Gis-based Analysis of Water Quality Parameters of Groundwater with Proximity to Onsite Wastes Pits in Vom Community of Jos South, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author RED designed the study, carried out the GIS analysis and wrote the first draft of the manuscript. Author MIA supervised the laboratory analysis and carried out the literature searches. Author ESI also carried out the GIS analysis for the study. All authors read and approved the final manuscript.

Original Research Article	

ABSTRACT

Water quality assessment is an important part of environmental quality management especially in groundwater resources located close to sources of contamination. This study involved the assessment of groundwater quality for hand dug wells at locations with proximity to pit latrines in Vom community, Plateau State, Nigeria and the use of GIS for data analysis. Water samples were collected from six (6) locations in a small area to assume possible interaction between the water in the sampling wells, the maximum distance between any two points being 100 m and the minimum distance being 22 m. Eleven (11) physical, bacteriological and chemical parameters were analyzed for the water samples. The results were compared with World Health Organization and Nigerian Standard for Drinking Water Quality standards. The chemical parameters in the samples tested met the WHO and NSDWQ limits with the exception of pH which was slightly acidic for four samples. The results also showed that *E. coli* was found in all the samples tested. This may be attributed to the proximity of the wells to pit latrines. The results obtained from laboratory analyses

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were inputted into a GIS database in ILWIS 3.8 where the variation maps were developed and also classified maps for each of the parameters based on whether they meet WHO standards or not. The classified maps were all overlaid in GIS to develop the groundwater quality information map where any point highlighted gives information on the parameters for that point. This makes the retrieval of water quality parameters easy and also the comparison of the parameters with respect to location. Treatment of the groundwater with chemicals like soda ash and chlorine are recommended before consumption. It is generally recommended that wells should not be located in close proximity to onsite underground wastes disposal pits. Government should provide sufficient potable water for the Vom Community.

1. INTRODUCTION

Groundwater provides the largest source of usable water storage in Nigeria. Worldwide, more than a third of all water used by humans comes from groundwater [1,2]. The volume in groundwater resources exceeds by more than a thousand times the volume of fresh water in all water courses [3]. The fact that groundwater can be used with little or no treatment [4] makes it attractive to both urban and rural dwellers because of economic reasons related to easy abstraction and direct use [5].

Water is normally withdrawn from groundwater reservoirs through wells and boreholes but the rate of its natural replenishment is extremely low. The need for potable water in both rural and urban communities has resulted in the rapid increase of hand dug wells and boreholes with some, located within the proximity of on-site wastes disposal facilities such as soak away and pit latrines which are considered to be point sources of pollution [6]. Groundwater sources are often contaminated by pit latrines when the safe distance between a water point and pit latrine is not adequately maintained [7]. The quality of groundwater resource therefore depends on the management of human waste as well as the natural physico-chemical characteristics of the catchments area [8].

Groundwater sources are being increasingly used as drinking water yet [9], testing to assess the quality of the water is almost non-existent. Although, it is true that soils generally perform the function of reducing the effect of microorganisms by simple filtration mechanism [3,4], pollution of groundwater by micro-organisms, especially those located near septic tanks or soak away can occur significantly.

Pit latrines are pretty much in use in semi-urban and rural areas of Plateau State and most parts of Nigeria. In most cases the latrines are not lined thereby permitting direct leaching of contaminants into groundwater resources. There communities have no access to pipe-borne water so they resort to digging shallow wells in their individual households without information on latrines that may be located nearby. Since the wells are within individual households, there is no assessment of water quality.

Pollutants from septic tanks and pit latrines systems may contribute nitrates to the groundwater if free oxygen is present [10]. The geology of an area, underground waters are typically rich in dissolved solids especially carbonates, sulphates, calcium and magnesium. Other ions may also be present including chlorides and traces of bicarbonates. The fact that these sources are open to pollutants which often distort the integrity of the water has made it important that the quality is assessed from time to time.

It is often there necessary to obtain physical, chemical and bacteriological characteristics of the groundwater so as to monitor water quality and compare with water quality standards for domestic use.

Results of groundwater quality can be presented in geographic information system (GIS) format for better visualization and easier access to policy makers and other stakeholders. GIS provides the use of improved communication tools/techniques for water quality interpretation. It is a powerful tool for mapping groundwater vulnerability to solve and assess water quality problems. Furthermore, it helps in understanding spatial and temporal variations of the physical, chemical and bacteriological parameters [11-15,4].

A study by Beka, et al. [16] in Jos and environs which is within the study area utilized 30 water

samples from hand dug wells within different rock types. The samples were analysed for the following chemical parameters: pH, TDS, Total Hardness, Ca, Mg, Cu, Fe, Mn, NO_3, SO_4 and Cl. High nitrate levels were obtained predominantly within the most developed areas which may have resulted from sewage, pit latrines and refuse dumps. They recommended adequate siting and planning of well locations. Another study carried out by Jidauna, et al. [17] examined the quality of 20 well water samples in Jos metropolis with about 80% close to sources of contaminants. 90% of the samples tested positive to faecal coliform while 80% of the chemical parameters tested were within the national standard for drinking water quality set by Standard Organization of Nigeria. They recommended treatment of the well water before drinking and enforcement of sanitary laws. Junaid and Agina [18] also carried out a study to assess the bacteriological quality of drinking water sources in Plateau state with three of the samples being groundwater. The water tested were all contaminated because coliform exceeded the permissible limit recommended by World Health Organization (WHO) standard for drinking water. They concluded that the water sources tested were not fit for human consumption and hazardous to health. They recommended that the water should be boiled before consumption, preventive public health measures should be reinforced especially among domestic animal handlers and pregnant women. None of these methods employed GIS for data storage and analysis.

The aim of this research is to carry out physico-chemical and bacteriological analysis on water samples obtained from randomly selected hand dug wells within areas near pit latrines in Vom Jos South Local Government Area, Plateau State, Nigeria with the following objectives:

  i.   To assess the level of contamination in ground water near pit latrines within the study area.
  ii. To determine the levels of the physical, chemical and bacteriological parameters present in the samples and compare to World Health Organization (W. H. O.) standards for drinking water and Nigerian Standard for Drinking Water Quality (NSDWQ).
  iii. To produce groundwater quality information Maps for the study area using GIS software.

2. MATERIALS AND METHODS

2.1 Study Area

Vom is a settlement in Jos South Local Government Area in Plateau State, Nigeria. The study area is located within 9º43'21"N to 9º43'29"N and 8º47'50"E to 8º47'57"E and it is about 17 km to Bukuru, the Local Government Headquarters. Vom has an approximate population of 12,000 in habitants.

2.1.1 Climate and vegetation

The climate of the area is typical of the Jos-Plateau which is the tropical zone type. It is characterized by two contrasting climatic conditions namely: rainy season and the dry season. The rainy season starts around April and ends around October while the dry season starts around October and ends around March. The study area lies within the Guinea Savannah vegetation zone which is characterized by sparsely distributed shrubs and trees. The area is dominated by quartz rich soils as a result of the high resistance of quartz to weathering.

2.1.2 Topography and drainage pattern

The area has a very rugged terrain which is rocky and hilly with some parts characterized by low lands giving the hill a very prominent relief.

The drainage pattern of the Vom hills can be described as dendritic and the streamflow is structurally controlled. The Ouree River is the main river that drains the surface water from the surrounding hills and mountains and it's a major tributary of the Kaduna River.

2.1.3 Geology, hydrogeology and hydrology of the area

The younger granite complex areas comprise of a series of high level intrusive granites of different chemical composition within the basement complex.

There are four types of aquifers:

  • The alluvial aquifers as a result of infill of river channels
  • Weathered soft overburden aquifers - consist predominantly of clay and insitu chemically weathered rocks with sand and gritty clays as the most common

constituents formed as a result of burrowing activities of termites. It is suitable for hand dug wells.
- Fractured crystalline aquifers - these contain water in amounts on which open wells and boreholes can be sited in tectonically fractured zones resulting in high yielding boreholes in the major fractured zones with yields from $10m^3/hr$ and above.
- Fluvial volcanic aquifer

Most of the first two types of aquifers water depths range between 10 – 15 m. The fractured aquifers range between 35 – 40 m but sometimes up to 100 m. There are also cases of artesian aquifers.

2.2 Methodology

The methods used for the study are:

2.2.1 Sample collection

Water samples were collected from six (6) randomly selected hand dug wells situated close to pit latrines in Vom community within Jos South LGA. The locations where samples were collected were influenced by identifying pit latrines with close proximity to wells within the study area and the accessibility for sample collection. Depths to static water level and depths of the wells were measured.

Geographic Positioning System (GPS) was used to collect locational coordinates and elevation data which were plotted in GIS software to obtain the general overview of the topography of the area.

The samples were collected in November just after the rainy season that ended in October in the year 2019. Sterilized bottles with screw caps were used and introduction of contaminants from external pollutants apart from the water was avoided.

2.2.2 Laboratory analyses

Laboratory analyses using standard methods were carried out on the samples for the following parameters:

- Physical parameters: Turbidity, Conductivity, Total Dissolved Solids, Temperature, pH and Colour.
- Chemical parameters: Chloride, Nitrite, Nitrate, Phosphate and Ammonia.

- Bacteriological parameters: Escherichia Coli and Faecal Streptococcus

2.2.3 GIS-based analysis

The results obtained from laboratory analyses were inputted into a GIS data base in ILWIS 3.8. The results for each of the parameters was then plotted in the GIS software and the moving average point interpolation method was used to show the distribution of the different parameters tested for the study area of Vom being a compact area of about 16900 m^2. The method performs a weighted averaging on point values and returns a raster map as output. The weight function was specified as 1.0 and a limiting distance as 100 m.

The World Health Organization limiting values for drinking water were used to develop maps that showed whether the parameters plotted were 'OK' or 'NOT OK' by using the method of 'slicing' that classifies the values of a raster map. Ranges of values of the input map were grouped together into values that were within W.H.O. standard limits classified as 'OK' and those that were above the limit classified as 'NOT OK' to produce one output map for each parameter. The maps were then crossed in GIS to show the conformity of all the samples to the WHO standards for all the parameters tested.

3. RESULTS AND DISCUSSION

3.1 Sample Locations

The location of the samples, elevation, depth to static water level and depth of the wells are as tabulated in Table 1.

The depths of wells within the study area were found to be between 8.4 m to 11.3 m and depth to static water level was between 3.6 m to 5.2 m for Vom. From the data collected the distances of pit latrines to the wells where water samples were collected were found to be between 5.5 m to 9.7 m.

3.2 Analysis of Physical Parameters

The results for the physical parameters tested are as shown in Table 2.

The results in Table 2 shows that all measured physical parameters met both the standard of WHO and NSDWQ except pH for some samples. The pH of the samples 1, 2 and 3 showed they were acidic with values between 6.1 and 6.2

Table 1. Location of wells and well information

Sample Number	Onsite Contaminant	Well coordinates		Elevation (m)	Static water well		Distance from Contaminants (m)
		N	E		Level (m)	Depth (m)	
1	Latrine	09°43´24.1	008°47´51.4	1282	3.6	10.3	7.6
2	Latrine	09°43´22.8	008°47´53.2	1281	4.4	10.9	5.0
3	Latrine	09°43´25.5	008°47´54.4	1272	4.7	11.3	9.7
4	Latrine	09°43´23.8	008°47´54.5	1279	5.0	9.6	5.5
5	Latrine	09°43´26.5	008°47´55.3	1273	5.2	10.5	5.5
6	Latrine	09°43´25.8	008°47´55.3	1273	5.1	10.9	6.0

Table 2. Results of physical analysis

Sample	Turbidity (NTU)	Conductivity (µs/cm)	TDS (ppm)	Temp °C	pH	Colour (TCU)
1	2.60	110.0	50.0	28.2	6.2	2.4
2	2.68	120.0	70.0	28.5	7.6	3.0
3	2.63	110.0	60.0	28.5	6.1	2.5
4	3.04	160.0	80.0	28.5	6.7	3.2
5	3.01	130.0	70.0	27.7	6.2	3.2
6	2.44	140.0	60.0	27.6	6.4	2.8
NSDWQ	5	1000	500	-	6.5-8.5	15
WHO	5	750	500	-	6.5-8.5	15

Table 3. Results of chemical analysis

Sample Number	Chloride ion (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	Phosphate (mg/L)	Ammonia (mg/L)
1	26.0	0.14	26.0	0.04	0.00
2	28.0	0.18	28.0	0.05	0.01
3	24.0	0.16	24.0	0.04	0.01
4	35.0	0.14	28.0	0.03	0.00
5	30.0	0.15	26.0	0.04	0.02
6	28.0	0.14	25.0	0.06	0.01
NSDWQ	250	3.0	50.0	-	-
WHO	250	3.0	50.0	-	-

while the other samples were within the acceptable range of 6.5 – 8.5.

Acidity increases the capacity of the water to attack geological materials and leach toxic trace metals into the water making it potentially harmful for human consumption but the values obtained for samples that were acidic were not too significant.

Turbidity and colours in ground water can be caused by clay, silt, finely dissolved organic and inorganic materials, and sometimes even microorganism. They can be disturbing in terms of aesthetics of the water which makes it not to be appealing to the user though they may not be of significant health effect.

3.3 Analysis of Chemical Parameters

The results of the chemical parameters tested are shown in Table 3.

The results indicate the chemical parameters for all the samples investigated are within the WHO and NSDWQ standard limits for drinking water.

Phosphate has no standard but its presence in large quantity can affect the health of the consumer.

Chloride can result in salty taste at high concentrations in water. No health –based limit is proposed for chloride in drinking water [19].

Nitrates represent the final product of the biochemical oxidation of ammonia. Its presence is probably due to the presence of nitrogenous organic matter [10]. Generally, nitrates disclose the evidence of previous pollution of water that has been modified by self-purification processes to a final mineral form.

Nitrites represent the first product of the oxidation of free ammonia by biochemical activity. Free oxygen must be present. Unpolluted natural waters contain practically no nitrites, so concentrations exceeding the very low value of 0.001 mg/l are of sanitary significance, indicating water subject to pollution [10]. The water samples tested were close to pit toilets and the values of nitrite ranged between 0.14 – 0.18 mg/l showing some sanitary significance though not at levels that can be of harmful effect to health. Nitrites in concentrations greater than 1 mg/l in drinking water are said to be hazardous to infants and should not be used for infant feeding [10].

Ammonia has a toxic effect on healthy humans only if the intake becomes higher than the capacity to detoxify. Apart from other sources, ammonia can originate from sewage infiltration in groundwater. It is an indicator of possible

11

bacteria, sewage and animal waste pollution. On the odour threshold Ammonia has a limit of 1.5 mg/l with a taste threshold of 35 mg/l though it has no direct relevance to health at these levels [19]. The values obtained from the laboratory tests conducted showed that Ammonia content in the water was not of significant values ranging from 0 – 0.02 mg/l.

3.4 Analysis of Biological Parameters

Biological analysis of the groundwater samples yielded the results presented in Table 4.

E. coli was discovered in all samples, with the values ranging between 30-50. The reason may be attributed to the proximity of the wells to latrines or it could be from external contaminants. E. coli can cause many illnesses such as pneumonia, urinary tract infections, diarrhea, and similar diseases.

Ebri, et al. [5] in their investigation of groundwater quality in boreholes with proximity to soak away concluded that siting borehole close to any pollution source (soak away) is very detrimental to the quality of the ground water resources. Singh et al. [20] also showed in their research that the quality of groundwater source has deteriorated by human and industrial

activities some of which are release of effluent from pits, releases of residential wastewater in defective channels, improper management of sanitary landfills, contaminated industrial sites, industrial discharges and others.

3.5 GIS-based Data Analysis

The elevations of sample points plotted in ILWIS 3.8 showed that the elevations ranged between 1272 m and 1282 m as shown in Fig. 1.

Static water levels for the wells were plotted in ILWIS and shown in Fig. 2. The levels ranged between 3.6 m and 5.2 m.

Figs. 3, 4, 5, 6 and 7 show the variations of Chloride, Nitrite, Nitrate, Phosphate and Ammonia in the study area. The implications of these chemical parameters to health have already been discussed. The study was carried out in a small area where there is possibility of interaction between the water in the sampling wells, the maximum distance between any two points being 100 m and the minimum distance being 22 m. This is to allow for the assumption that the values for parameters obtained at one point may be similar and/or closely related to values obtained in close by points in that the points can be interpolated into a surface.
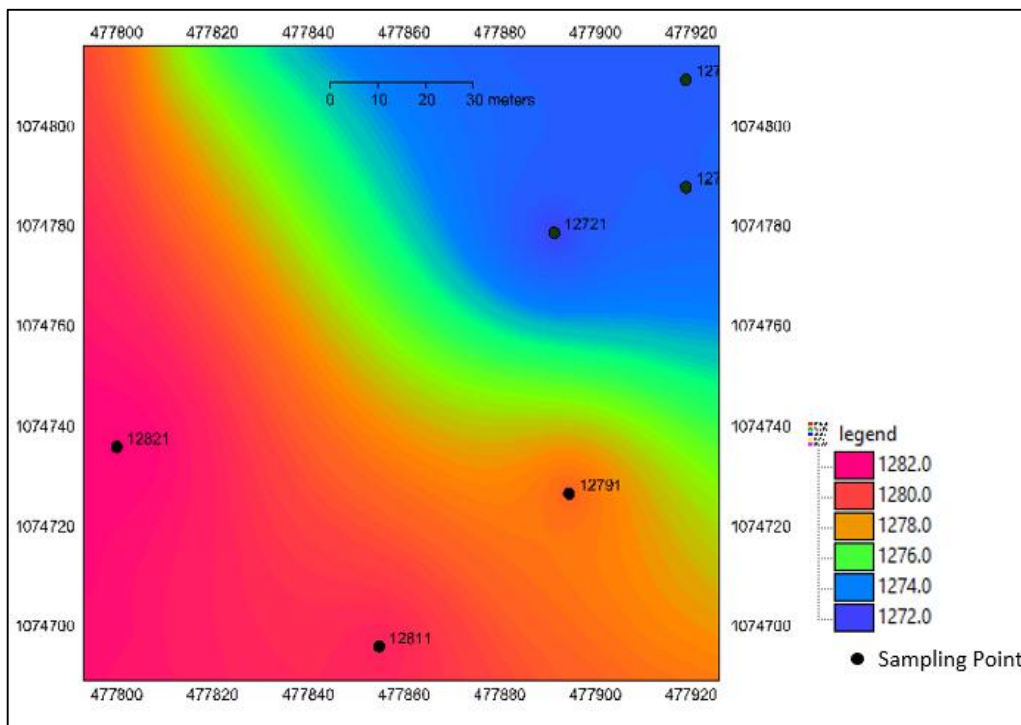

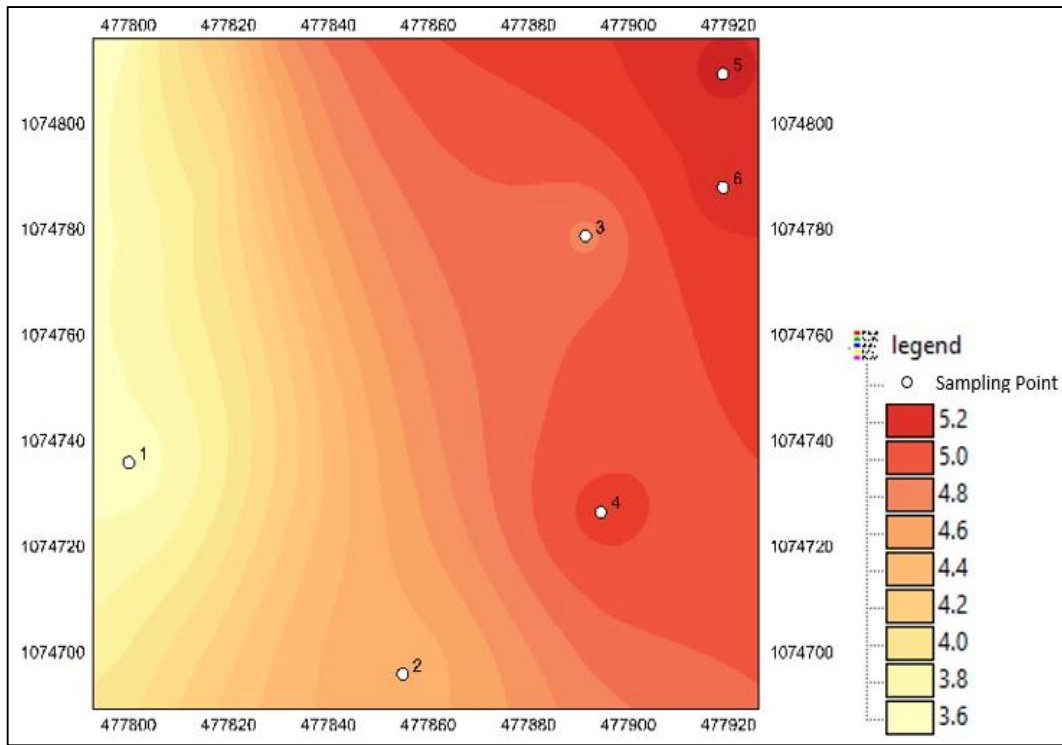**Fig. 1. Elevation map of vom showing the sampling points**

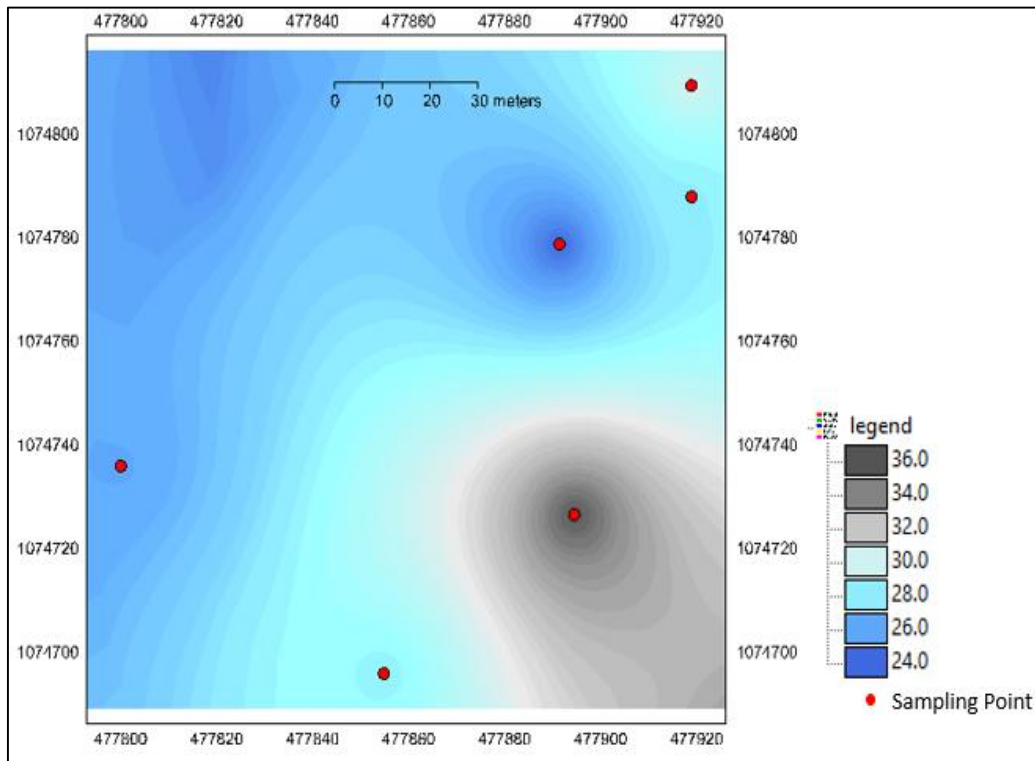**Fig. 2. Depth to static water level in sampling wells in vom**
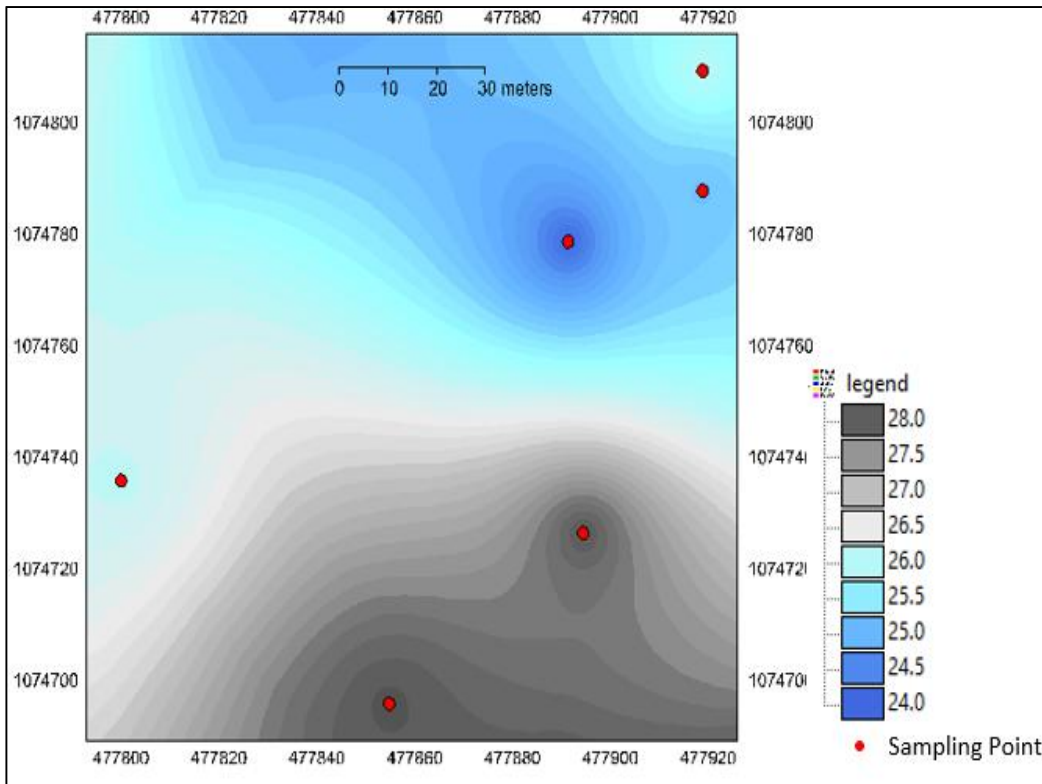

Fig. 3. Chloride distribution of the study area
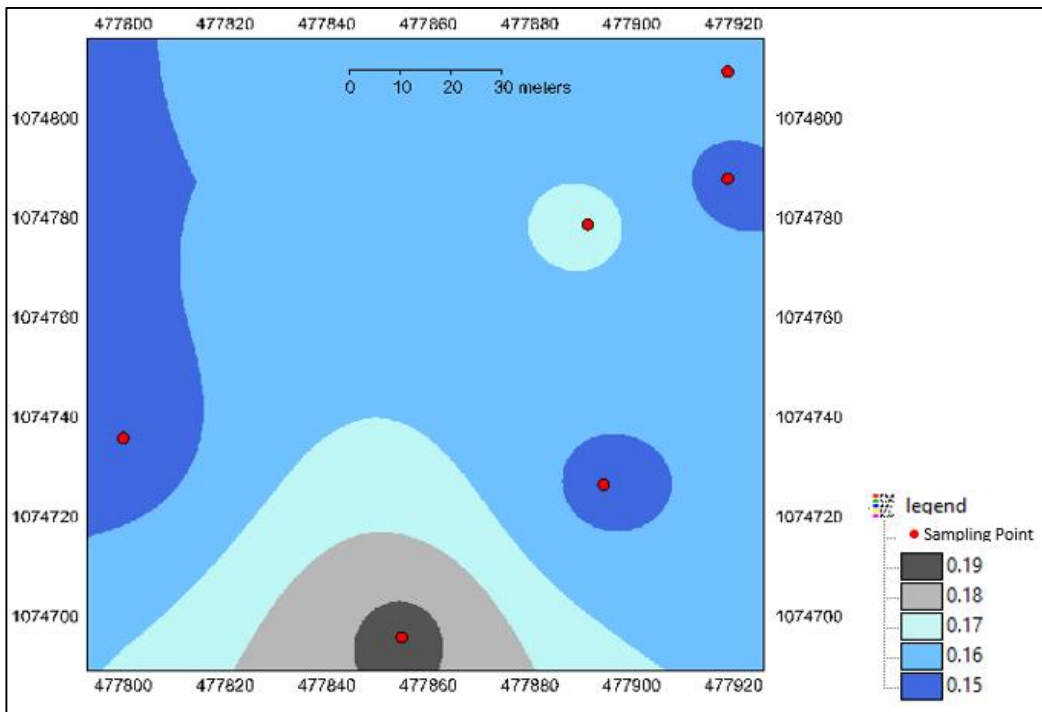
Fig. 4. Nitrite distribution of the study area
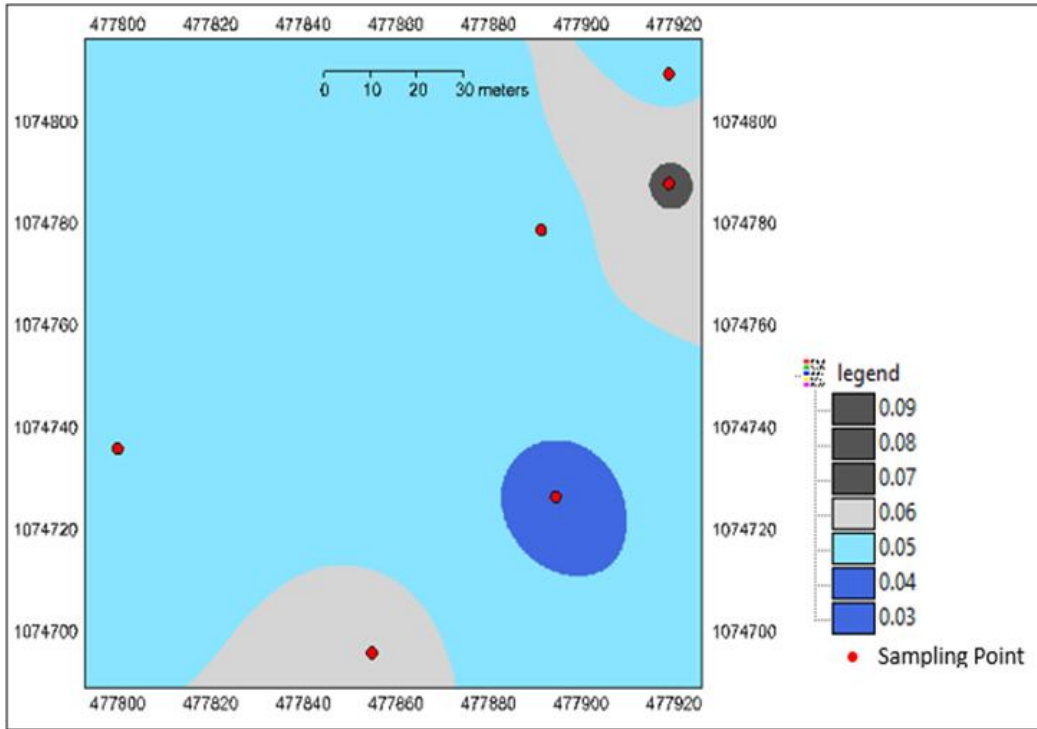

Fig. 5. Nitrate distribution of the study area

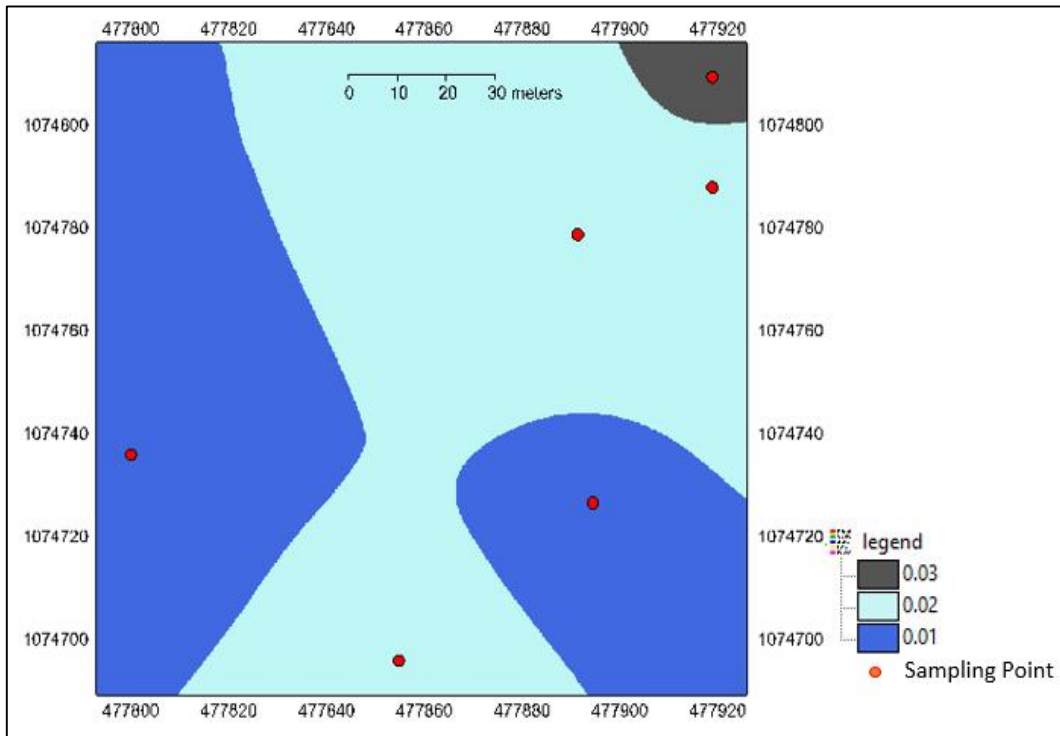**Fig. 6. Phosphate distribution of the study area**

Fig. 7. Ammonia distribution of the study area

Coordinate	(477799.83,1074736.25)
Vom_Cl_NO2_NO3_Phosphate_Ammonia_Ecoli_Turbidity_Conductivity_TDS_pH_Colour	OK * OK * OK * OK * OK * NOT_OK * OK * OK * OK * NOT_OK * OK
Vom_GWSD1	798,68
vom_points	Pt 1
Northings	477800.1
Eastings	1074735.7
Elevation	1282.0
Static_Depth	3.6
Chloride_Ion	26.0
Nitrite	0.14
Nitrate	26.0
Phosphate	0.04
Ammonia	0.00
EColi	30.0
Turbidity	2.6
Conductivity	110.0
TDS	50.0
pH	6.2
Colour	2.4

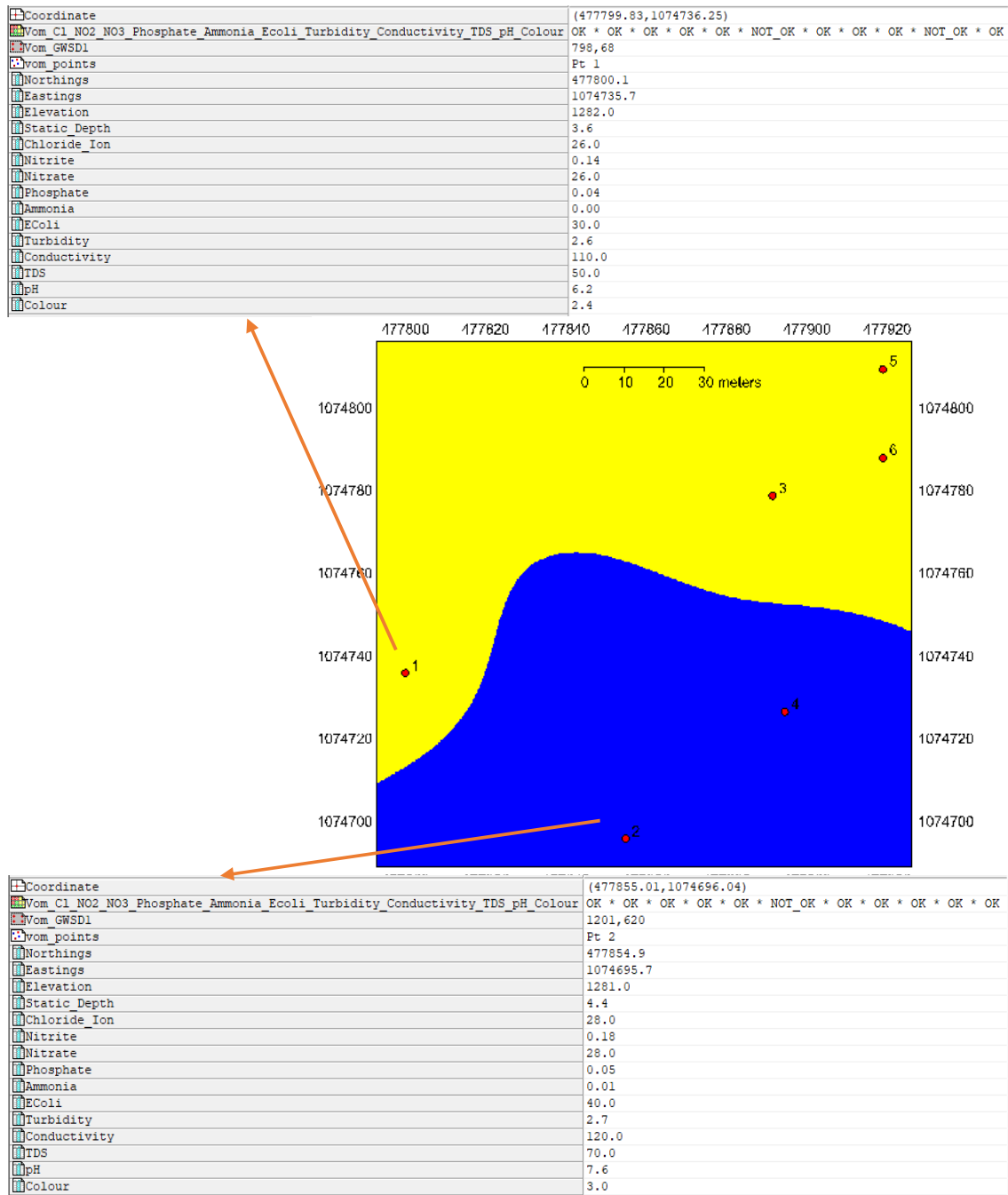| Coordinate	(477855.01,1074696.04)
Vom_Cl_NO2_NO3_Phosphate_Ammonia_Ecoli_Turbidity_Conductivity_TDS_pH_Colour	OK * OK * OK * OK * OK * NOT_OK * OK * OK * OK * OK * OK
Vom_GWSD1	1201,620
vom_points	Pt 2
Northings	477854.9
Eastings	1074695.7
Elevation	1281.0
Static_Depth	4.4
Chloride_Ion	28.0
Nitrite	0.18
Nitrate	28.0
Phosphate	0.05
Ammonia	0.01
EColi	40.0
Turbidity	2.7
Conductivity	120.0
TDS	70.0
pH	7.6
Colour	3.0

Fig. 8. GIS cross map of the study area with the physical, biological and chemical parameters

Fig. 8 shows the output of the raster maps for Chloride ion, nitrite, nitrate, phosphate, ammonia, Ecoli, turbidity, conductivity, total dissolved solids, pH and colour that have been classified as either 'OK' or 'NOT OK' according to their conformity to the WHO guidelines for drinking water standards and all overlaid in GIS. At a glance any point highlighted shows the parameters that are within the standard and are 'OK' and those that fall below the standard and are 'NOT OK'. From Fig. 8, Pt1 shows that two parameters are 'NOT OK', these are *E. coli* and pH while Pt2 shows that one parameter is 'NOT OK', that is Ecoli. The parameters for other points can also be viewed in similar manner.

Safe drinking water is one of the necessities in sustaining life and residents of the study area, which is a rural area, use water from groundwater sources for their domestic and other uses. The need to evaluate the quality of the water consistently and get immediate information on the physical, chemical and biological parameters cannot be overemphasized. The use of GIS to analyse and view the spatial distribution of groundwater quality within the study has aided in easy retrieval of the parameters tested and viewing at once their conformity or nonconformity to WHO standards for every sampling point. The use of GIS is useful for viewing groundwater quality for the whole study area and makes spatial assessment and comparison easy for decision making. GIS has allowed a database of groundwater quality to be stored for the study area and this has given the opportunity for the database to be updated anytime more data is collected.

Table 4. Results of biological analysis

Parameters	*E. coli* MPN
1	30.0
2	40.0
3	40.0
4	50.0
5	40.0
6	30.0
NSDWQ	0
WHO	0

4. CONCLUSION

This study has provided data on the level of physical, chemical, and biological properties of water from some hand dug wells with proximity to pit latrines in Vom, Jos south LGA. The study was carried out to compare the level of the properties from the various sources with WHO and NSDWQ standard for drinking water with emphasis on the WHO standard. The chemical parameters in the samples tested were all within the WHO limits with the exception of pH in four samples which were slightly acidic but not of adverse difference to the standard. This can be tolerated and treated with chemical neutralizers. The results also showed that *E. coli* was found in all the samples tested and this can be attributed to the proximity of the wells to pit latrines. This is dangerous to human health and should be properly treated before consumption. The common method of remedying bacteriological contamination, such as *E. coli*, in a residential well is the use of disinfectants such as chlorine.

The water can also be boiled before use. The location of wells within the proximity of pit latrines and soak away or other onsite sources of wastes disposal should generally be avoided. From the study it can also be concluded that GIS is a tool that can be used effectively to study and understand spatial distribution of various water quality parameters of groundwater in any study area. It makes the retrieval of water quality parameters easy and also the comparison of the parameters with respect to location. The use of GIS for analyzing groundwater quality is useful for planners, water quality managers and decision makers for groundwater development and management. A temporal aspect can be included in the GIS data base by continuous assessment of water quality in wells located close to point sources of pollution like pit latrines and soak away.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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