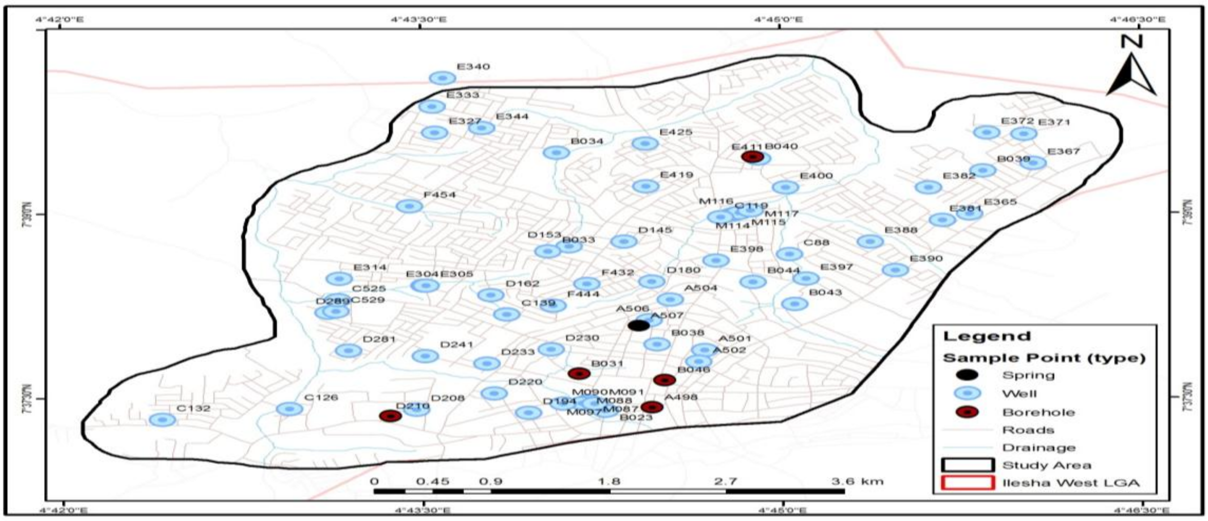


Figure 2: Map of the Different Water points

households water sources (hand-dug wells and boreholes), 2 community/public boreholes and one public spring water were finally used as sampling locations for the groundwater quality evaluation. The non-spatial data was obtained by collecting and analyzing groundwater samples from each of groundwater sources.

Geology and hydrogeology

The study area is within the basement complex of Nigeria crystalline rocks. It is under-lained by crystalline metamorphic rocks, mainly biotite gneiss, schist and amphibolites complex (Malomo *et al.,* 1990). The biotite gneiss is a medium-grained rock, rich in biotite along with quartz, feldspars, hornblende. The major elements of amphibolite in Ilesa basement complex are SiO (49%), Alumina (15%), iron (11%), Mg (10%) and Ca0 (12%). Na_2O is higher than K_2O in the amphibolite rock but Na_2O concentration is less than K_2O in the biotite granite gneiss (Oyinloye, 2011). Hydro-geologically, the groundwater phenomenon is in confined weathered regolith aquifers, which are generally sporadic and basically under phreatic restricted to semi-restricted state (Tijani, 1994). The geological map is presented in Figure 3.

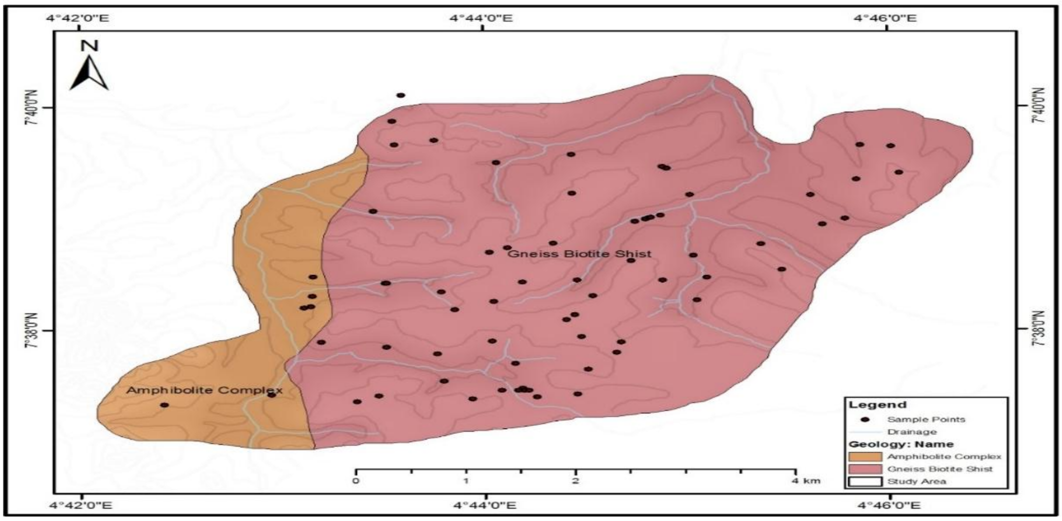


Figure 3: Geological Map of the Study area

Drainage

The drainage patterns identified in Ilesa town are dendritic, parallel and trellis; thus revealing that the underlain rock is extremely weathered and fractured. Hydrologically, the groundwater occurs in localized weathered regolith aquifer which is generally sporadic and basically under phreatic restricted to semi-restricted state as in the example of the majority crystalline basement bedrock in Nigeria (Tijani, 1994). The closeness of groundwater sources to drainage pattern is shown in Figure 4.

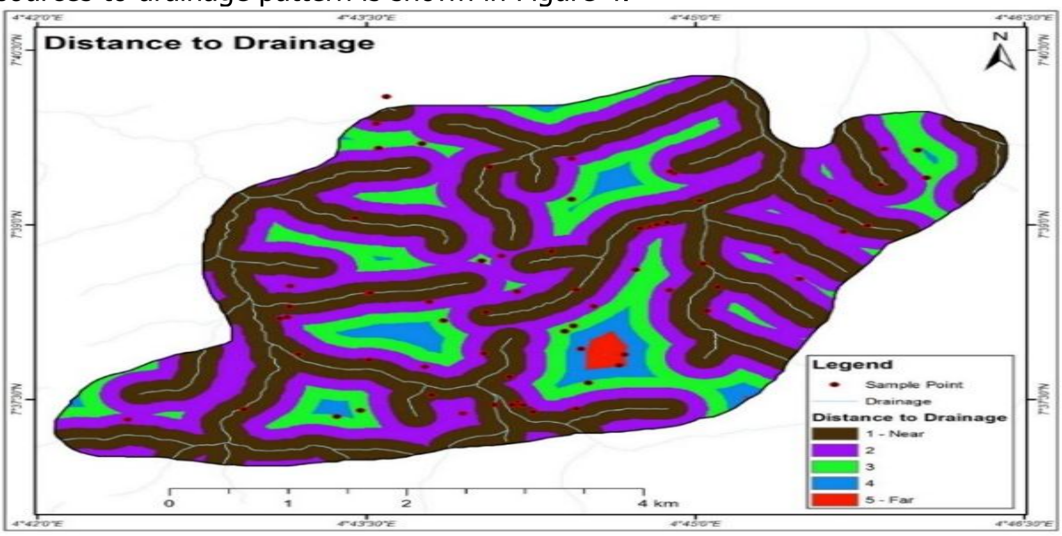


Figure 4: Map of distance of groundwater sources to drainage of the study area

Soil

The soils found within the area of research are in-situ weathering products. Typically, those formed on amphibolites are highly rich in cemented gravels and are dark brown. As a result of the presence of hematite and magmatite released during the weathering of the amphibolites to form the overburden soil, the overburden soil is strikingly red (Oyinloye, 2011). On biotite gneiss, light yellowish-brown to reddish-brown soils are formed and have very little cemented gravel (Malomo *et al.,* 1990). The soil map is shown in Figure 5.

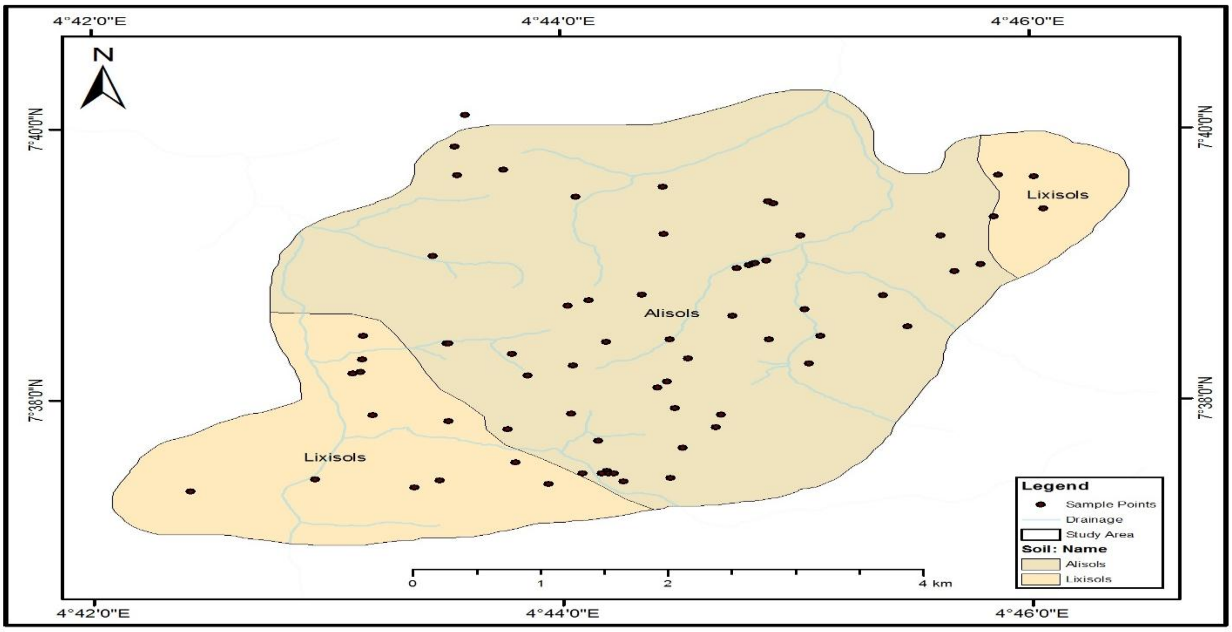


Figure 5: Soil Map of the Study area

Digital Elevation Model (DEM) and Land Use/ Landcover

The digital elevation model (DEM) map of the area of study is as shown in Figure 6. The land-cover/land-use distribution pattern (Figure 7) indicated the dominance of the built-up areas in the LGA. Within the built-up areas, groundwater sources were clustered around different household systems. Three class names were identified namely: vegetal cover, built up and cultivation as shown in Figure 7.

Groundwater Sampling

The groundwater sources were sampled for one year covering the rainy season and dry season. Water was sampled from taps connected to the modernized dug wells (dug wells with pumping machine and taps) and boreholes. Bucket and ropes were used to sample water from manual dug.

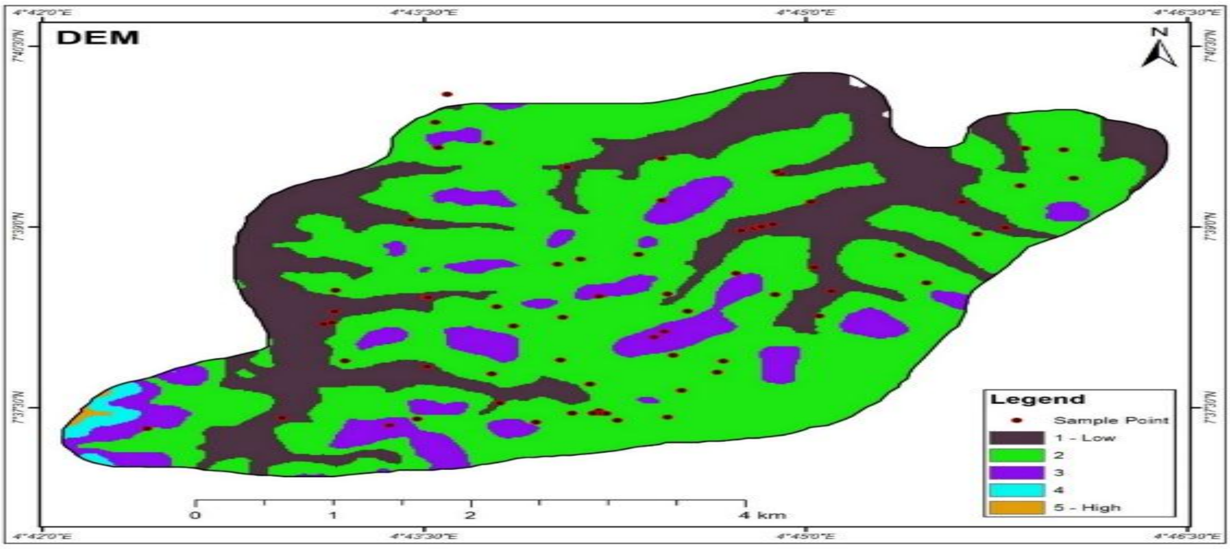


Figure 6: DEM Map of the Study Area

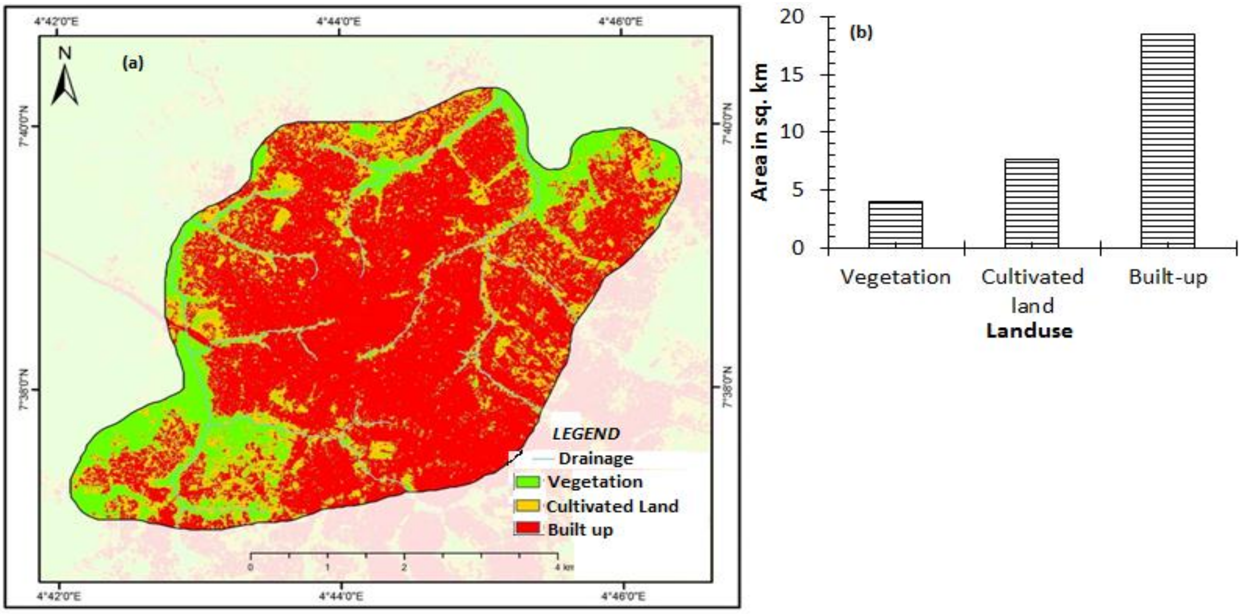


Figure 7: Land use/Land cover Map of the Study area

wells (hand- dug wells without taps and pumping machine installed). Prior to collection, 2.5 litres of white plastic bottles were washed, sterilized and rinsed with the sampled water; and a total of 414 water samples were collected within the period of assessment. Total dissolved solids (TDS), pH, temperature and electrical conductivity (EC) were all measured on-site using HANNA pH and TDS meter since they are very unstable parameters. Physicochemical parameters and heavy metals were analysed in the Zoology and Central Science Laboratory of Obafemi Awolowo University respectively. At the laboratory, the brucine method was used for the analysis of nitrate, the turbidimetric method was used for sulphate, the titrimetric method was used for chloride, calcium, magnesium, hardness, alkalinity, bicarbonate according to the standard method (APHA,2001). Instrumentation method was used for the analysis of the sodium, iron and potassium.

Geostatistical Analysis

The location points of the 69 groundwater sources obtained with the handheld GPS instrument (GARMIN 60) was imported to the ArcGIS 10.1 software environment using the

UTM Projection, Minna Zone 32, and they were converted to point features with each source having its own assigned identifier (ID). The groundwater quality data obtained forms the non- spatial database. It is stored in the excel sheet of the Microsoft word and linked with the spatial data using the Join option of the ArcGIS. The spatial and non-spatial database formed are then integrated to generate the different spatial maps. The inverse distant weighting interpolation technique was used for the spatial interpolation.

To evaluate the value of B at an unsampled location j, IDW equation was used as shown in equation 1.

$$\widehat{B_J} = \frac{\sum i\, Bi \;\Big/ {d_{i\,j}}^{r}}{\sum i\, 1 \;\Big/ {d_{i,j}}^{r}}$$

1

$\widehat{B_J}$ shows that variable B is estimated at j

r = the weight parameter that is applied as an exponent to the distance (i.e) amplifying the irrelevance of a point at the location I as distance to j increases

Results and Discussion

The descriptive analysis of all the parameters is presented in Table 1. The mean pH is 5.63; this is lower than the 6.5-8.5 recommended by WHO (2004). Figure 8 show the spatial distribution of the pH and it revealed that the variation in pH in the study area is high but seems to be more alkaline in the South-East of the study area.

Table 1. Descriptive statistics of physicochemical parameters

Parameters	**Mean**	**Min**	**Max**	**Std.Error**
pH (no unit)	5.63	4.1	7.4	0.04
TDS (mg/L)	175.24	8.40	1022.00	10.21
EC (µS/cm)	282.57	12.34	1625.00	17.09
Cl (mg/L)	29.90	1.40	212.70	1.933
SO_4 (mg/L)	11.41	1.28	33.76	0.45
NO_3 (mg/L)	1.42	0.07	24.22	0.09
Ca (mg/L)	18.36	1.66	132.29	1.01
Mg (mg/L)	1.83	0.00	7.35	0.09
Total Hardness(mg/L)	54.37	6.50	330.15	2.54
Alkalinity (mg/L)	46.53	4.00	260.00	2.54
HCO3 (mg/L)	55.83	4.80	312.00	3.05
Na (mg/L)	23.19	0.98	107.50	1.19
K (mg/L)	16.33	0.02	176.01	1.39
Iron	1.34	0.00	9.25	0.15

Naturally, groundwater contains dissolved substances that can change the chemistry. Depending on the composition of the rocks and sediments surrounding the travel route of the recharge water infiltrating the groundwater, the pH of the groundwater will differ. Also, when the groundwater is in contact with a specific rock for a long time, groundwater chemistry can also differ. The longer the time of contact, the more the effect of the rock chemistry on the groundwater pH and composition. The geology (Figure 3) of the study area revealed a gneiss in some parts; the groundwater would appear to remain acidic if the geology of the aquifer containing the groundwater has little carbonate rocks (e.g., sandstones, metamorphic granitic schists and gneisses, etc) . The result of this study agreed with reports of Malomo *et al*. (1990) and Fadipe *et al*., (2019). However, the land use pattern of the area should also be investigated.

The mean TDS is 175.3 mg/L but the maximum concentration (1022 mg/L) in some water samples is alarming; it is higher than the 500mg/L recommended by NIS (2007). The spatial map (Figure 9) shows that the TDS concentration increases towards the South East. Fadipe *et al*. (2019) reported that the major dumpsite in the study area is located around the South East region, thus, the land use pattern may have influence on the TDS value. The TDS of a water sample represents the total concentration of dissolved substances in the water; these dissolved substances are made up of inorganic salts and a small amount of organic matter. The most common inorganic salts are chlorides, sodium, potassium, calcium, magnesium, nitrates, sulfates, carbonates and bicarbonates. This is particularly true when excessive dissolved solids, by runoff and wastewater discharges, are added to the water as human contamination. The basic measures of the overall mineral content of water are electrical conductivity and total dissolved solids, which may be related to issues such as corrosive properties, excessive hardness or other mineral contamination (Anilkumar *et al.,* 2015). Heart complications, high blood pressure and kidney dysfunction are some of the detrimental environmental consequences of high salt concentrations (Scheelbeek *et al*., 2016). The EC spatial distribution (Figure 10) shows high concentration around the South-East region of the research area suggesting a link between the pH, TDS and EC. The mean concentration (29.90 mg/L) of chloride is below 250 mg/L maximum limits. The spatial variation (Figure 11) revealed higher concentration towards the South-East region of the area of study. The natural source of chloride is sedimentary rock (evaporites) and a little from igneous rocks; it is usually < 10 mg/l in humid areas.

The spatial variation of nitrate and sulphate (Figures 12 and 13) is entirely different. The distribution is not concentrated in the south-east region of the study area. Sulphate is a common constituent of water; sulphur originates generally in groundwater and wastewater in the oxidized form of sulphate and the reduced form of sulphite. High nitrate content in drinking water decreases the capacity of the blood to retain oxygen, which can lead to a condition called blue baby or methemoglobinemia (APHA,2001). The maximum concentration of Hardness is more than the recommended 150 mg/L (NIS, 2007). The spatial distribution (Figure 14) reveals higher values of hardness in the South East region. Hardness concentrations above 200 mg/L have no associated adverse health-related effects on humans; only the concentrations of Ca and Mg ions are reflected. The natural sources of calcium and magnesium are limestone and dolomite respectively. The spatial distribution of Calcium (Figure 15) is similar to that of Hardness but that of magnesium (Figure 16), (highest concentration is 10.8 mg/L) is entirely different. This implies that calcium is contributing more to the hardness of the area.

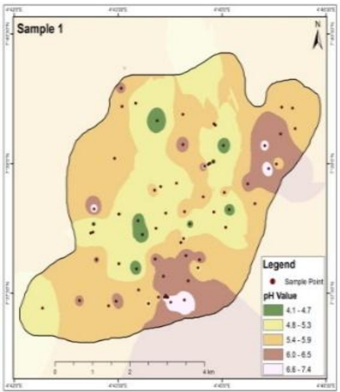
When carbon dioxide is present, calcium compounds are stable in water, but when calcium carbonate precipitates due to increased water temperature, photosynthetic activity or loss of carbon dioxide due to pressure increase, calcium concentrations can decrease. In natural waters, calcium concentrations typically less than 15 mg/L. On the other hand, concentrations may reach 30-100 mg/L for waters associated with carbonate-rich rocks. An increased risk of kidney stones can be one potential adverse effect of ingesting large concentrations of Ca over long periods (Scheelbeek *et al*., 2016). Two types of hardness exist; temporary hardness caused by carbonates and bicarbonates; and permanent hardness caused by sulfates and chlorides. By boiling, temporary hardness is eliminated, but after boiling, permanent hardness is maintained (DeZuane, 2017). Soft waters with hardness less than 100 mg/L are more corrosive for water pipes because of their low buffer capacity. Areas with higher hardness in drinking water are associated with lower heart attack incidents (Environmental Fact Sheet, 2008). Increased incidence of prenatal mortality, anencephalia, urolithiasis, cardiovascular disorders and certain forms of cancer can result from long-term consumption of extremely hard water (Sengupta, 2013). The presence of hardness will disallow water from forming lathe with soap, increase the boiling point of the water thereby preventing economic management of water resources. The spatial variation of alkalinity (Figure 17) reveals higher concentration towards the South-East region of the study area. No permissible limit of alkalinity has been set by NIS (2007) but the United State Environmental Protection Agency (USEPA) set a limit of 120 mg/L (Adamou *et al.,* 2020). Total alkalinity is due to hydroxides and carbonates of magnesium, calcium, bicarbonates, potassium and or a mixture of the two ions in water but high levels of alkalinity in water can be from industrial or chemical pollution. To determine the amount of lime and soda required for water softening, it is important to measure the alkalinity content in any drinking water. Also, alkalinity provides a buffering action and it maintains the pH of water in case there is an infiltration of runoff. The alkalinity in the research area may be a result of the underlying geology. The spatial variation of bicarbonate (Figure 18) shows the maximum concentration (312 mg/L) towards the South East region of the study area. The acceptable concentration of bicarbonate in drinking water is less than 120 mg/L (Adamou *et al.,* 2020). The natural sources of bicarbonate in groundwater are from dolomite and limestone and it is usually less than 500 mg/L. Bicarbonate is also derived from the dissolution of carbonates and silicates; and soil zone by carbon-dioxide. The rock itself contributes about half of the carbonate and bicarbonate found in carbonate rocks, but the bicarbonates and carbonates derive solely from the atmosphere and soil carbon dioxide in areas of non-carbonate rocks.

The spatial variation of sodium and potassium (Figures 19 and 20) reveal high concentration towards the South East region of the study area. The highest concentration (107 mg/L) of sodium is lower than the recommended levels of 200 mg/L of WHO and NIS (2007). One of the most common elements on earth is sodium, it occurs in water and many igneous rocks, thus, it is an essential component of most groundwater. The result agrees with study of Malomo *et al.* (1990). There is a large variation in Na and K concentrations between the different water sources but the trend of sources having higher concentration is constant.

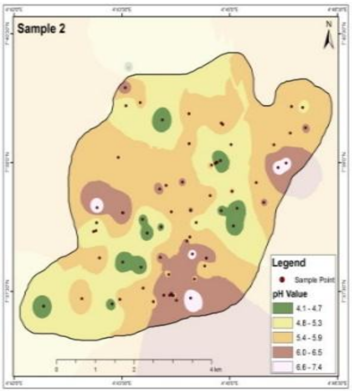
The natural sources of potassium are feldspathoids, feldspars (microcline, orthoclase), clay minerals and some micas; and the concentration is usually less than 10 mg/L. The maximum desirable of potassium is 100 mg/L (WHO, 1997) but the maximum allowed limits by NAFDAC is 10 mg/L (Ufoegbune *et al.,* 2007); the permitted concentrations in the United Kingdom is 12 mg/L (Saleem *et al.*, 2012). People in high-risk groups (i.e. people with kidney failure or other disorders, such as cardiac disease, coronary artery disease, hypertension, diabetes, adrenal insufficiency, pre-existing hyperkaliemia; people taking drugs that interfere with normal potassium-dependent functions in the body; and older individuals or infants) are connected to the health consequences associated with high potassium intake in drinking water. Excessive potassium in the sample of drinking water can contribute to nervous and digestive disorders (Tiwari, 2001). The highest concentrations obtained in this study agreed with values of Malomo *et al.* (1990) and this suggests that the concentration of the cations has not changed over time. The spatial variation of iron (Figure 21) is different from the cations and anions. The variation is high and not particular to any part of the study area. The highest concentration (9.25 mg/L) is more than the maximum permitted of 0.3 mg/L of NIS (2007). The natural sources of iron in water are from igneous rocks: Fe_2O_4, FeS, FeS_2, ferromagnesian, amphiboles, micas, and magnetite; Sandstone rocks: oxides, carbonates, sulphides or clay minerals and the concentration is usually less than 0.5 mg/ L. Fully aerated groundwater with pH < 8 can contain 10 mg/L; infrequently, 50 mg/L may be present. Solubility increases in low pH (more acidic) groundwater. Excess levels in domestic water sources are related to clothing and utensil staining, blackening of food and bitter taste, while hemochromatosis, a genetic condition that causes diabetes, impotence and liver failure, is associated with a high concentration in the body (Andrews & Micheal*,* 2000).

Conclusion and Recommendation

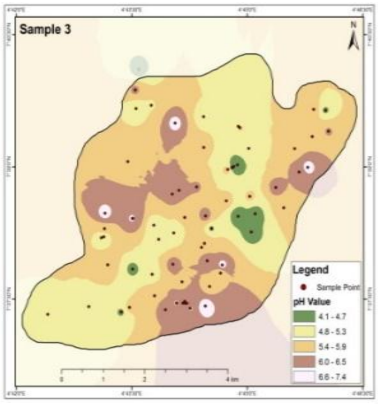
The spatial distribution maps reveal that the South East region of the study area has high concentrations of Hardness, bicarbonate, alkalinity, potassium, TDS, EC, Iron and pH. The concentrations varied for the different months but they were consistently higher for the South East. The concentrations of sulphate, magnesium and nitrate were below the NIS recommended values but their spatial distribution is not constant. The results obtained in this study and the spatial database established in GIS will be helpful for site suitability information, monitoring and management of the groundwater resources. It is recommended that the land-use pattern of the study area should be re-evaluated and the residents should be enlightened on the adequate treatment needed to reduce the concentrations of parameters above recommended values.



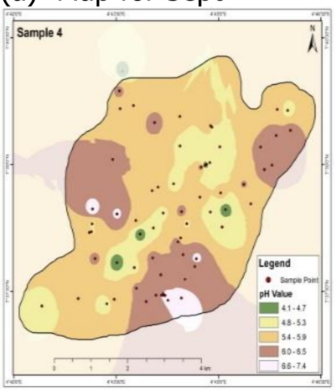
(a) Map for Sept



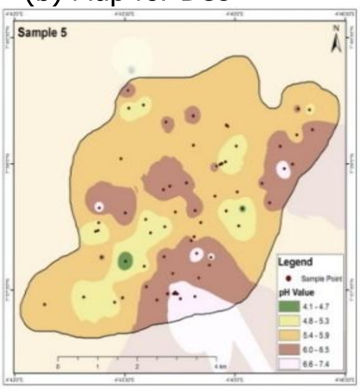
(b) Map for Dec



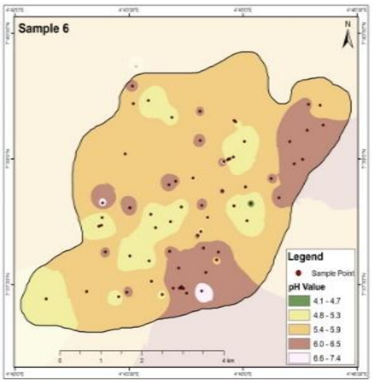
(c) Map for Feb



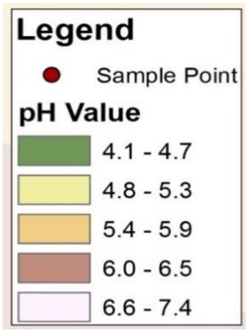
(d) Map for April



(e) Map for June

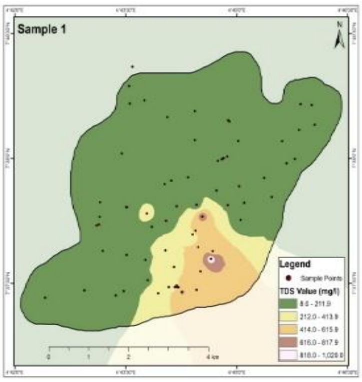


(f) Map for Aug

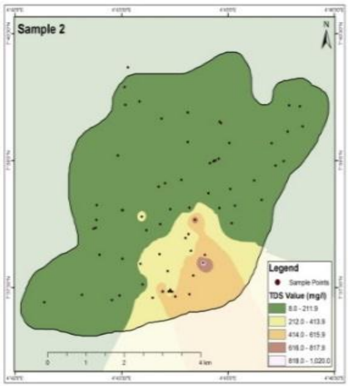


Legend for the 6 Maps

Figure 8: Spatial distribution of pH over the sampling periods



(a) Map for Sept



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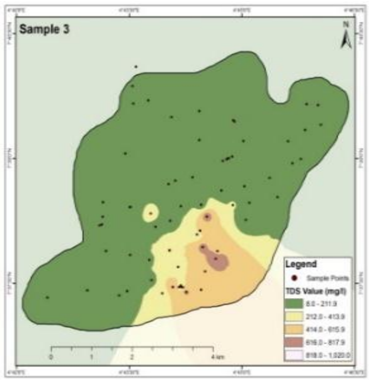
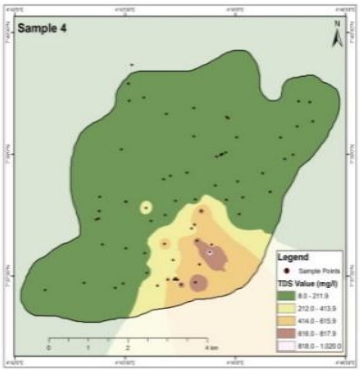
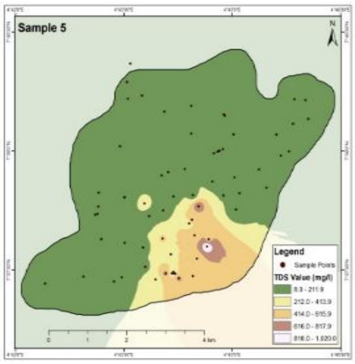


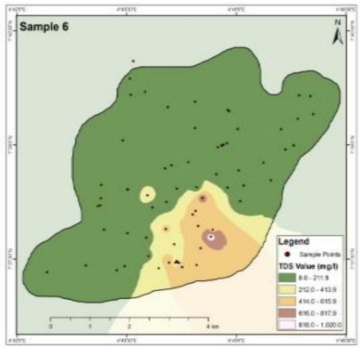
(c) Map for Feb



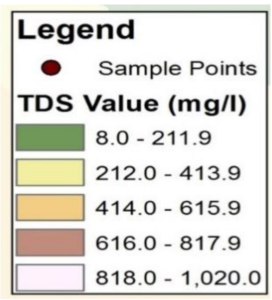
(d) Map for April



(e) Map for June

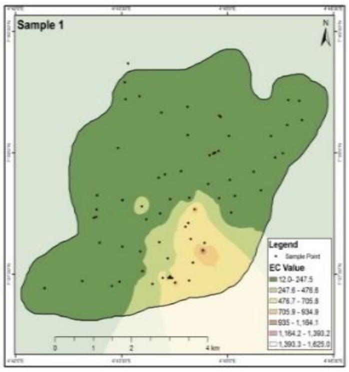


(f) Map for Aug

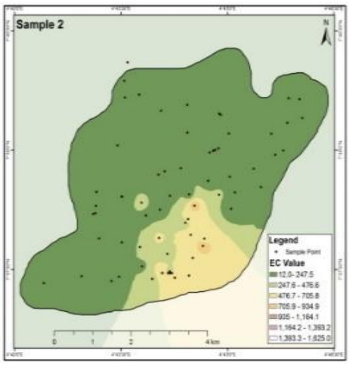


Legend for the 6 Maps

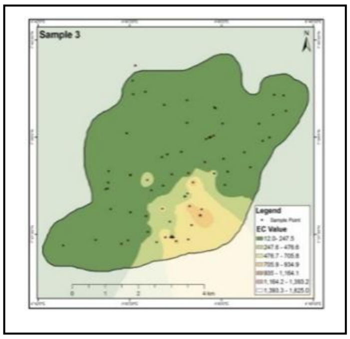
Figure 9: Spatial distribution of TDS over the sampling periods



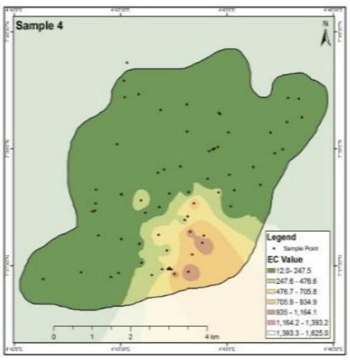
(a) Map for Sept



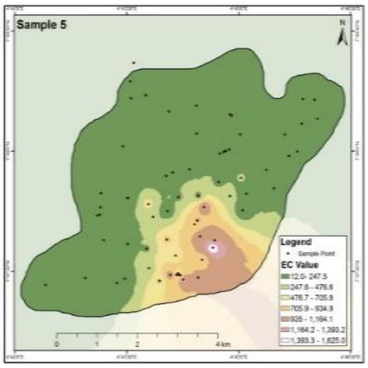
(b) Map for Dec



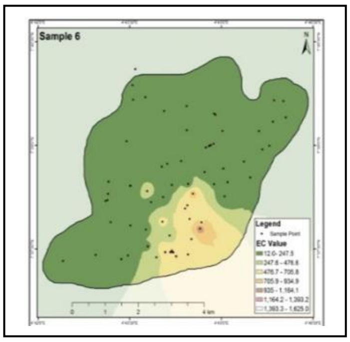
(c) Map for Feb



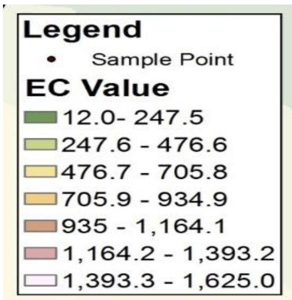
(d) Map for April



(e) Map for June



(f) Map for Aug



Legend for the 6 Maps

Figure 10: Spatial distribution of electrical conductivity (EC) over the sampling periods

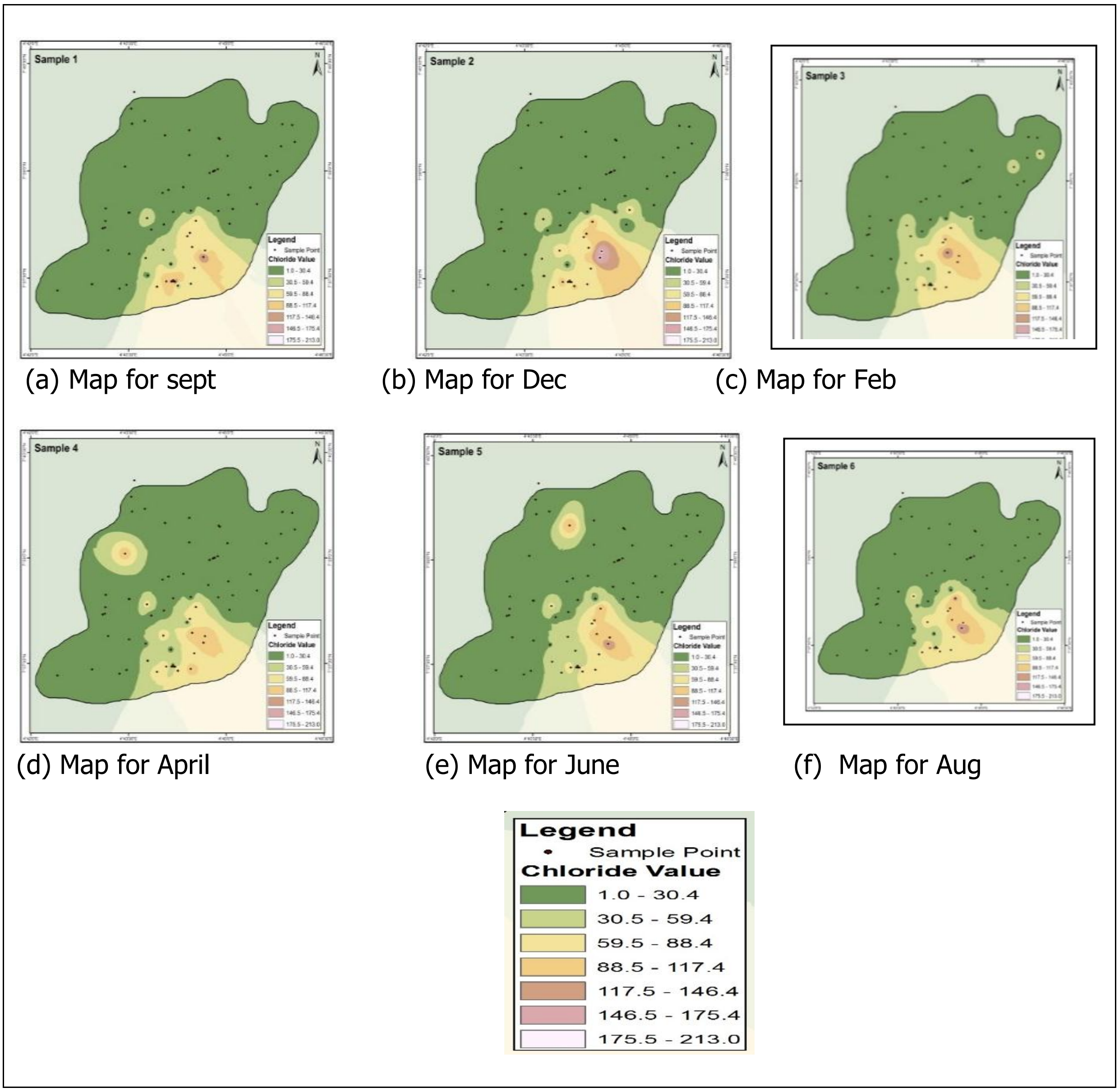
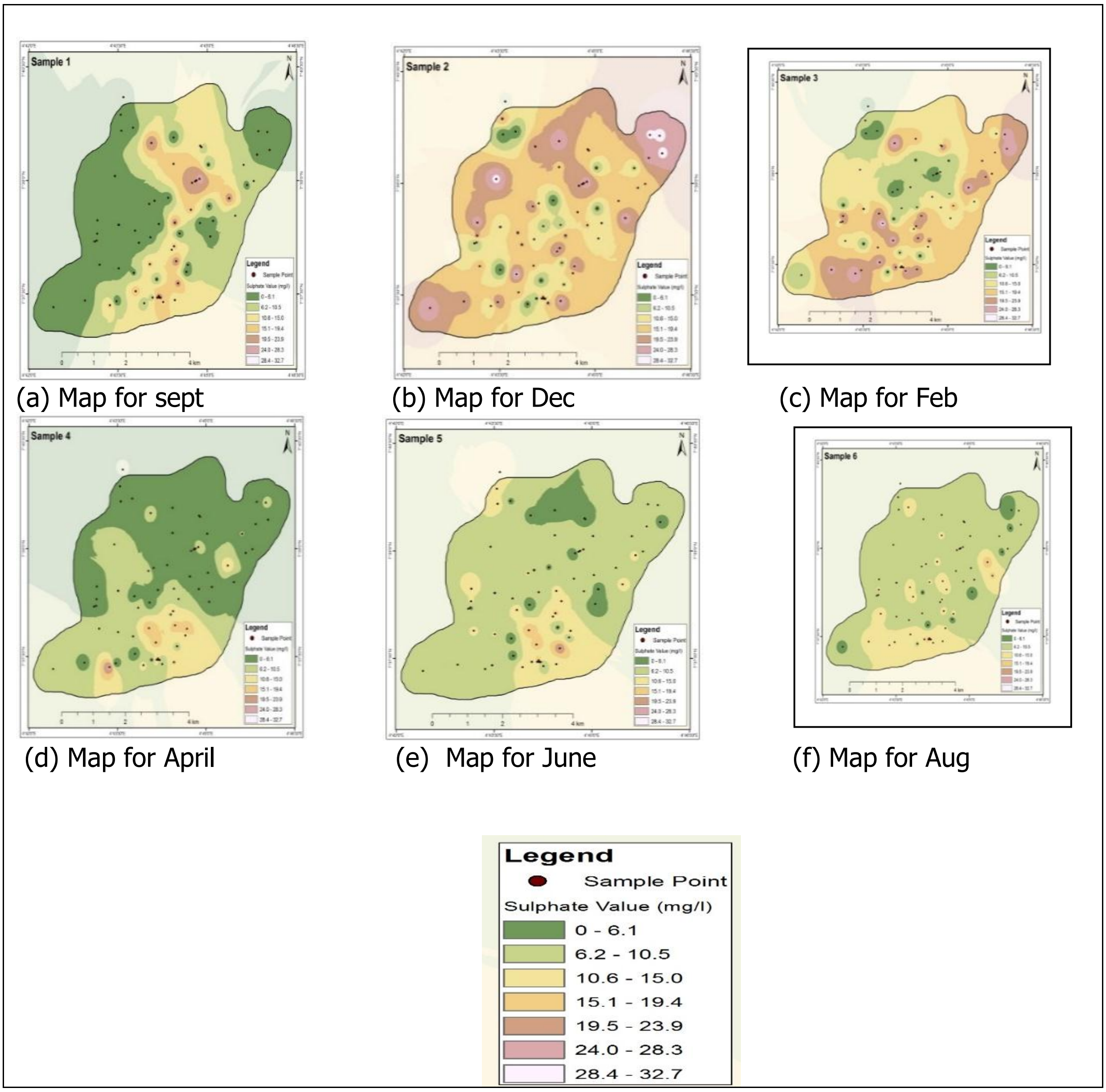


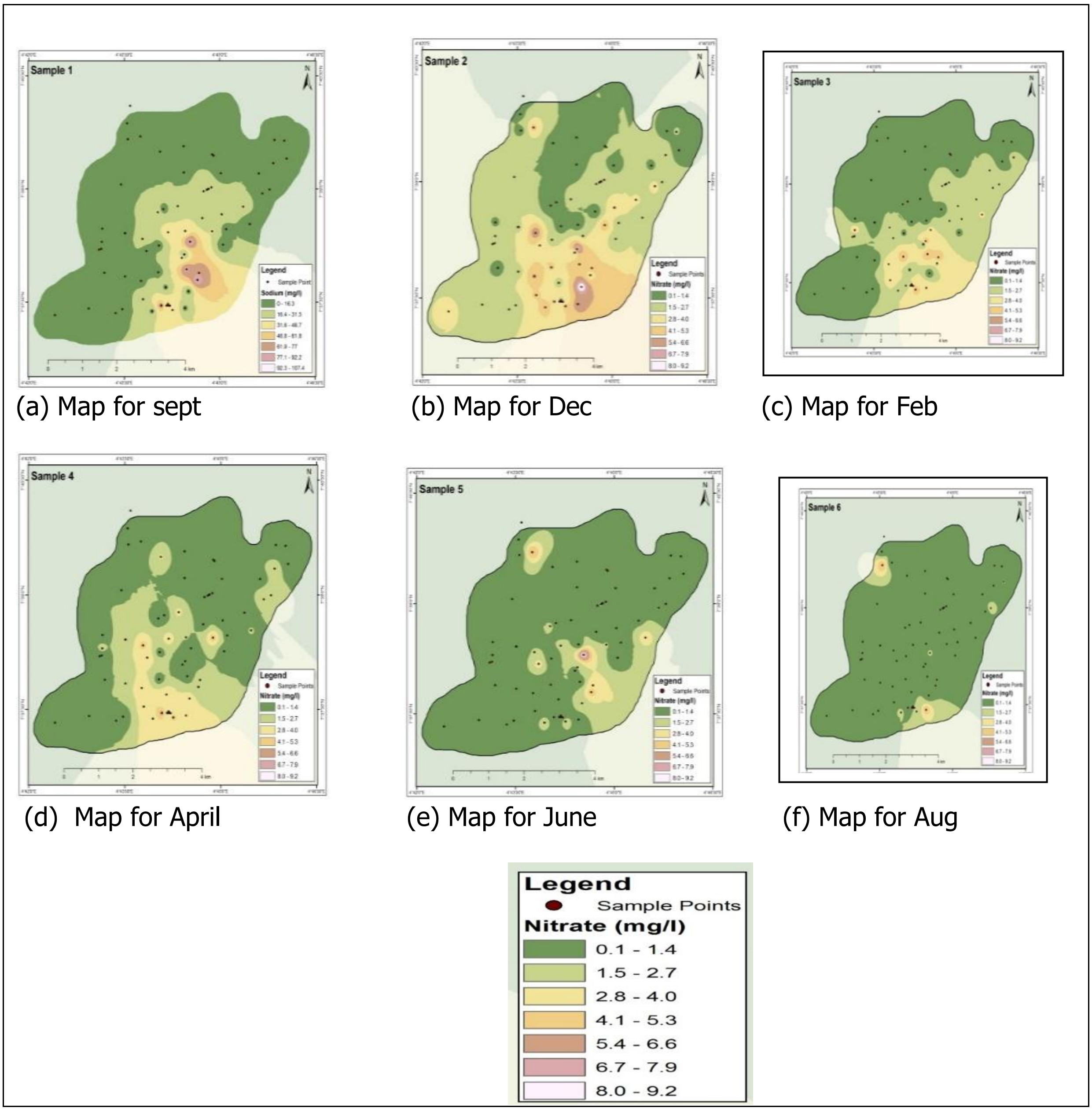
Figure 11: Spatial distribution of chloride over the sampling periods



(a) Map for sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

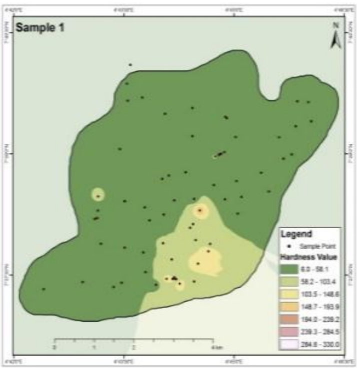
Figure 12: Spatial distribution of sulphate over the sampling periods



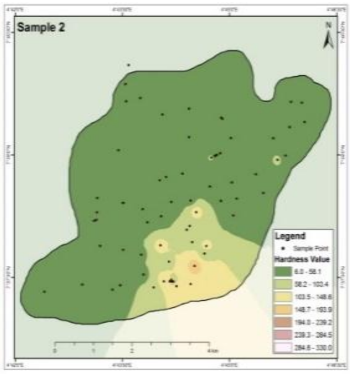
(a) Map for sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

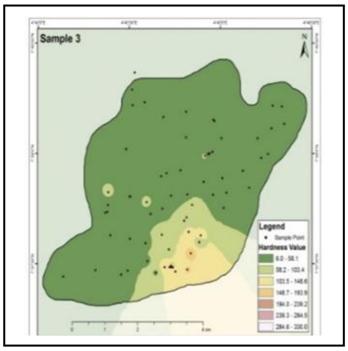
Figure 13: Spatial distribution of nitrate over the sampling periods



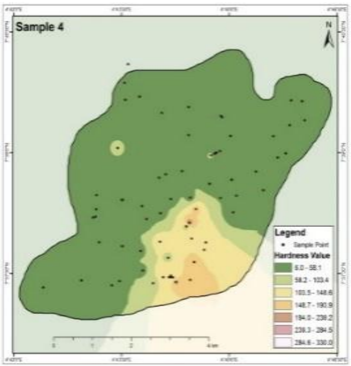
(a) Map for Sept



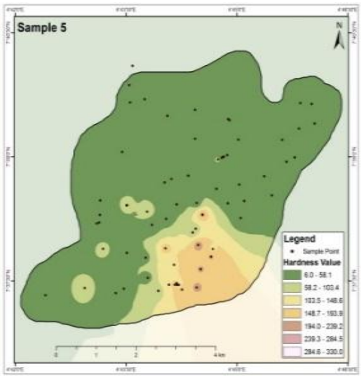
(b) Map for Dec



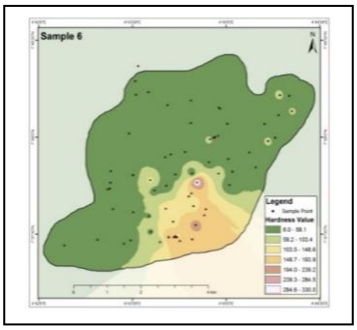
(c) Map for Feb



(d) Map for April



(e) Map for June



(f) Map for Aug

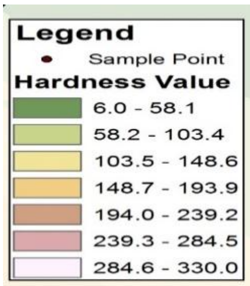
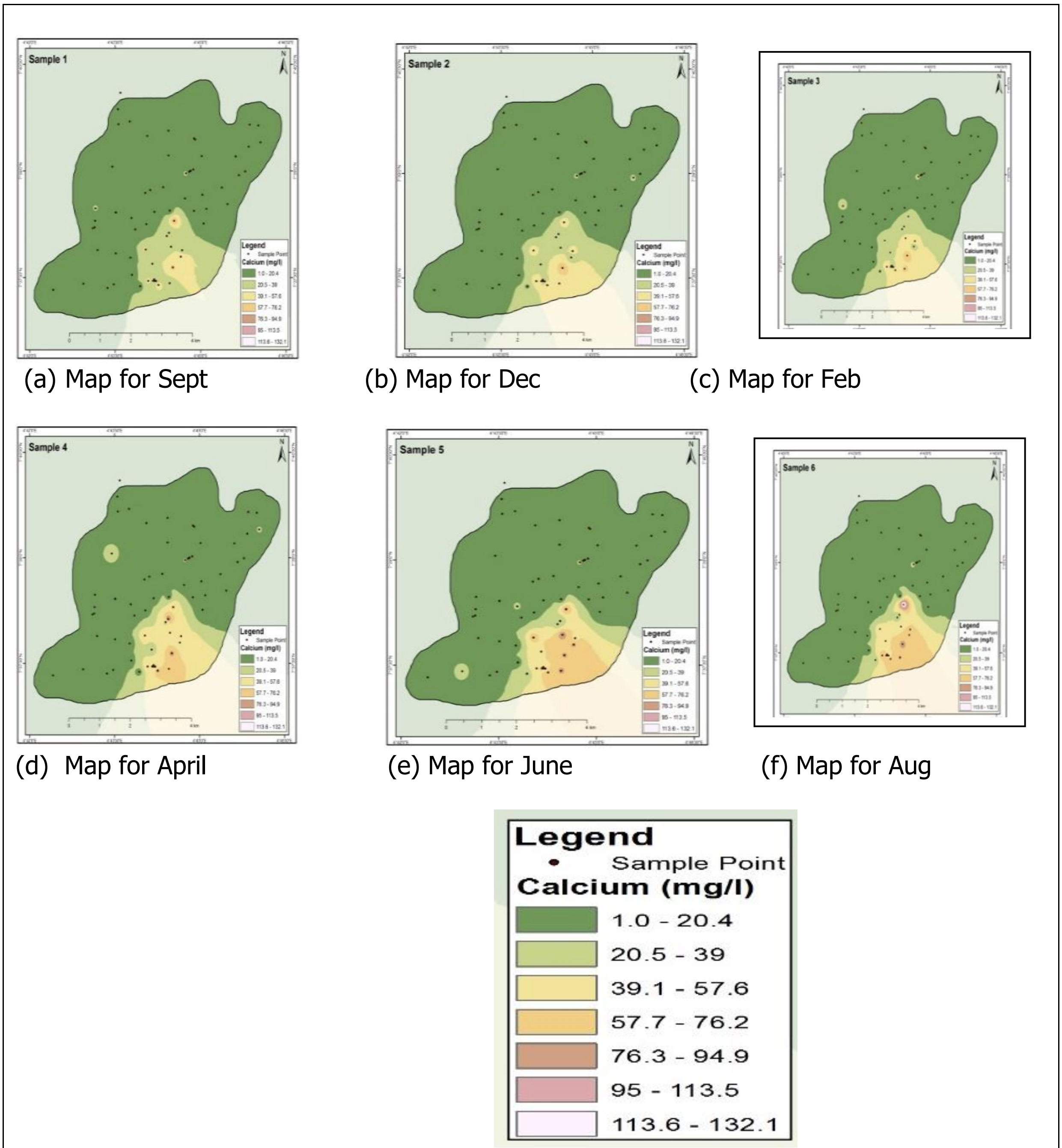


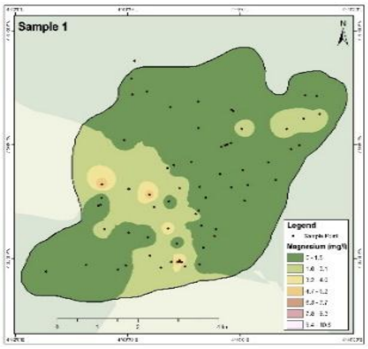
Figure 14: Spatial distribution of hardness over the sampling periods



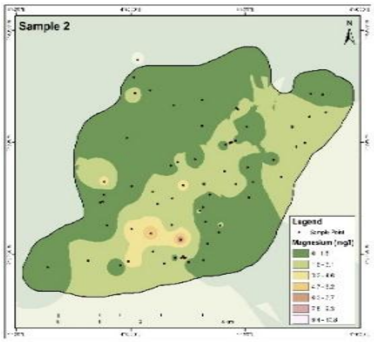
(a) Map for Sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

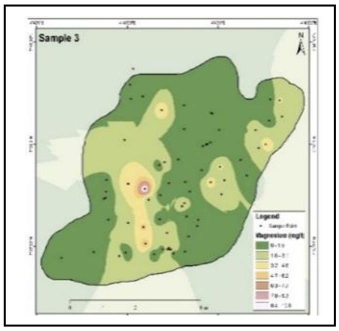
Figure 15: Spatial distribution of calcium over the sampling periods



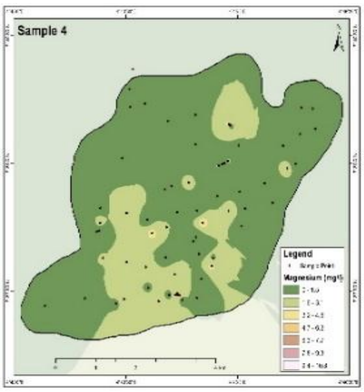
(a) Map for Sept



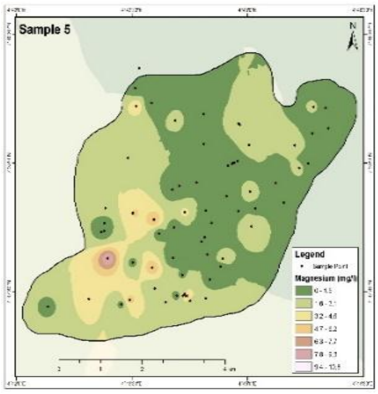
(b) Map for Dec



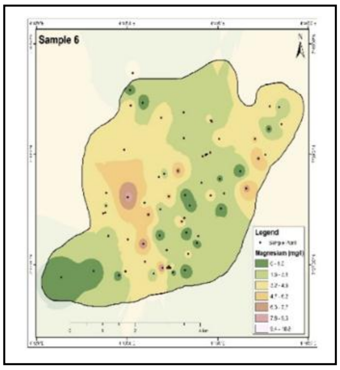
(c) Map for Feb



(d) Map for April



(e) Map of June



(f) Map for Aug

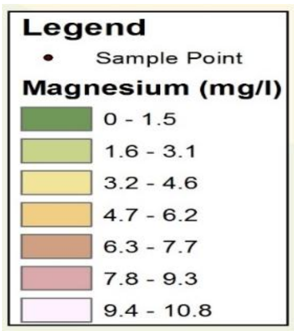
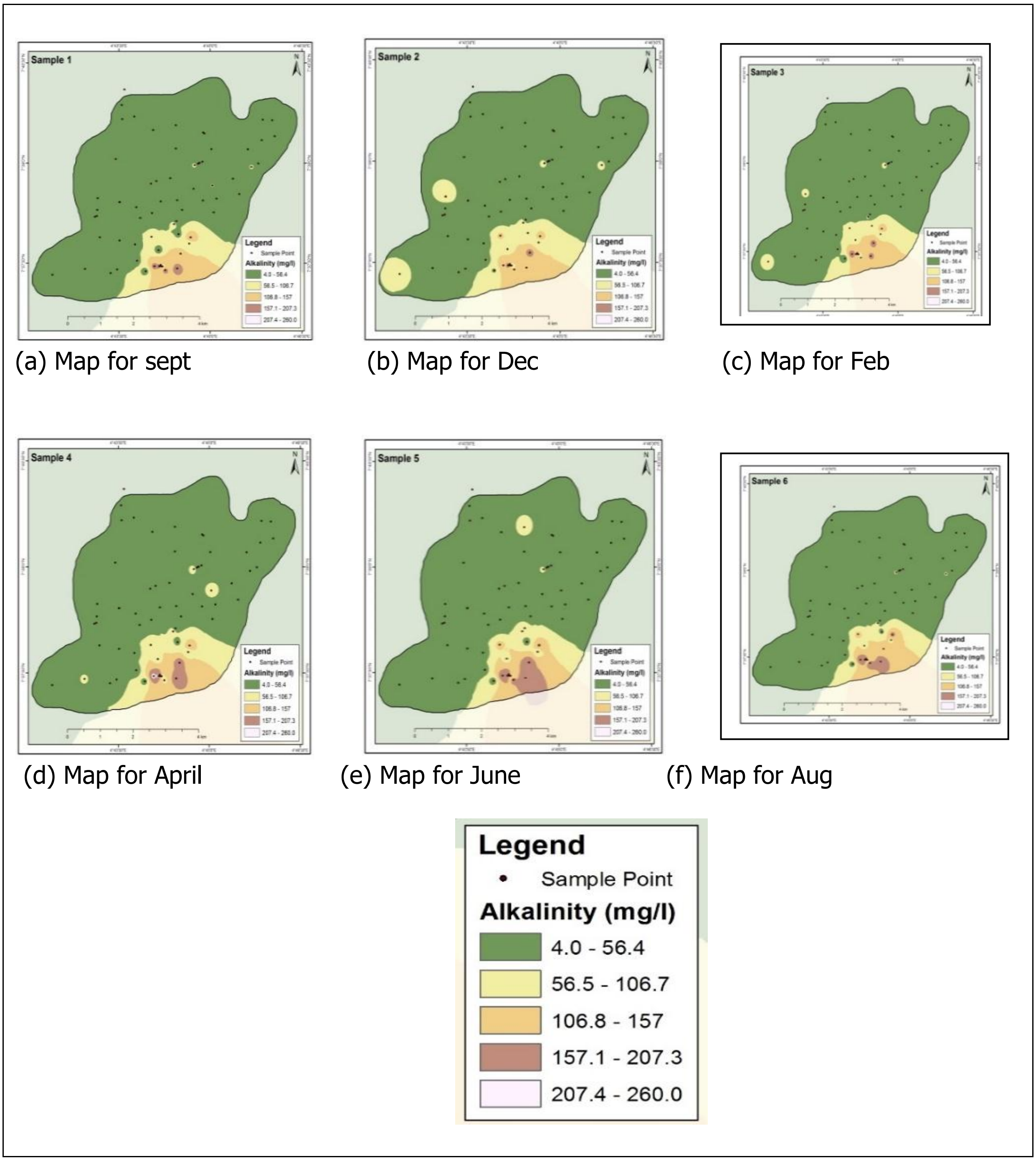


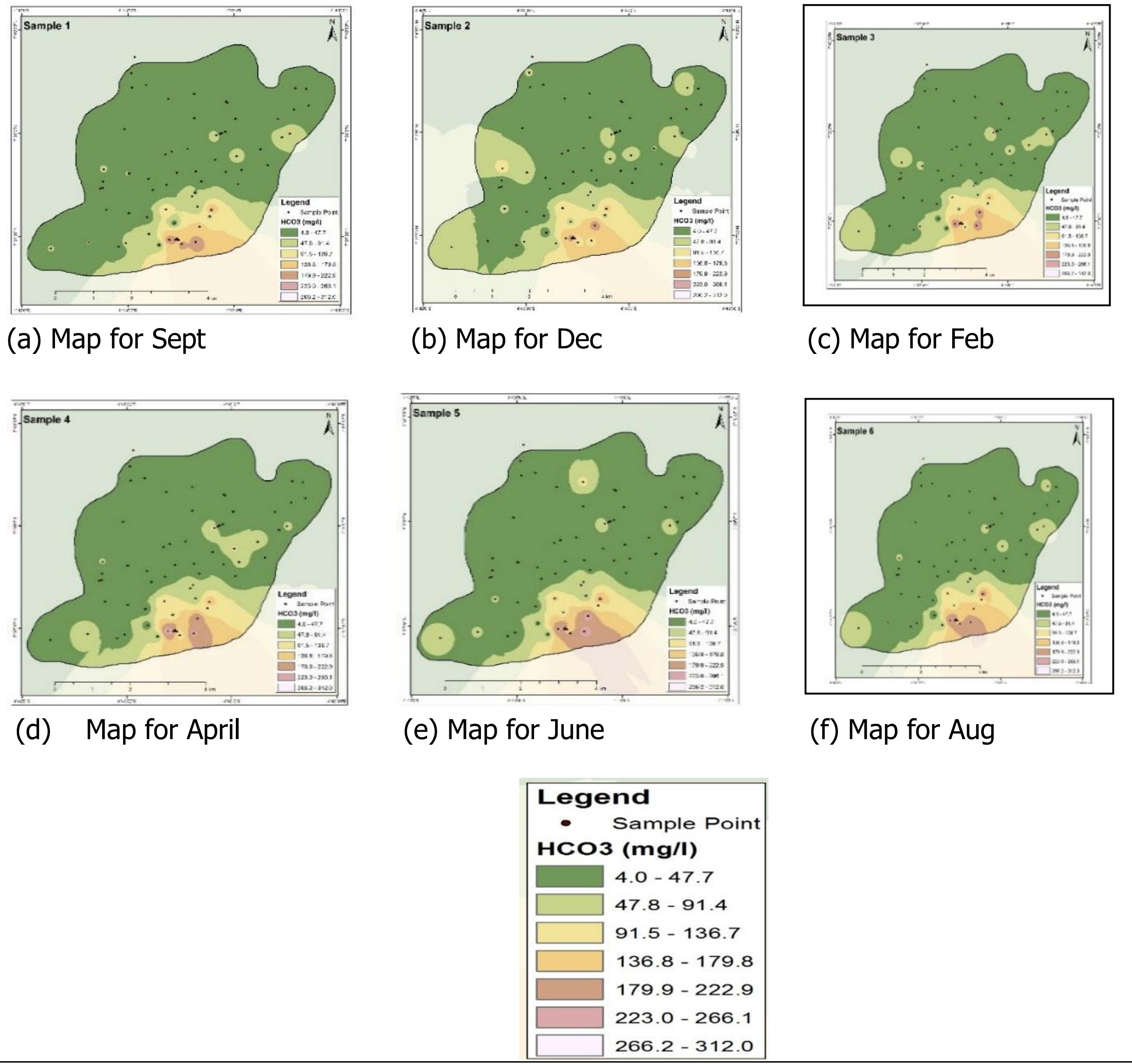
Figure 16: Spatial distribution of Magnesium over the sampling periods



(a) Map for sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

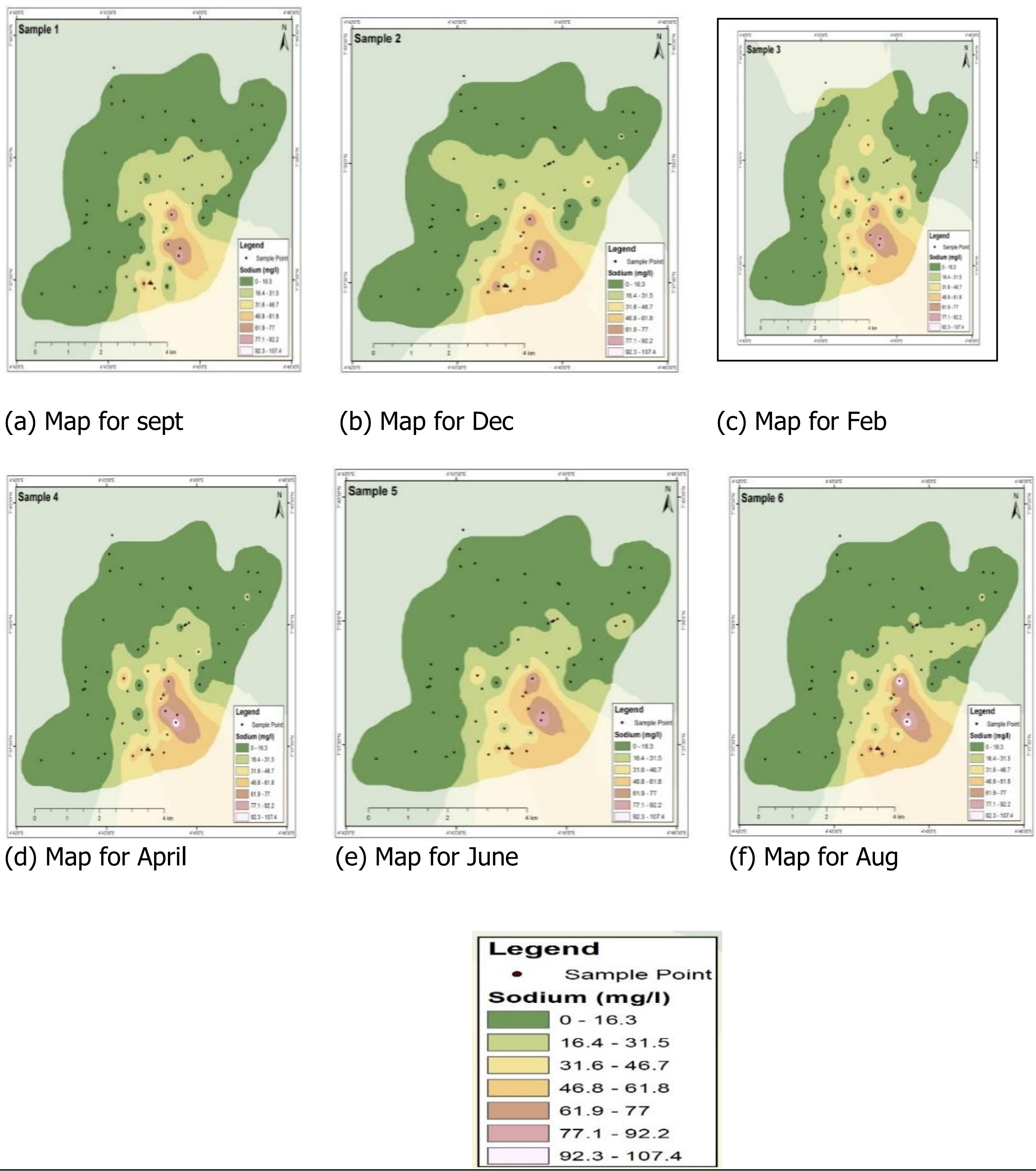
Figure 17: Spatial distribution of alkalinity over the sampling periods



(a) Map for Sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

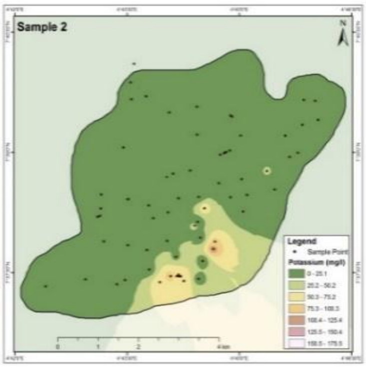
Figure 18: Spatial distribution of Bicarbonate over the sampling periods



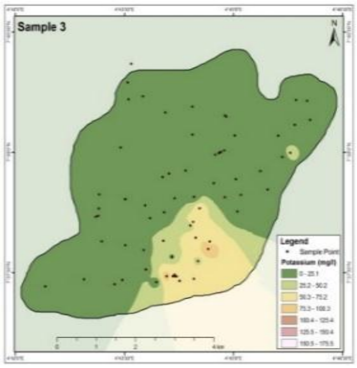
(a) Map for sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

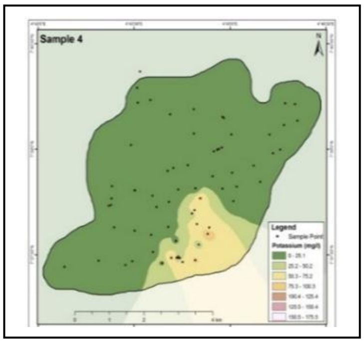
Figure 19: Spatial distribution of sodium over the sampling periods



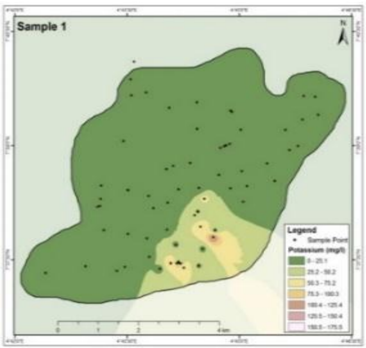
(a) Map for sept



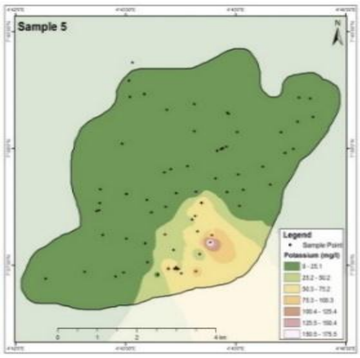
(b) map for Dec



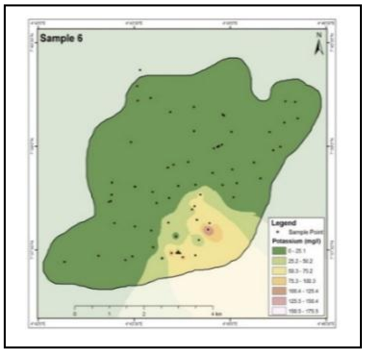
(c) Map for Feb



(d) Map for April



(e) Map for June



(f) Map for Aug

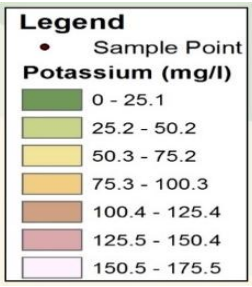
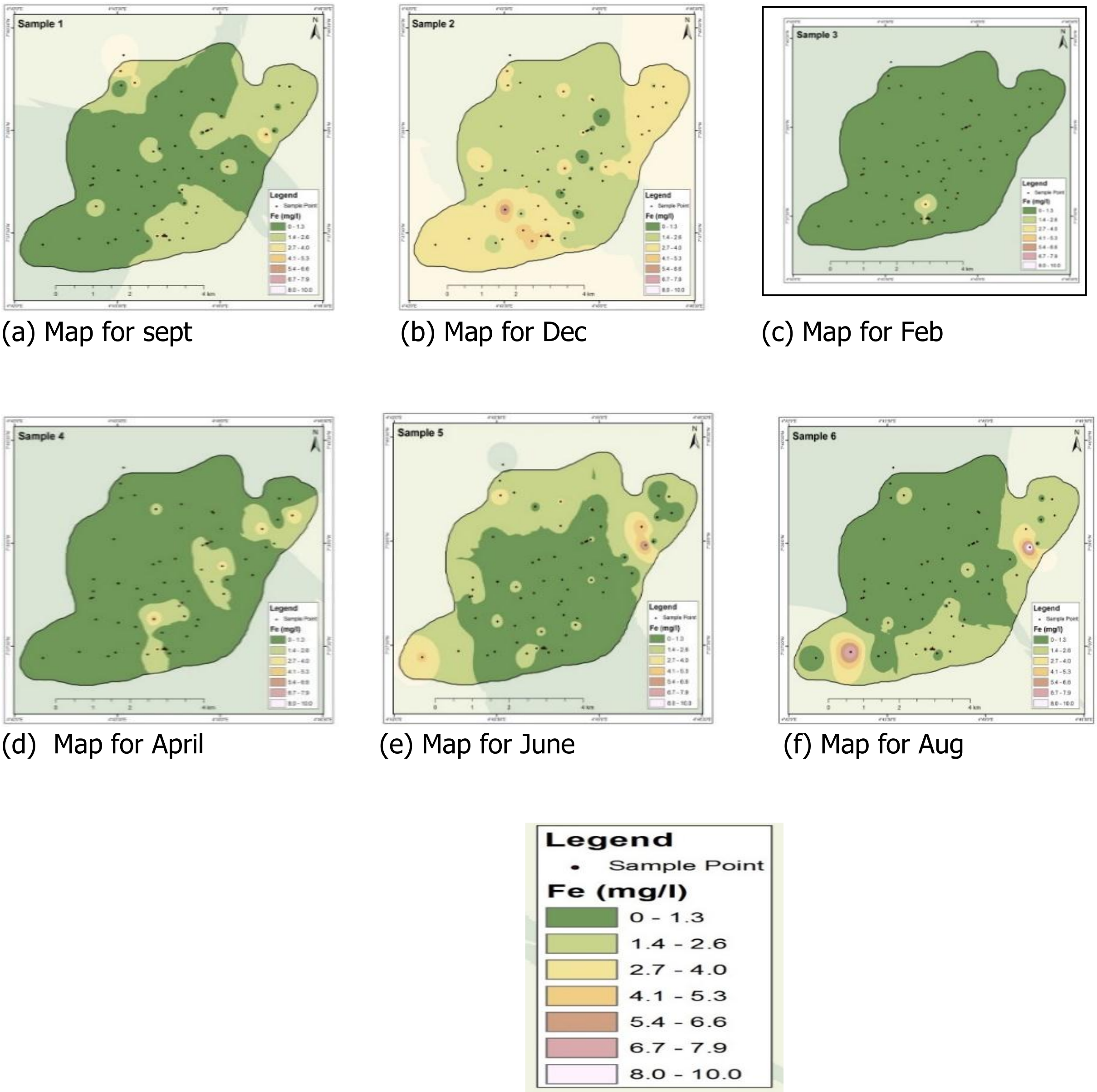


Figure 20: Spatial distribution of potassium over the sampling periods



(a) Map for sept (b) Map for Dec (c) Map for Feb

(d) Map for April (e) Map for June (f) Map for Aug

Figure 21: Spatial distribution of Fe over the sampling periods

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