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Application of Geographic Information System in Mapping of Groundwater Quality for Michael Okpara University of Agriculture Umudike and its Environs, Southeastern Nigeria

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ABSTRACT

Geographic Information System (GIS) has become a particularly useful and important tool in the scientific study and management of water resources. In this paper the GIS software ILWIS 2.1 was used to analyze and create groundwater pollution sensitive zone map for Michael Okpara University of Agriculture Umudike and its environs, Southeastern Nigeria. Spatial variability maps of different groundwater quality parameters were generated using interpolation operation in the software and were incorporated as data layers in the software for further generation of groundwater pollution sensitive zone map. The effect of various data layers (elevation map, contour lines, and land use activities) on the distribution of groundwater pollution was also studied. The water quality parameters of concern were pH and turbidity because they had marked departure from WHO standard. The pH values in the area varied from 4.71 to 6.94 which reveal acidic groundwater. The turbidity values ranged from 86.10 to 92.60 NTU. The turbidity values recorded for all the samples were above the WHO acceptable limit of 5.00 NTU. The pollution sensitive zone map delineates the area into four zones: low hazard zone, moderate hazard zone, high hazard zone and very high hazard zone. The very high hazard zone seems to be the largest zone and extends mostly towards the southern part of the study area, indicating that the contaminants seem to concentrate at the southern part of the area, which also has low elevation.

Keywords: Groundwater, Pollution, mapping, GIS, Umudike, quality

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INTRODUCTION

Over few decades, competition for economic development, associated with rapid growth in population and urbanization, has brought in significant changes in land use, resulting in more demand of water for domestic activities. Groundwater is one among the Nation’s most important natural resources. Very large quanta of ground water are pumped each day for industrial, agricultural, and commercial use [1]. The quality and availability of ground water will continue to be an important environmental issue. Long-term conservation, prudent development and management of this natural resource are critical for preserving and protecting this priceless national asset [2].

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. The impact of this trio on soil and groundwater is alarming with years of devastating effects on humans and the ecosystem. Groundwater is said to be contaminated when it is unfit for the intended purpose and therefore constitute a nuisance to the user [3].

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Continued research, guidance and regulations by government agencies and pollution abatement programmes are necessary to preserve the Nation's groundwater quality and quantity for future generations. The impact of Industrial effluents is also responsible for the deterioration of the physico-chemical and bio-chemical parameters of groundwater [4]. Knowledge on water chemistry is important to assess the quality of aquatic resources for understanding its suitability for various needs [5]. Information on the status and changing trends in water quality is necessary to formulate suitable guide lines and efficient implementation for water quality assessment, water quality monitoring and enforcement of prescribed limits by different regulatory bodies [6].

Geographic Information System (GIS) has become a particularly useful and important tool in hydrology and to hydrologists in the scientific study and management of water resources. A Geographic Information System (GIS) or Geographical Information System is any system that captures, stores, analyzes, manages, and presents data that is linked to location. It is a tool for storing, manipulating, retrieving and presenting both spatial and non-spatial data in a quick, efficient and organized way [7].

Technically, a GIS is a system that includes mapping software and its application to remote sensing, land surveying, aerial photography, mathematics, photogrammetry, and geography. The advantages of using GIS over traditional methods in groundwater monitoring are: effective storage and analysis system for spatial and temporal database, spatial analysis of depicting the source- pollutant relationship, graphical presentation, visual impacts and spatial distribution of graphical outputs on water quality changes, pollution load and relationship with sources and management of river basin by generating buffer zones on the basis of water quality criteria. GIS can serve as a very useful tool for not only groundwater modeling but also for analyses of decadal variations in the groundwater quality, and development of conceptual groundwater model. Various layers of information such as canal network, recharge zones, subsurface geology and digital terrain model (DTM) can also be developed [8].

This study was carried out to analyze the impact of various data layers viz. topographic slope, groundwater slope and land use activities on the distribution of groundwater quality; map groundwater quality with respect to certain significant groundwater quality parameters, as well as prepare the groundwater quality sensitive zone map for Michael Okpara University of Agriculture, Umudike and its environs, Southeastern Nigeria.

Geology and Hydrogeology of the Study Area

Michael Okpara University of Agriculture, Umudike (MOUAU) is located in Ikwuano Local Government Area of Abia State, Southeastern Nigeria. It is located within the deltaic marine sediments of Cretaceous to re- cent age, between latitude 5°28'N and 5°30'N and between longitude 7°31'E and 7°33'E, and has an elevation range of 60 to 180 m above mean sea level (Figure 1).

The Geology of the area is the deltaic marine sediment of Cretaceous to Recent age. There are two principal Formations in the area namely: the Bende-Ameki and the coastal plain sands otherwise known as the Benin Formation. The Bende-Amaki Formation of Eocene to Oligocene age consists of medium to coarse-grained white sandstone, which may contain pebbles, gray-green sandstone, bluish calcareous silt, with mottled clays and thin limestone. Considerable lateral variation in lithology has also been observed. The lower part of the Formation consists of fine-coarse-grained lenses of sandstone with abundant calcarceous shales and thin shelly limestone. The Bende-Ameki Formation overlies the impervious Imo shale group of Paleocene age, which is characterized by lateral and vertical variations in lithology. The coastal plain sand otherwise known as the Benin Formation overlies the Bende-Ameki Formation and dips south-westward. The Formation sediments were deposited during the late Tertiary-early Quaternary period. The Formation is shallow and has an expected thickness of about 200 m [9]. The lithology consists of unconsolidated loosely medium to coarse-grained cross-bedded sands occasionally pebbly with localized clays and shales. Umudike soil is acidic with average pH range of 4.5 - 5.7.

The two principal geological formations: the Bende- Ameki and the coastal plain sands otherwise known as the Benin Formation have comparative groundwater regime. They both have reliable groundwater that can sustain regional borehole production. The Bende-Ameki Formation has little groundwater when compared to the Benin Formation. The high permeability of the Benin Formation, the lateritic overburden earth and the weathered top of this formation as well as the underlying clay-shale member of the Bende-Ameki series provide the hydrologic conditions favouring aquifer formation in the area. The study area has aquifer thickness of about 88.00 m, hydraulic conductivity of about 8.00 m/day and a transmissivity of about 704.00 m2/day [9].

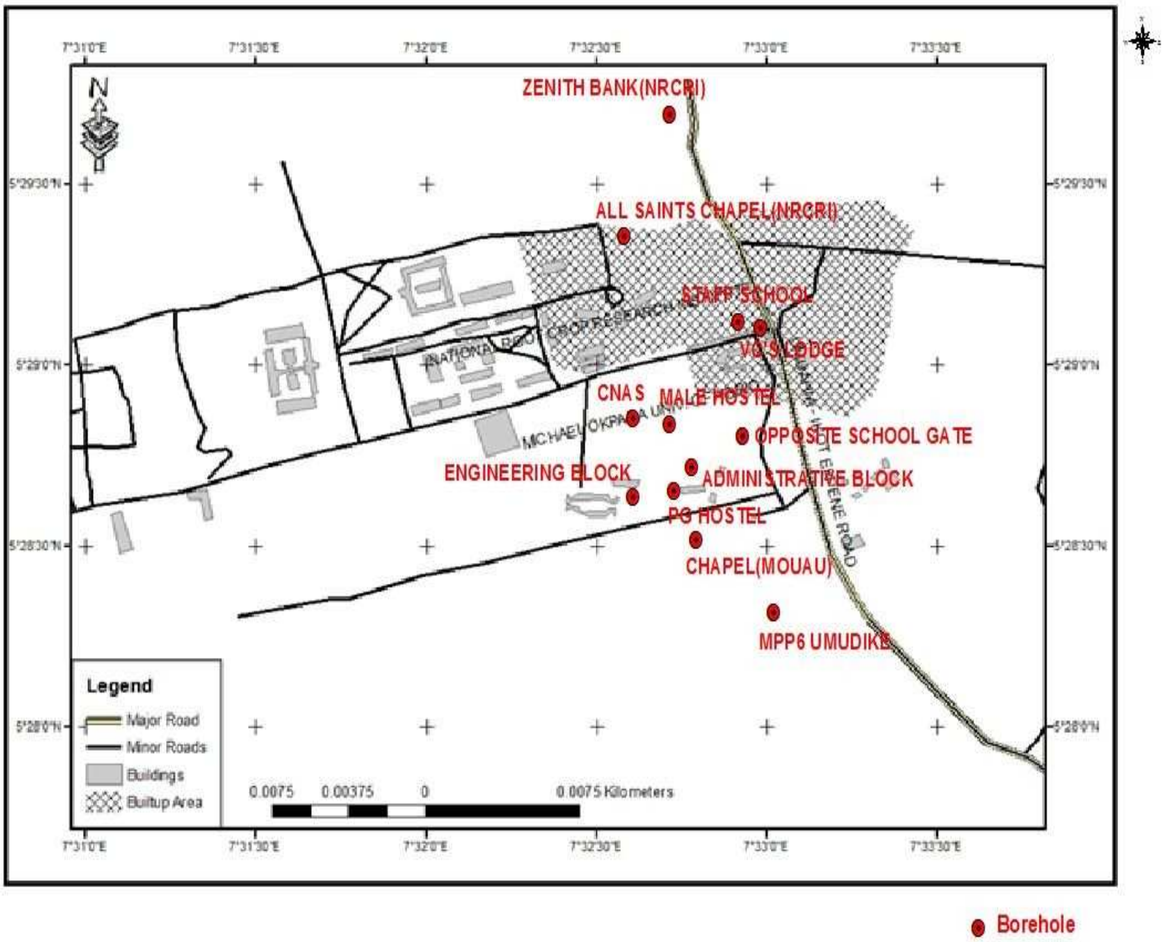

Figure 1: Source map of the study area showing borehole locations

Methodology

The source map (Umudike area) was extracted from the satellite imagery downloaded from Global Land Facility Cover Website, Google Earth. The map was geo-referenced using Arc Map 9.2 GIS software. The data was captured through heads-up digitizing in Arc Map 9.2. The final layout was prepared using the mapping functions of the same software [10]. The source map (Umudike area) and borehole locations are shown in figure 1.

The source map of the area was registered into the software (ILWIS 2.1) through the steps of scanning, import, creation of coordinate system and georeferencing. The borehole locations captured using GPS were located on the digitized Umudike map (Table 1). The various spatial features (well location, elevation, contour lines) were digitized. Contour lines and elevation information were used to prepare the digital elevation model of the study area. Interpolation operation was used to prepare the vulnerability maps of different groundwater quality parameters and finally cross operation was used for the preparation of the final hazard map of the area.

For the samples collection, twelve borehole locations were identified. These locations were identified in such a way that the boreholes were evenly distributed over the study area. The Laboratory tests were conducted on these samples for eight different physico-chemical potable water quality parameters. The standard procedure criteria were adopted for testing these samples [11]. The groundwater quality data were used for the preparation of vulnerability and hazard maps. These features were the boundary lines between mapping units, elevation and point features (borehole points, etc.). The contours were developed for pH, conductivity, total dissolved solids, total suspended solids, total solids, acidity, alkalinity and turbidity. The sampling locations of all the stations are shown in Table 1.

Table 1: Borehole locations and their coordinates

Well No	Location	Latitude ^{0}N	Longitude^{0}E	Elevation (m)
1	PG hostel	$5^0 28.658^1$	$7^0 32.539^1$	117.2
2	Chapel of revelation	$5^0 28.517^1$	$7^0 32.\ 633^1$	123.7
3	Engineering block	$5^0 28.637^1$	$7^0 32.390^1$	91.1
4	Staff school	$5^0 29.128^1$	$7^0 32.765^1$	144.0
5	Male hostel	$5^0 28.\ 846^1$	$7^0 32.523^1$	122.7
6	Administrative block	$5^0 28.728^1$	$7^0 32.612^1$	125.3
7	VC's lodge	$5^0 29.112^1$	$7^0 32.858^1$	136.5
8	Zenith bank(NRCRI)	$5^0 29.688^1$	$7^0 32.529^1$	125.5
9	Opposite gate 6 (MOUAU)	$5^0 28.798^1$	$7^0 32.786^1$	127.3
10	MPP6 Umudike	$5^0 28.318^1$	$7^0 32.904^1$	166.3
11	CNAS	$5^0 28.855^1$	$7^0 32.393^1$	103.2
12	All saints' chapel(NRCRI)	$5^0 29.355^1$	$7^0 32.358^1$	131.4

RESULTS AND DISCUSSION

Digital elevation model

Digital elevation model is a digital file providing a highly detailed representation of the topographical variations in the earth's surface. Combined with other digital data such as maps, it can provide a 3D image of the land surface. Consisting of terrain elevations for ground positions at regularly spaced horizontal intervals, the added dimension and visualization offered by a digital elevation model can help in many decision making processes. Digital elevation model is used in the determination of direction of water flow and pollution dispersion, as well as watershed delineation. The elevation of the area as shown in Figure 2 decreases from north to south, indicating that the groundwater flow in the area is from north to south. Pollutants seem to migrate towards the southern part of the study area. The elevation values in the area ranged from 90.90 to 138.90 m, with an average elevation of 118.82 m. This value is in agreement with the elevation value of 119.97 m as obtained from the satellite imagery of the study area.

Hydrochemical Evaluation

Physio-chemical groundwater quality assessment by deterministic method for drinking groundwater usage on the basis of eight water quality parameters were compared with the WHO standards. The water quality parameters of concern were pH and turbidity because they had marked departure from WHO standard. The hydro chemical analyses revealed that water samples in the study area were characterized by low pH (high acidity) and high turbidity values. This is connected with the low pH range of the soil in the area, which has great influence on the groundwater quality. The pH values in the area varied from 4.71 to 6.94 which reveal acidic groundwater. The turbidity values ranged from 86.10 NTU to 92.60 NTU with a mean value of 90.17 NTU. The turbidity values recorded for all the samples were above the WHO acceptable limit of 5.00 NTU.

The conductivity values in the area ranged from 66.67 to 600.03 µs/cm, with locations 7, 11 and 12 having conductivity values higher than the WHO limit of 500.00 µs/cm (Table 2). Conductivity of the water can be related to the total dissolved solids concentration, but the relationship may not be a constant [12]. Total dissolved solids (TDS) values ranged from 100.00 to 1200.00 mg/L for the area. The average value of TDS for the area is 504.00 mg/L, which is fairly above the WHO limit of 500.00 mg/L. Values of total suspended solids (TSS) ranged from 100.00 to 1200.00 mg/L for the area. The area has a mean TSS value of 429.99 mg/L, slightly below the WHO standard of 500.00 mg/L.

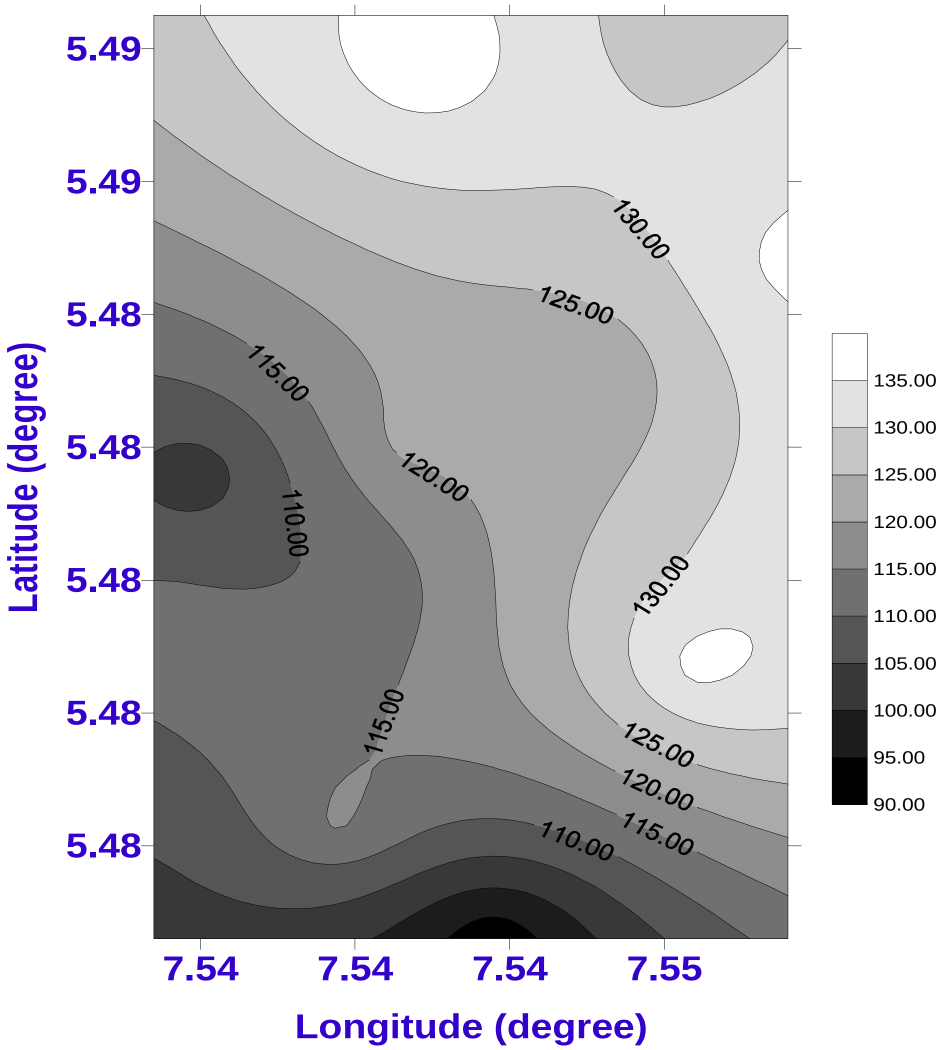

Figure 2: Digital elevation model of the area

Table 2: Some physical and chemical properties of the groundwater samples

No	Location	pH	Conductivity (µs/cm)	Turbidity (NTU)	Total dissolved Solids (mg/l)	Acidity (mg/l)	Alkalinity (mg/l)	Total suspended Solids (mg/l)	Total solids (mg/l)
1	PG hostel	4.71	100.00	91.80	150.00	1.61	21.50	350.00	500.00
2	Chapel of revelation	5.09	66.67	89.20	100.00	1.52	36.00	200.00	300.00
3	Eng. Block	6.90	233.30	90.50	350.00	0.75	28.75	250.00	600.00
4	Staff school	6.27	300.00	86.10	450.00	0.91	21.40	350.00	800.00
5	Male hostel	4.81	400.00	89.60	600.00	2.00	20.30	200.00	800.00
6	Admin block	5.27	400.00	92.60	600.00	1.12	15.60	300.00	900.00
7	VC's lodge	6.94	600.00	88.50	900.00	0.74	18.90	100.00	1000.00
8	Zenith bank (NRCRI)	4.96	333.33	91.40	500.00	1.91	20.10	700.00	1200.00
9	Opposite gate 6 (MOUAU)	4.98	266.68	91.80	400.00	1.82	21.20	400.00	800.00
10	MPP6 Umudike	5.04	200.01	92.00	300.00	1.04	22.10	800.00	1100.00
11	CNAS	5.49	600.03	88.70	900.00	1.01	23.40	1200.00	2100.00
12	All saints' chapel (NRCRI)	5.22	533.36	89.80	800.00	1.32	21.45	300.00	1100.00
WHO		**6.50- 8.50**	**500**	**5.00**	**500.00**	**1.00**	**200.00**	**500.00**	**1000.00**

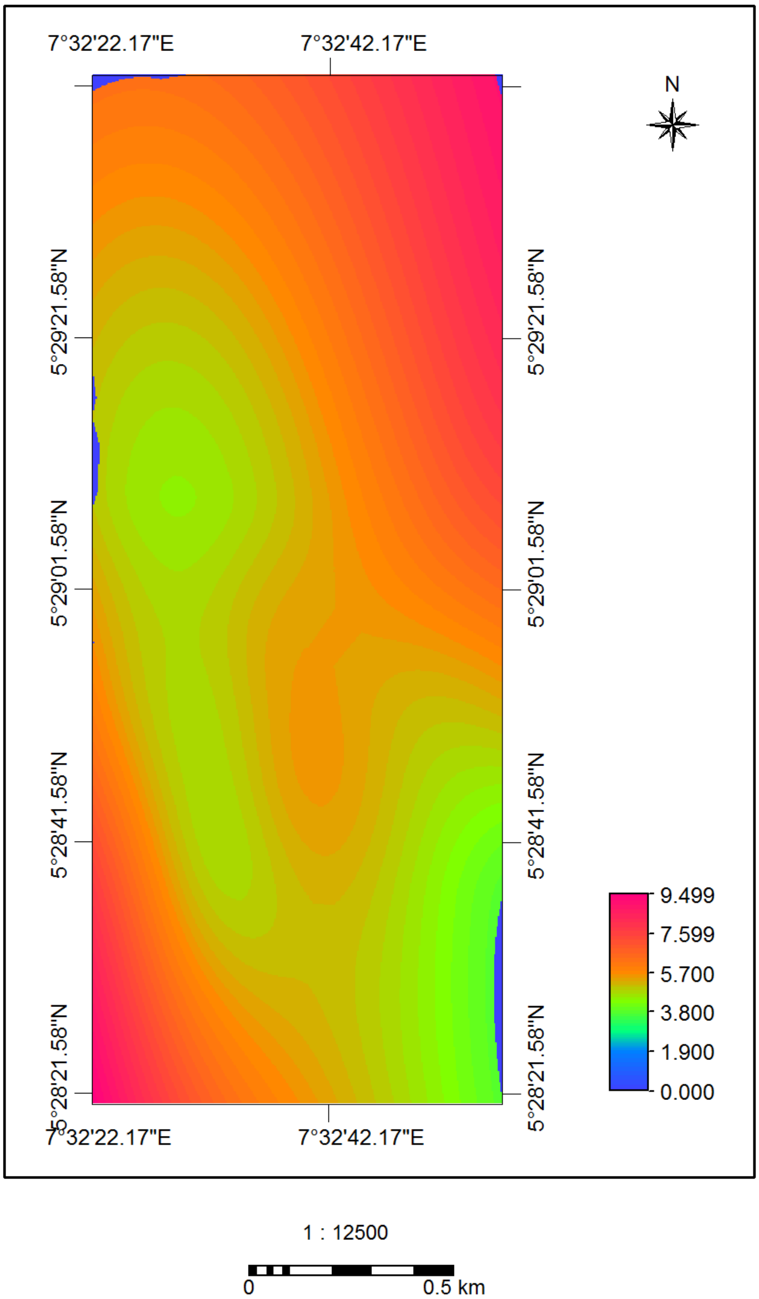

Figure 3a: Digital terrain model of pH

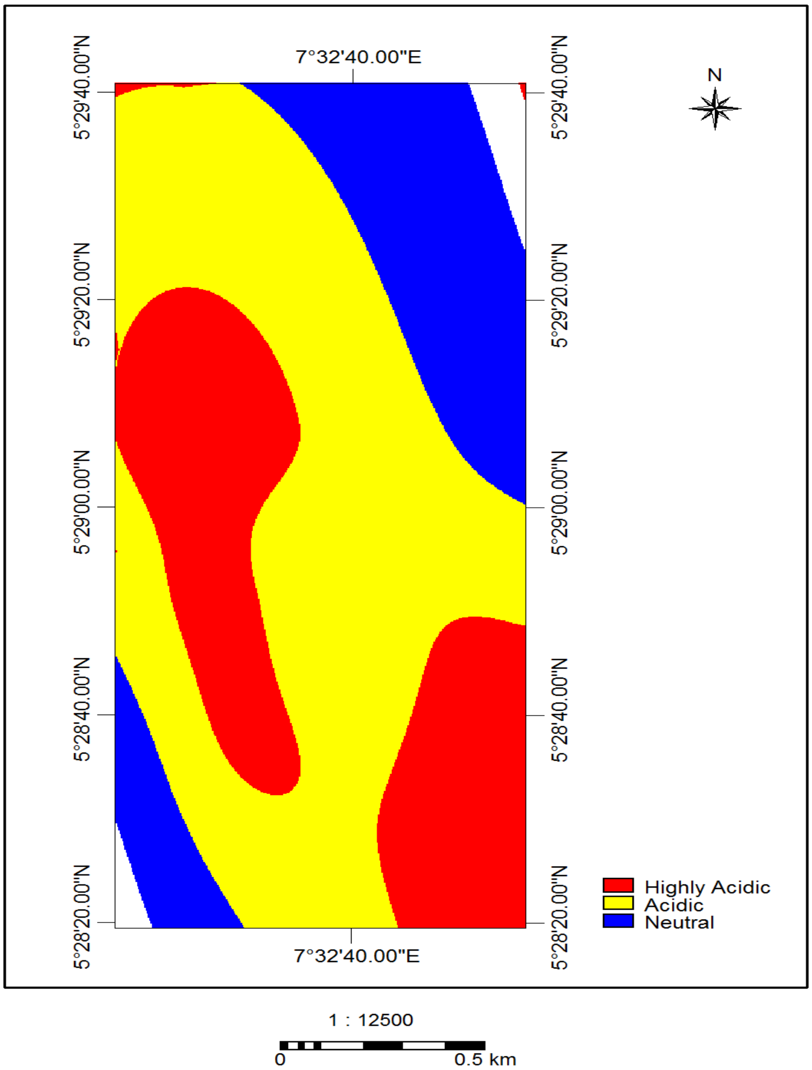

Figure 3b: Vulnerability map of pH

Final Hazard Map

High performance remote sensing/GIS computer based tool, ILWIS 2.1 plays an important role for water resource management. It represents a technological advancement in terms of overlay mapping techniques [13]. The GIS software ILWIS 2.1, an acronym for the Integrated Land and Water Information System, integrates conventional GIS techniques; digital image processing and raster based spatial modeling. It can generate information from available data on spatial and temporal patterns and processes on the earth surface [8]. The digital terrain models and vulnerability maps for each groundwater quality parameter were prepared using the ILWIS 2.1. These parameters were then combined to produce the final hazard map of the area.

The degree of hazard of a certain area is determined by a combination of factors. The different factors, which influence the degree of hazard, can be observed separately, although they do influence each other [14]. The factors are provided in the form of parameter maps, each of them describing a potentially damaging phenomenon. Figure 3a shows the digital terrain model of pH, while Figure 3b shows the vulnerability of pH in the area. Figure 4a shows the digital terrain model of acidity, while Figure 4b shows the vulnerability map of acidity in the area. From the above two figures, areas with low pH seems to correspond with areas with high acidity, showing the pH and acidity are inversely related. Figure 5 represents the final hazard map of the study area based on the groundwater quality parameters used for the study. The map delineates the area into four zones: low hazard zone, moderate hazard zone, high hazard zone and very high hazard zone. The very high hazard zone seems to be the largest zone and extends mostly towards the southern part of the study area, indicating that the contaminants seem to concentrate at the southern part of the area, which also has low elevation.

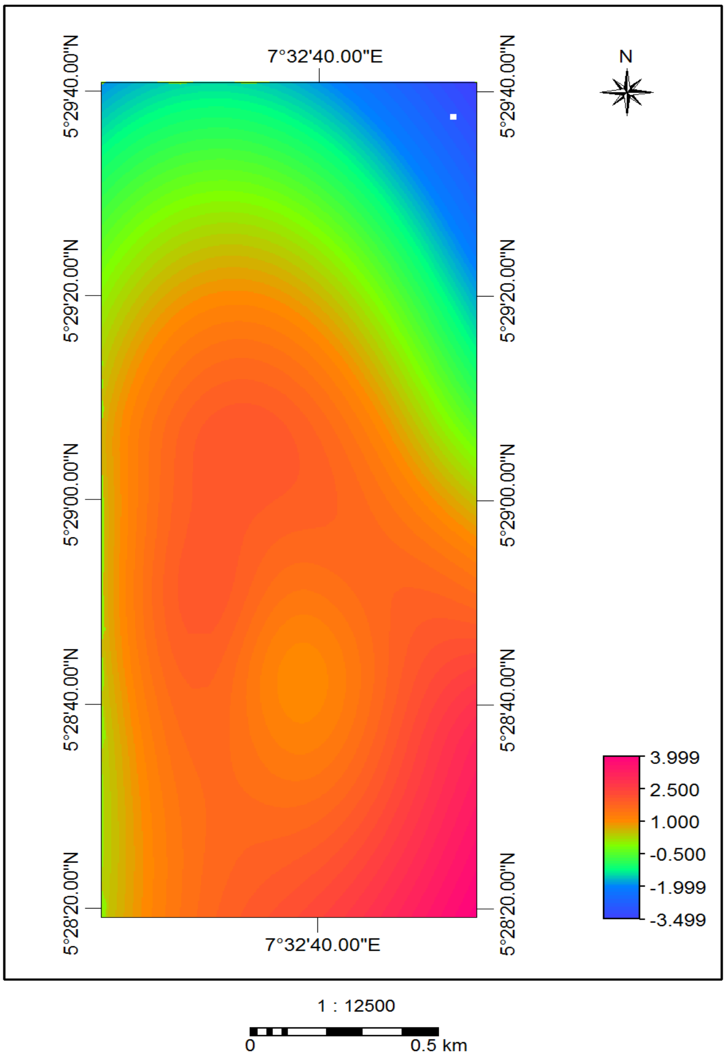

Figure 4a: Digital terrain model of acidity

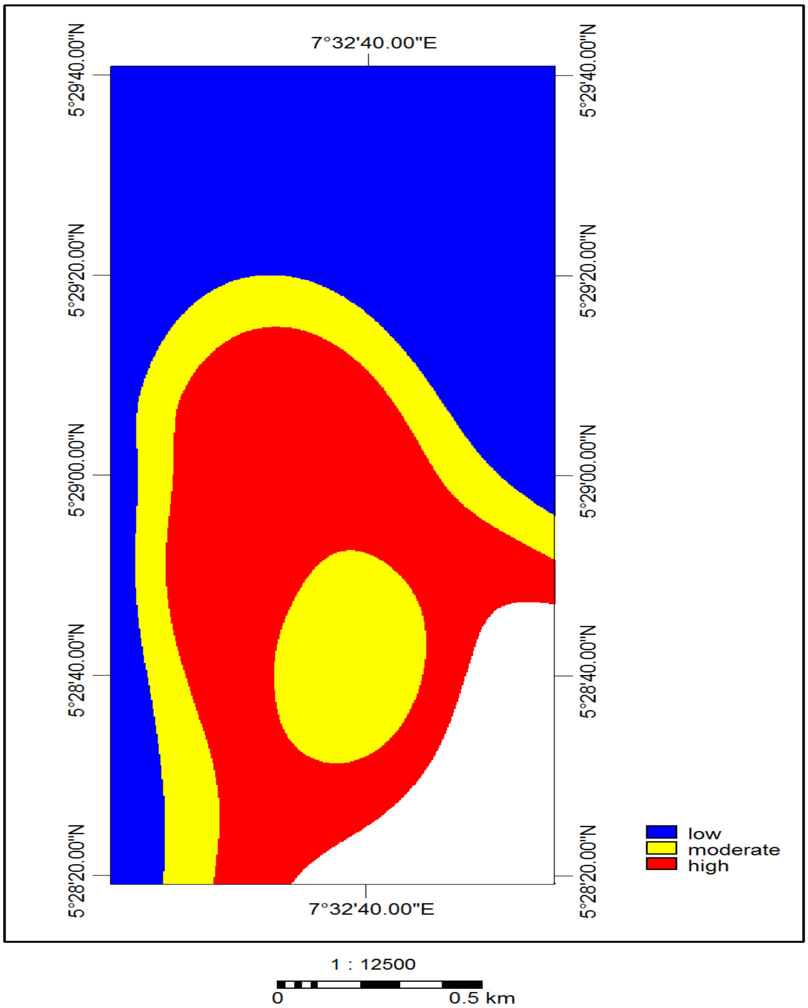

Figure 4b: Vulnerability map of acidity

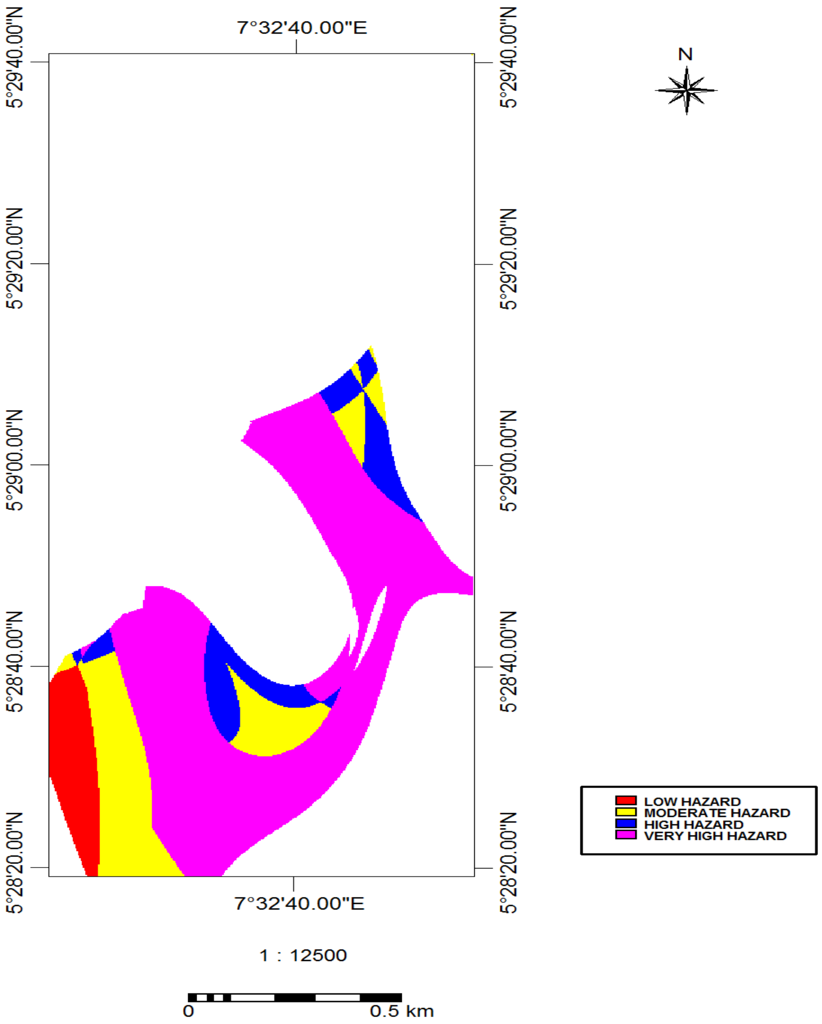

Figure 5: Final hazard map of the study area

CONCLUSION

This study was carried out to analyze the impact of various data layers viz. topographic slope, groundwater slope and land use activities on the distribution of groundwater quality; map groundwater quality with respect to certain significant groundwater quality parameters, as well as prepare the groundwater quality sensitive zone map for Michael Okpara University of Agriculture, Umudike and Its Environs, Southeastern Nigeria.

The digital elevation model of the area shows that groundwater flows from north to south, indicating that pollutants seem to migrate towards the southern part of the study area. The digital terrain models and vulnerability maps for each parameter were prepared using the ILWIS 2.1. These parameters were then combined to produce the final hazard map of the area. Therefore, combination of both groundwater quality parameters and GIS methods is very useful as GIS provides efficient capacity to visualize the spatial data [15]. The study has shown that Geographic

Information System (GIS) software is very useful in the analysis of topographic slope, groundwater table variation and land use activities in the distribution of groundwater pollution.

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