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SPATIAL ASSESSMENT OF GROUNDWATER DEGRADATION USING PHYSICOCHEMICAL ANALYSIS AND GIS: CASE STUDY OF THE BASEMENT COMPLEX OF ADO EKITI, SOUTHWEST NIGERIA

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ARTICLE INFO	**ABSTRACT**
	Spatial assessment of groundwater degradation has been carried out in Ado–Ekiti using physicochemical analysis and Geographical Information System (GIS). Groundwater samples from 108 wells were analyzed on a regional basis. Application of GIS enabled the preparation of various thematic maps which were analysed in terms of groundwater quality standards for drinking and domestic utility. The thematic maps of pH, Total Hardness, Total Dissolved Solids (TDS), Chloride, Calcium and Nitrate concentrations produced were re-classified for integration in a GIS environment to produce the groundwater quality map. Anthropogenic influences were observed on the groundwater quality status of the study area as non-potable groundwater was delineated at the built-up areas and regions adjacent to streams and rivers. The integration of the thematic maps proved useful for the delineation of zones of groundwater quality suitable for human consumption and domestic purposes. Spatial analysis of the groundwater quality is essential for a proper understanding of the present environmental challenges and a projection into the future. This will facilitate quick decision-making for holistic groundwater development and management.

I. INTRODUCTION

The need for the evaluation of groundwater quality in any area where the majority of the population derive their potable water from the shallow aquifers has been recognised [1-3]. The quality of water remains a vital concern for mankind since it is directly linked with human existence and welfare. In developing countries, it is a general remark that high proportions of diseases are directly related to poor drinking water quality and unhygienic conditions [4, 5].

The utility of water is constrained by its quality which may render it unfit for specific purposes. This underlines the importance of water quality assessment in groundwater resources development and management. Contamination of groundwater could result from inherent composition of aquifer material and anthropogenic sources due to human activities. Leachate from dumpsites, mining activities, buried petroleum pipes/tanks, latrines and septic tanks, indiscriminate disposal of domestic and industrial solid wastes and the widespread use of chemical products such as pesticides, herbicides, and solvents may endanger groundwater quality. A direct consequence might be a threat to public health [6-8].

Urbanization presents increasing challenges of how to ensure adequate water supplies and a suitable water environment. It is noted that humans have exerted large-scale changes on the terrestrial biosphere through land use including agriculture, mining, and waste management [9, 10]. According to [11] groundwater as the main source of potable water supply for domestic, industrial and agricultural uses has been under intense

pressure of degradation and contamination due to urbanization, industrial and agricultural related activities. [3] remarked that the quality of shallow groundwater system in the weathered basement aquifer is increasingly being endangered by urbanization, industrial activities, and the emerging threat of impacts of climatic changes. [4] observed an increase in environmental pollution with urbanization in Ekiti State. The highest percentage of pollution was reported in Ado-Ekiti. [12] examined the relationship of some socio-economic factors and household sanitation in Ado-Ekiti. An indifferent status was observed for the general attitude of the residents towards household sanitation and waste disposal. The large dependence on groundwater resources puts premium on its quality status.

II. THEORETICAL REFERENCE

Some studies have been conducted on quality status of surface water and groundwater from boreholes and hand-dug wells in Ado-Ekiti. [13] reported an assessment of physicochemical status of water samples from major dams in Ekiti State, including the Ureje dam located in Ado-Ekiti. [14] subjected water samples taken randomly from twelve hand-dug wells at three selected areas of Ado-Ekiti to some physicochemical and microbiological analyses with a view to assessing the suitability for drinking and other domestic applications. [15] carried out physical, chemical and bacteriological tests on water samples randomly collected from ten hand-dug wells to express the groundwater quality in Ado-Ekiti metropolis. Such studies only considered physicochemical parameters and/or the bacteriological status of the water at discrete instances. There have been no reports on groundwater quality mapping on Ado-Ekiti at a regional level. Spatial variation of the groundwater quality has not been reported.

Remarkably, some studies have used geographic information system (GIS) as a database system in order to prepare maps of water quality according to concentration values of different chemical constituents [16, 17]. The work of [18] demonstrated the effectiveness of geographic information system in groundwater quality mapping. The study utilized data from physicochemical analysis of 76 water samples collected from bore wells and open wells representing the entire area. Thematic layers of Total Dissolved Solids (TDS), Total Hardness (TH), Cl^- and NO_3^- were overlaid in a GIS environment. GIS has emerged as a powerful tool for creating spatial distribution maps. It would be useful to visualize the spatial variation of certain physicochemical parameters, integrate relevant thematic layers and generate groundwater quality map for Ado-Ekiti metropolis.

This paper presents the spatial assessment of groundwater degradation in the basement complex of Ado–Ekiti using physicochemical analysis and GIS techniques.

II.1 SITE DESCRIPTION AND GEOLOGY

The study area, Ado-Ekiti, Southwestern Nigeria, lies between latitude 7° 33′ and 7° 42′ North of the Equator and longitude 5° 11′ and 5° 20′ East of the Greenwich Meridian (Fig. 1). The area is underlain by the basement complex of Southwestern Nigeria comprising the migmatite–gneiss–quartzite complex, charnockitic and dioritic rocks, older granites and unmetamorphosed dolerite dykes (Figure 2). The region experiences a tropical climate with mean annual temperature of 27°C and distinct wet and dry seasons. About 75% of all rainfall events are of moderate to high intensities. Light showers of less than 10 mm/hr account for only 25%. The major rivers and streams draining the area include Alamoji, Elemi, Ireje; Omisanjana and Awedele Streams [19, 20].
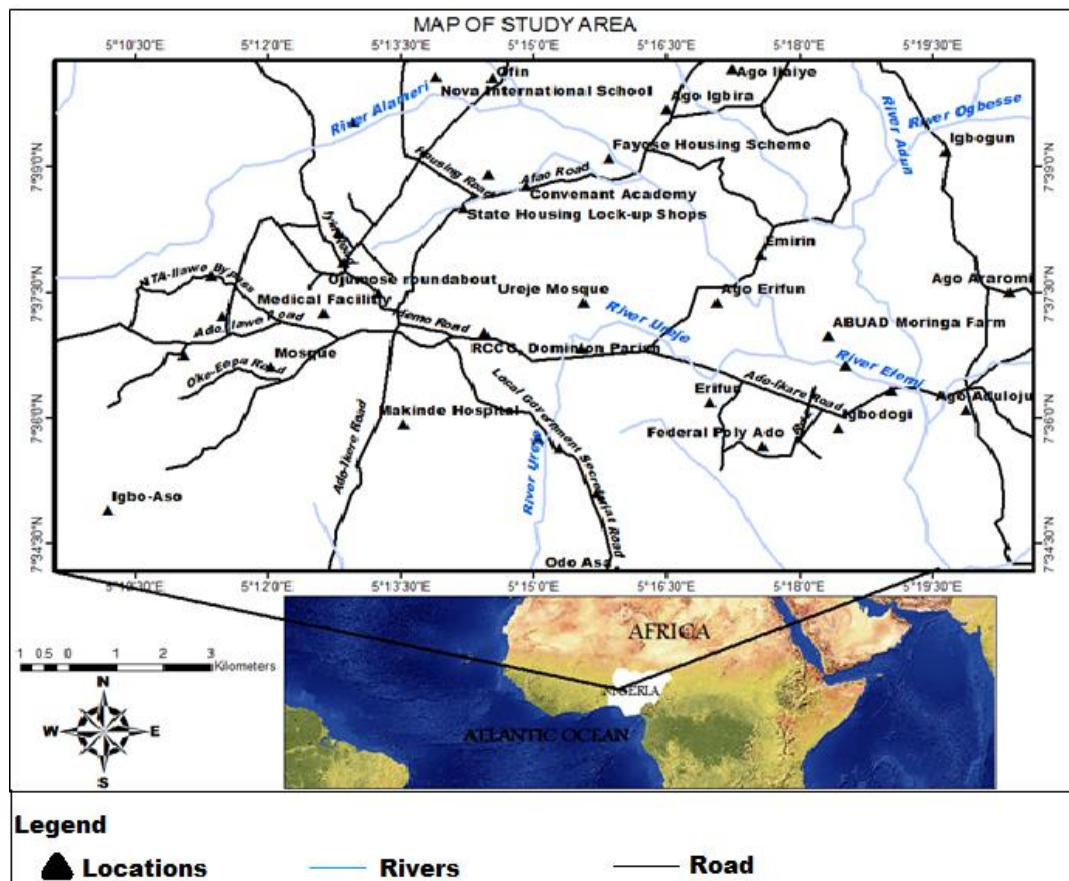

Figure 1: Location map showing the study area.
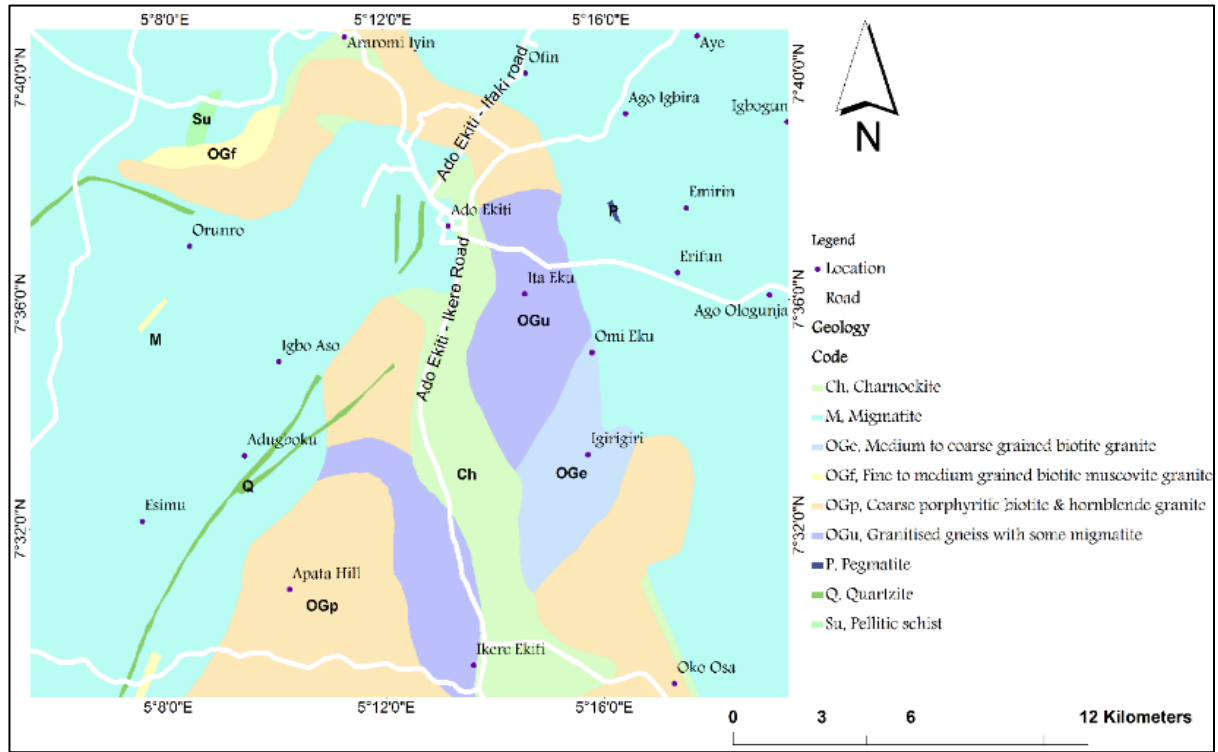Source: Authors, (2022).

Figure 2: Geological Map of Ado-Ekiti.
Source: Authors, (2022).

III. MATERIALS AND METHODS

Groundwater samples were taken from 108 wells across the metropolis on a regional basis (Figure 3). The samples were analyzed for pH, Total Hardness, Total Dissolved Solids (TDS), Chloride, Calcium and Nitrate concentrations. The physicochemical analysis of the water samples were carried out with a view to determining the potability according to the provisions of the Nigerian Industrial Standard (NIS) and World Health Organization (WHO) for potable water. Standard sampling and laboratory procedures were followed throughout the process [2, 7, 13].
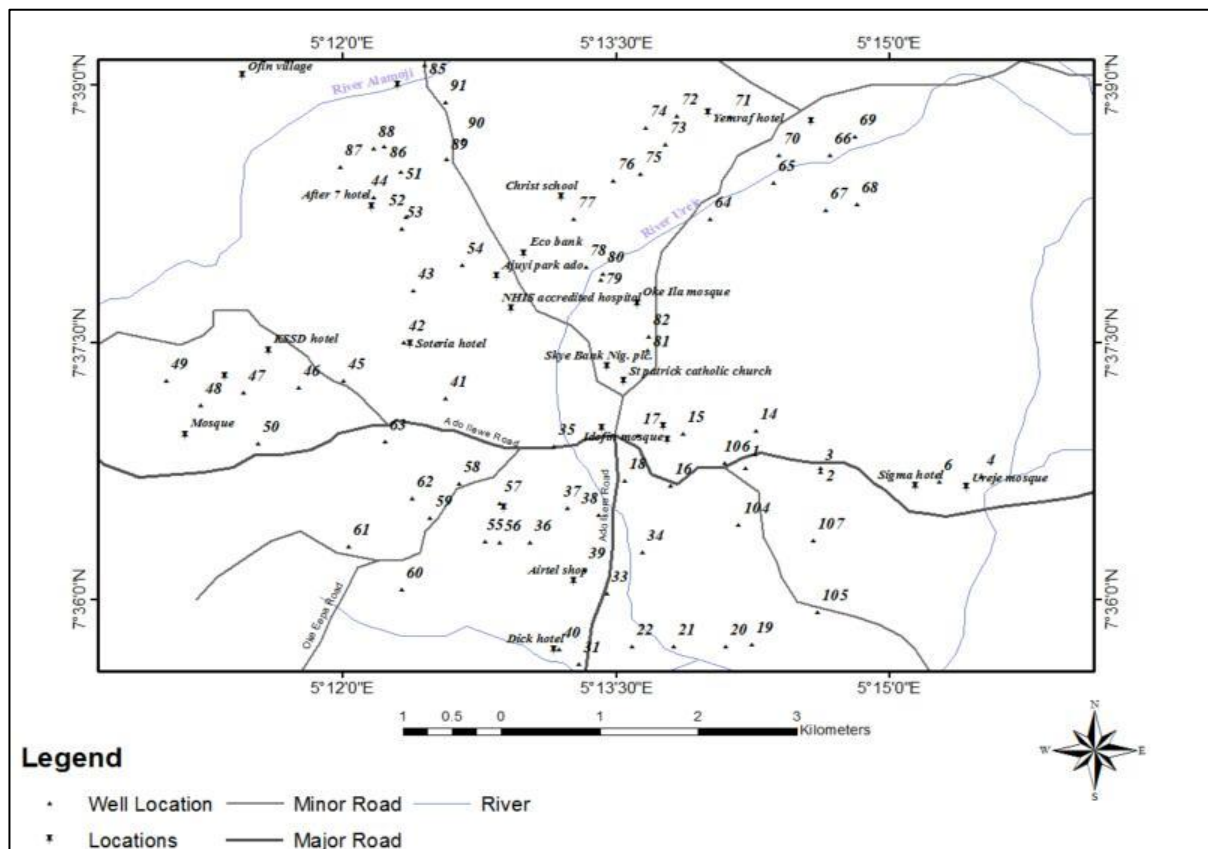

Figure 3: Location map of the study area showing the well points.
Source: Authors, (2022).

The results of the tests were recorded alongside the co-ordinates of the sampling points using a hand-held Garmin 12-Channel GPS Receiver. ArcGIS 10.2.2 was used to perform all operations including geo-referencing, derivation of thematic layers and the Weighted Index Overlay Analysis. GIS application for storing, displaying, and analyzing spatial data permitted creation of the data base [18, 21, 22].

The spatial distribution maps of concentrations of the selected parameters were prepared to show the variation in concentrations of the parameters in water samples across the study area using inverse distance weighted (IDW) raster interpolation technique of the spatial analyst module in ArcGIS software. Groundwater quality map was generated for the metropolis to provide an overview of present groundwater quality status.

IV. RESULTS AND DISCUSSIONS

IV.1 PHYSICO-CHEMICAL ANALYSIS

The summary of the results of the physico-chemical analysis are presented in Table 1. The colour rating of the water samples varied across all the sampling points with the range of 5 - 60 HU and mean value of 15.58 (SD =12.35) HU. Colour in water is attributable to materials in solution. It may be indicative of dissolved organic material. Inorganic contaminants, such as metals, are also common causes of colour. The values of the suspended solids in the water samples varied from 0.00 to 455; with the mean value of 16.95 (SD = 52.67) mg/l.

Table 1: Summary of Descriptive Statistics of Physico-chemical Parameters.

Parameters	Minimum	Maximum	Mean	Std. Deviation
Colour (HU)	5.00	60.00	15.58	12.35
Turbidity (NTU)	0.65	105.50	12.48	14.81
Temp (°C)	4.25	33.00	30.92	2.70
Electrical Conductivity (µS/cm)	0.79	77.00	13.20	13.62
Total Solid (mg/l)	0.50	420.00	42.16	72.57
Suspended Solid (mg/l)	0.00	455.00	16.95	52.67
Dissolved Solids (mg/l)	0.00	405.00	33.57	64.10
pH	3.50	8.20	6.50	0.88
Calcium (mg/l)	3.20	346.00	51.76	51.05
Magnesium (mg/l)	6.30	220.00	51.29	39.22
Chloride (mg/l)	0.51	480.00	53.38	71.94
Total Hardness (mg/l)	20.00	420.00	112.23	67.40
Nitrate (mg/l)	0.00	50.00	3.80	11.29

Source: Authors, (2022).

Turbidity, a measure of suspended minerals, bacteria, plankton, and dissolved organic and inorganic substances, varied from 0.65 to 105.5 NTU with a mean of 12.48 (SD = 14.81) NTU. The materials may also include dust particles and colloidal organic matter. High value of turbidity might be due to high sediment discharge from run - off as suggested by corresponding high colour values. Toxic contaminants can cling to suspended particles, which in turn may be ingested by humans and ultimately invoke health problems [6, 7]

The pH values varied from 3.50 to 8.20 with an average of 6.50 ± 0.88 for the study area. pH is a measure of the hydrogen ion concentration in water. It indicates level of acidity or alkalinity. Drinking water with a pH between 6.5 and 8.5 generally is considered satisfactory. Waters with a pH above 8.5 may have a bitter or soda-like taste. The primary cause of a low pH is the addition of acidic rain water. Other ions found in groundwater such as nitrates and sulphates may result in lower pH. Highly acidic water may result in pipe corrosion, causing the possible release of iron, lead, or copper into the tap water. A low pH may discolour the water and give it a bitter taste [19, 23-25].

The total dissolved solids (TDS) averaged 33.57 mg/l with standard deviation of 64.10 mg/l. Total dissolved solids give a direct measurement of the interaction between groundwater and subsurface minerals. High TDS, greater than 1000 mg/l, is commonly objectionable or offensive to taste. TDS levels over 2,000 mg/l are generally considered undrinkable due to strongly offensive taste. A high TDS (levels above 1,000 mg/l) may promote corrosion of pipes / plumbing systems and appliances [14, 17, 22].

Electrical conductivity (EC) reflects the degree of salinity. It is a direct function of the total salt content in water. As low as EC value of 250 µS/cm is prescribed for drinking water [24-26].

Electrical conductivity varied from 0.79 to 77 µS/cm with a mean of 13.20 µS/cm and most frequently occurring value of 5.00 µS/cm across the study area. High values of electrical conductivities imply high salinity [7, 8, 18].

The concentrations of calcium in the wells ranged between 3.20 and 346 mg/l with average value of 51.76 ± 51.50 mg/l while values obtained for magnesium ranged between 6.30 and 220 mg/l with an average of 51.29 ± 39.22 mg/l. Total Hardness in the samples varied from 20 to 420 mg/l with a mean of 112.23 ± 67.40 mg/l. Total Hardness, made up of temporary hardness and permanent hardness, is due to the presence of certain salts, such as carbonates, bi-carbonates, chlorides and sulphates, of calcium and magnesium dissolved in it [6, 8, 24].

Chlorides concentrations in the wells varied widely between 0.51 and 480 mg/l with mean value of 53.38 (SD = 71.94) mg/l. An increase in the normal chloride content of water may indicate possible pollution from human sewage, animal manure or industrial wastes. An upper limit of 250 mg/l has been set for chloride ions. Objectionable salty taste and laxative effect which aids corrosion in hot-water plumbing fixtures are often associated with high concentrations of chloride ions [11, 15, 25].

Concentrations of nitrates values were moderate in most of the water contact sites except in some few sampling points where the values were high; the mean value being 3.80 (STD = 11.29) mg/l. Nitrate is harmful when it is above the WHO /NSI standard of 10 mg/l for drinking water [6, 14, 19]. Nitrates indicate contamination by anthropogenic activities, such as agriculture, industry, domestic effluents and emissions from combustion engines [19, 28, 29]. Extreme ingestion of nitrates in drinking water has been connected with the risk of methemoglobinemia/blue baby syndrome in humans [23, 30].

IV.2 HYDRO-GEOCHEMICAL CONTOUR MAPS

To demonstrate the regional dispersion of the dissolved ions, the results of the physicochemical analysis of the water samples are presented in the form of hydro-geochemical contour maps (Figures 4 - 9). Almost all the hydro-geochemical maps of the measured parameters show fairly similar patterns. The peripheral parts of the study area have low values and the contours are widely spaced. Contour spacing irregularly decrease towards the centre of the metropolis. The irregular spacing indicates uneven distribution of ions probably due to uneven rate of water movement within the aquifer. This is a consequence of differential soil permeability from one point to another which is characteristic of aquifers in the basement complex [1-3].
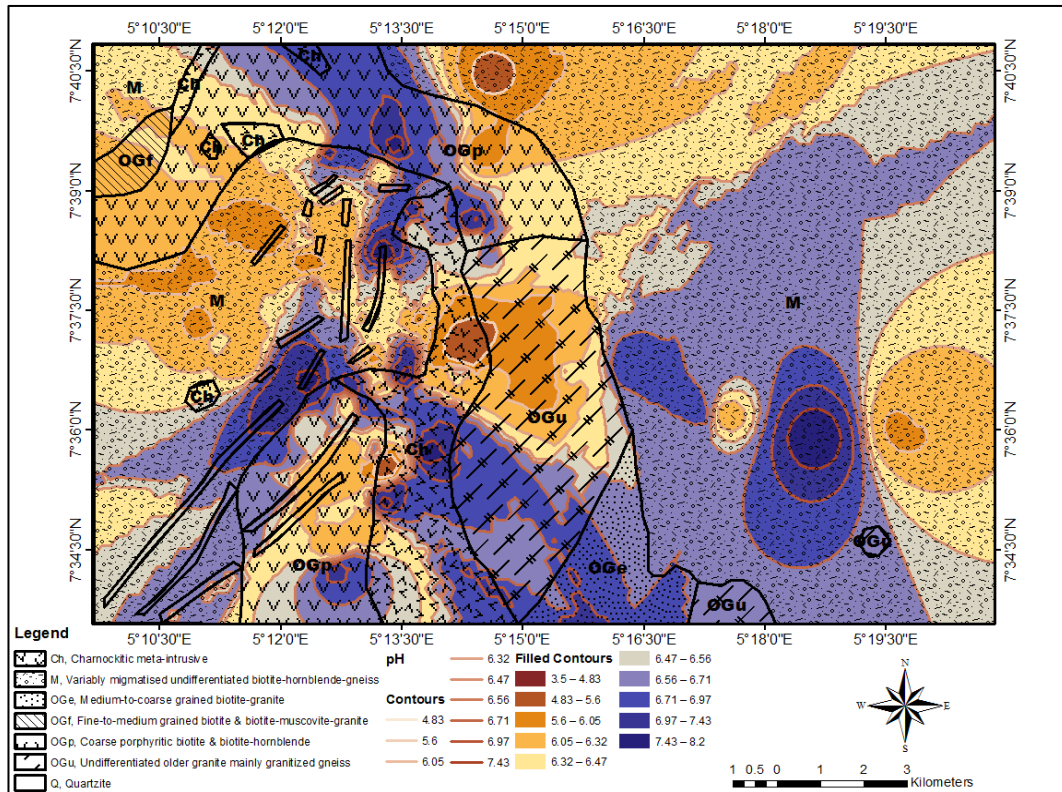

Figure 4: Spatial variation of pH in the study area.
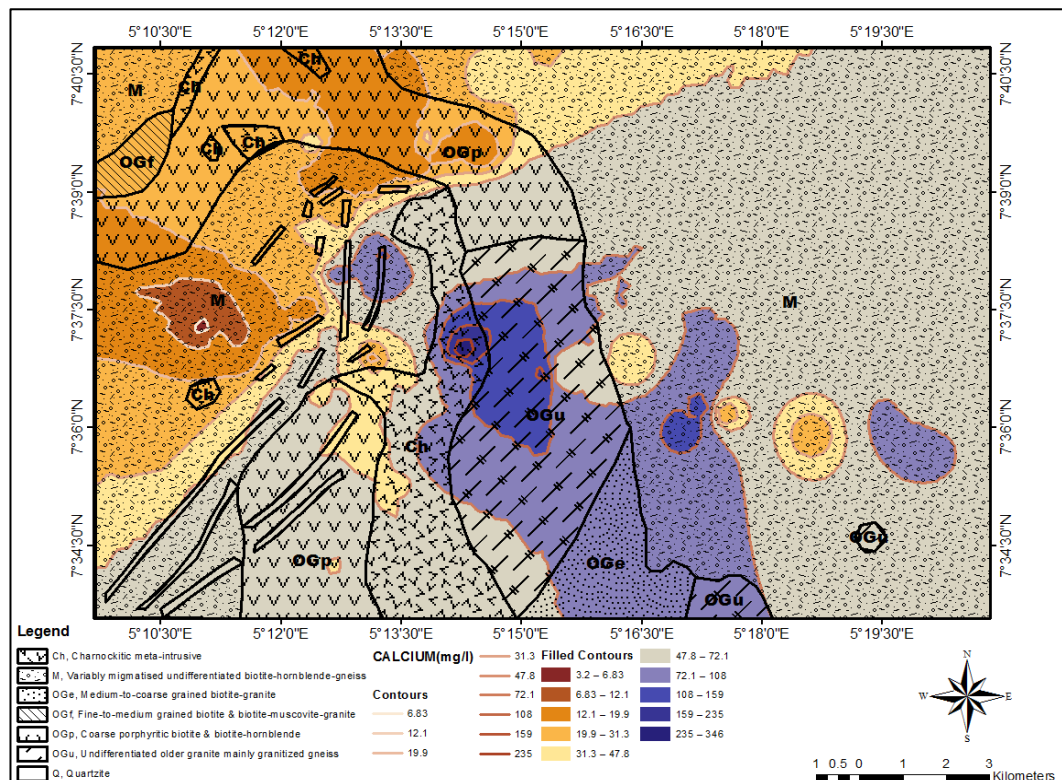Source: Authors, (2022).

Figure 5: Spatial variation of Calcium in the study area.
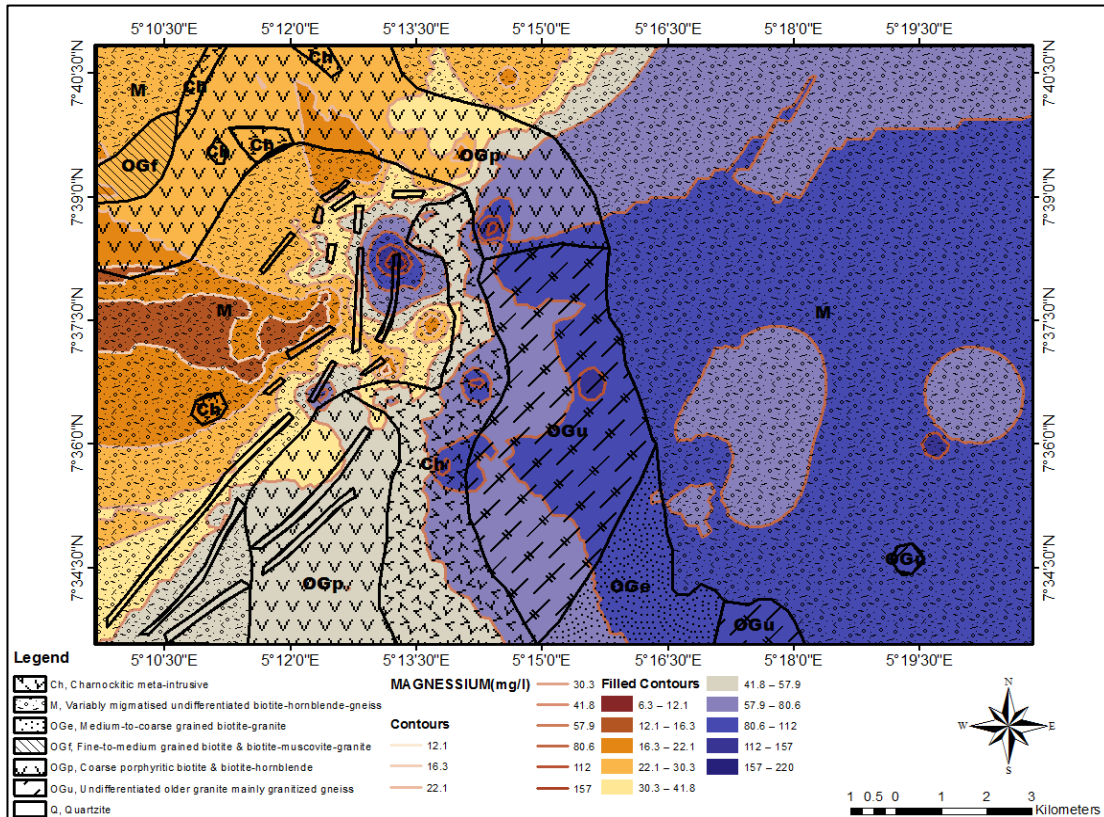Source: Authors, (2022).

Figure 6: Spatial variation of Magnesium in the study area.
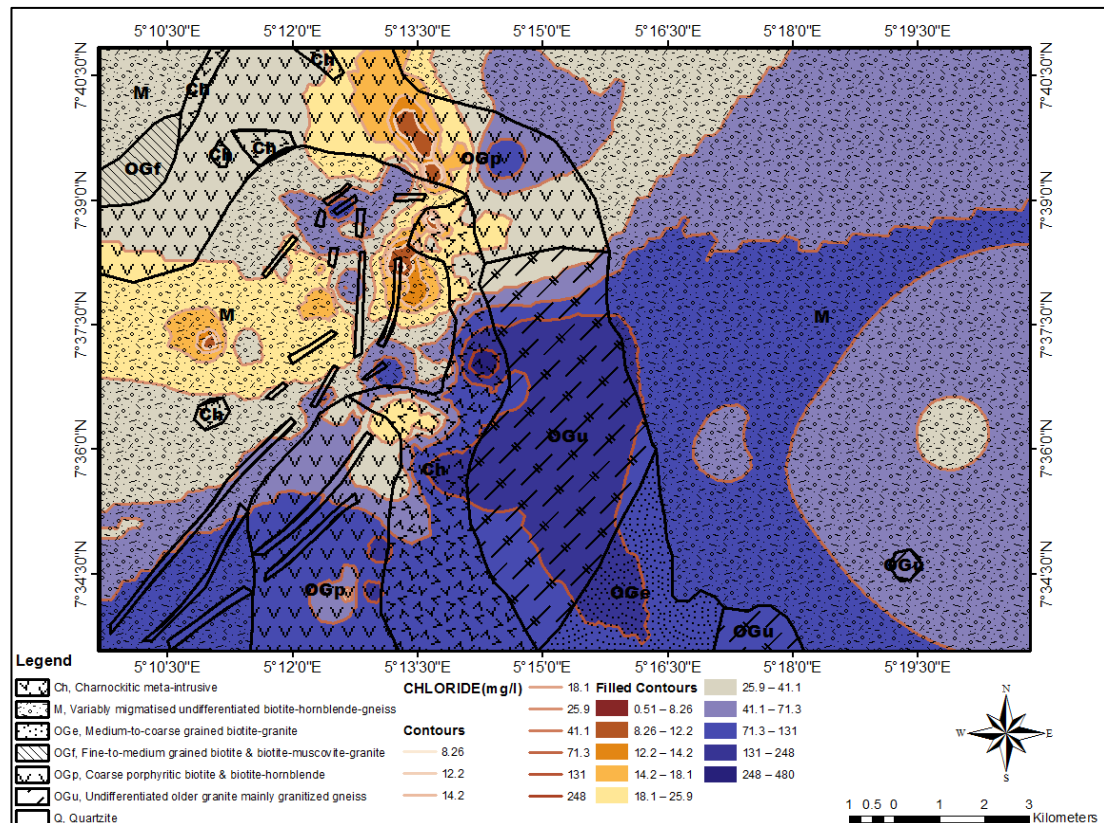Source: Authors, (2022).

Figure 7: Spatial variation of Chloride in the study area.
Source: Authors, (2022).

The contours cut across geological boundaries indicating the reduced influence of geology in determining the water chemistry. The contours seem to follow the demography of the area. High values are found in the densely populated parts of the study area while low values are found in the outskirt and sparsely populated parts [27, 3]. Contamination often occurs in areas with high population density, industries, and agricultural activities, where groundwater is frequently used as a freshwater source [10, 19, 29].
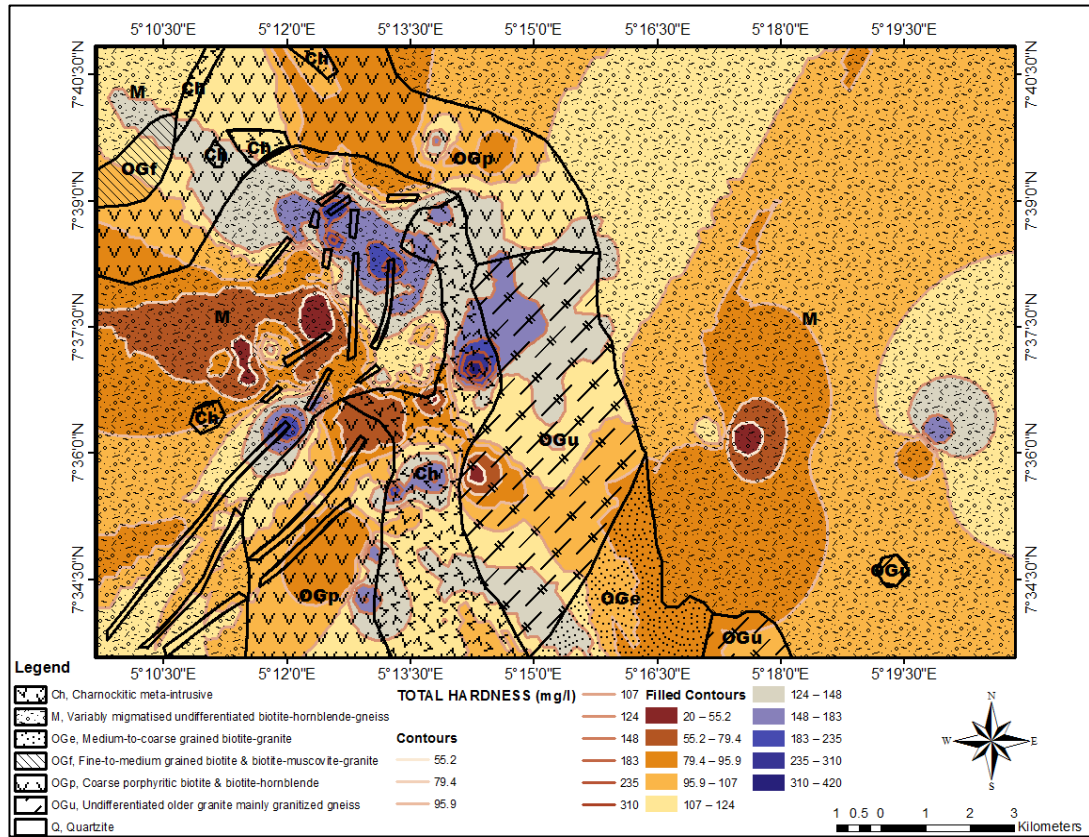
Figure 8: Spatial variation of Total Hardness in the study area.
Source: Authors, (2022).
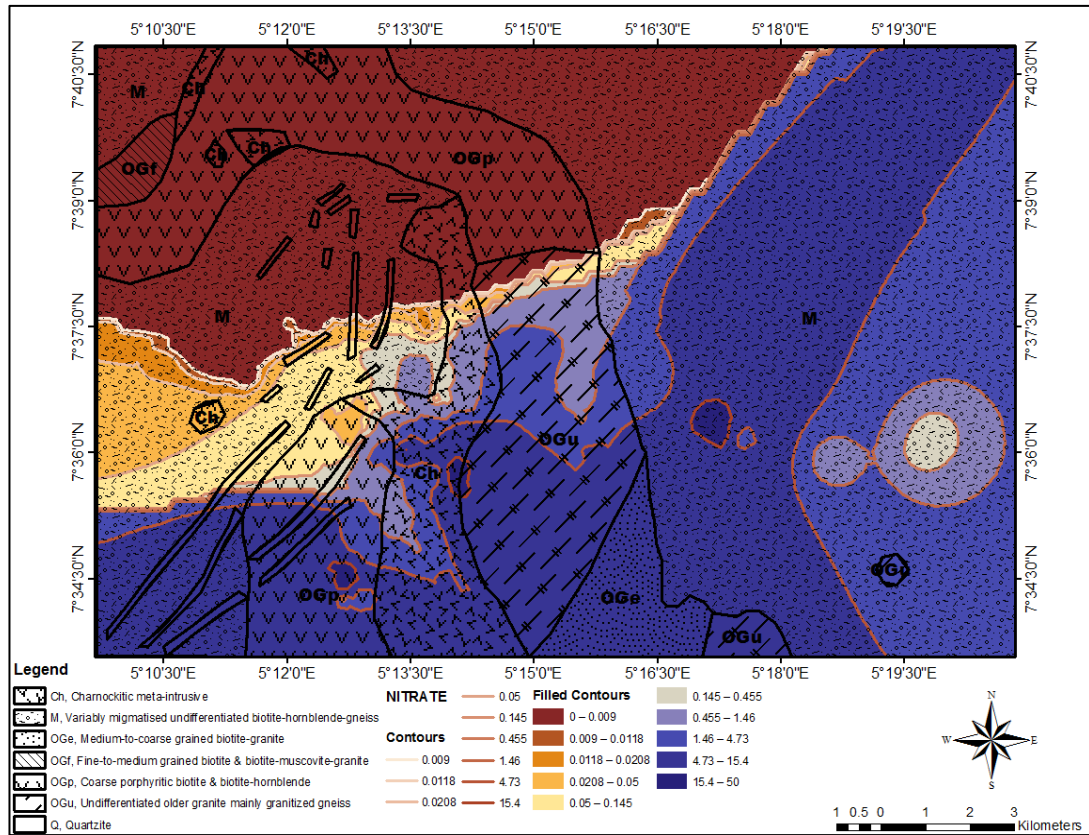
Figure 9: Spatial variation of Nitrate in the study area.
Source: Authors, (2022).

IV.3 THE GROUNDWATER QUALITY MAP

The Groundwater Quality Map of the study area, Figure 10, was produced by integrating re-classified thematic layers of Nitrate, pH, Total Hardness, TDS, Chloride and Calcium using the weighting of Table 2. Data of relevance can be integrated by weighted index overlay method to produce appropriate models [18, 21-23].

Figure 10: Groundwater Quality Map of the study area.
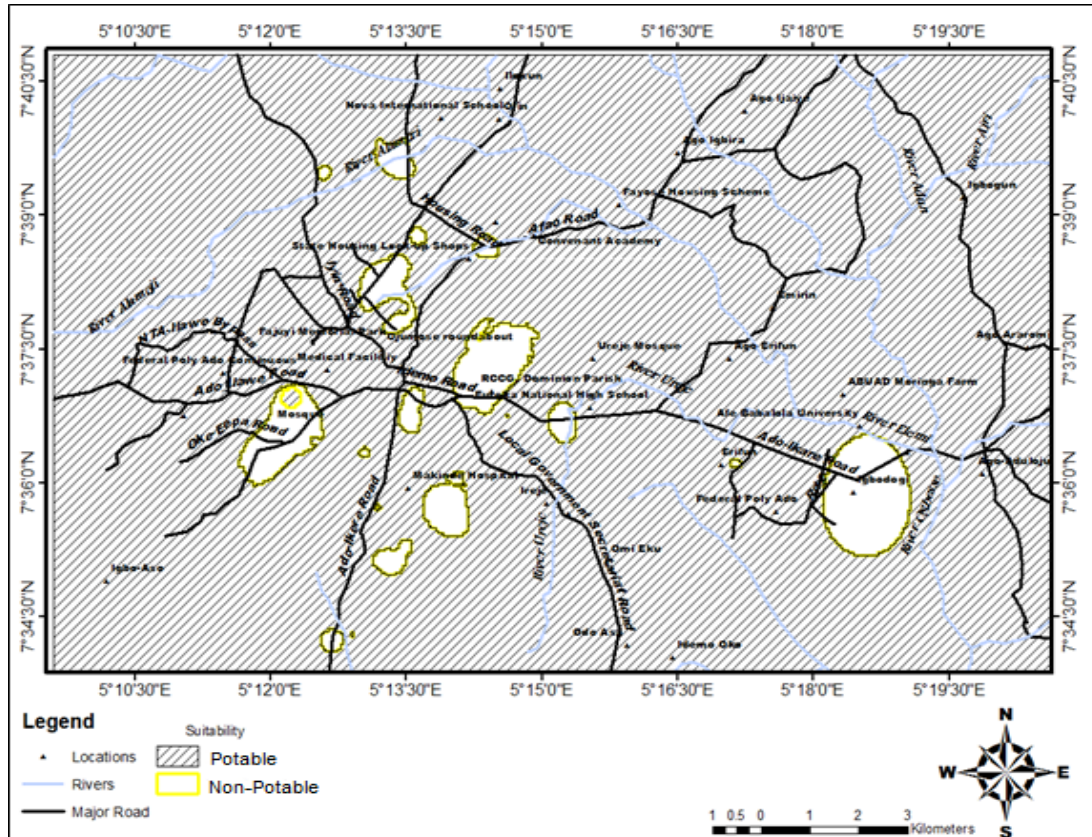Source: Authors, (2022).

Table 2: Classification of Themes for Groundwater Quality for Domestic Purposes.

Parameters	Classes	Scale value	Rank
pH	< 7 Acidic 7 Neutral > 7 Alkaline	1 3 1	20
Calcium	< 75 mg/l most desirable 75 - 200 mg/l max allowable > 200 mg/l	3 2 1	15
Chloride	< 250mg/l most desired limit > 250mg/l max allowable Limit	3 1	15
Total Hardness	< 75mg/l soft 75 - 150 mg/l moderately hard 150 - 300 mg/l hard > 300 mg/l very hard	4 3 2 1	15
Total Dissolved Solid	< 300 mg/l Excellent 300 - 377 mg/l Good	3 1	10
Nitrate	< 45 mg/l > 45 mg/l	3 1	25

Source: [24, 25].

The map revealed that the potable groundwater in the study area covered an areal extent of 248.87km^2 with non-potable groundwater over an areal extent of 9.73km^2 occurring at portions along the northwestern, southwestern, southeastern flanks and the central region.

According to [27], the management of groundwater quality requires a multidisciplinary approach with sufficient reflections on the continuous human pressure on natural resources. Regions adjacent to streams and rivers commonly have records of non-potable groundwater. These observations underline the processes of urbanization, industrialization and fast population growth in Ado-Ekiti. It is observed that houses have been built very close to the banks of the rivers and streams. Such streams are used for

disposal of domestic, industrial and urban wastes. The natural attenuation effects of the streams might have been over-stretched. Consequently, the groundwater quality might be compromised [4, 12, 19].

Human activity imprints were observed on the hydro-geochemistry of the study area. Densely populated regions have groundwater with high concentration of dissolved ions while the areas of low population exhibit low concentration of dissolved ions. The shallow aquifers are potentially vulnerable to pollution from point sources such as agricultural (fertilizers), domestic (waste dumps, latrines) and industrial sources, except where surface layers are of poor permeability and afford some protection of the underlying aquifers. The study of [29] suggests that specific

attention should be paid to land management. Generally, nitrate and nitrite contamination of groundwater occurs due to the use of inorganic fertilizers, household and industrial waste, septic tank leakage, alongside waste from landfills [3, 22].

Great care should be taken to protect domestic and public water supplies from pollution. Indiscriminate siting of refuse dumps and other waste disposal facilities should be discouraged to avoid the unpleasant consequences of polluting the near surface/shallow hand – dug wells. [31] reported that numerous landfills in the urban area could trigger groundwater pollution that could become a major health problem for nearby dwellings. The authors remarked that the plume would extend towards the main fracturing direction of the crystalline bedrock.

Groundwater quality conditions can be supervised by making regular monitoring wells to mitigate pollution [29]. The work of [32] emphasized the need to protect groundwater resources. The study made recommendations for groundwater management including environmentally sound groundwater use. Compliance with proper treatment of effluents and wastes in line with the NIS and WHO standards should be encouraged and put in place.

V. CONCLUSIONS

The use of physicochemical analysis in a GIS platform resulted in the development of an efficient spatial data management with a data base on groundwater quality. The study revealed non-potable groundwater at the built-up areas and regions adjacent to streams and rivers. The shallow aquifers are potentially vulnerable to pollution from agricultural (fertilizers), domestic (waste dumps, latrines) and industrial sources, except where surface layers are of poor permeability and afford some protection of the underlying aquifers. The integration and analyses of various thematic maps proved useful for the delineation of zones of groundwater quality suitable for domestic purposes. With the implementation of GIS, large volume of geospatial data and information are not only maintained in a standard format but can be revised and updated with additional features. Sustainable groundwater development and management are thus facilitated at real time.

VI. AUTHOR'S CONTRIBUTION

Conceptualization: Oyedele, Talabi and Adekanmi.
Methodology: Oyedele, Talabi and Afolagboye.
Investigation: Oyedele, Ojo, Afolagboye and Adekanmi.
Discussion of results: Oyedele, Ojo, Adekanmi and Afolagboye.
Writing – Original Draft: Oyedele.
Writing– Review and Editing: Talabi, Ojo and Afolagboye.
Resources: Oyedele, Ojo, Adekanmi and Afolagboye.
Supervision: Talabi and Adekanmi.
Approval of the final text: Oyedele, Adekanmi, Talabi, Afolagboye and Ojo.

VII. ACKNOWLEDGMENTS

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