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# Geospatial Modeling of Groundwater Quality in Jos South Local Government Area of Plateau, Nigeria

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## ABSTRACT

Water is an essential requirement by all living things for metabolism. It is universally acknowledged as fundamental, after air, to the needs of man and indeed his survival here on earth. There are different sources of water namely; atmospheric, surface and groundwater. Groundwater is the most dependable due to its widespread occurrence, drought reliability, pure natural quality and consistent temperature. This research examined the quality of groundwater in Jos South Local Government Area using geo-spatial technique within a two-year period. Within these years, samples were collected in five intervals from sixty-four wells/boreholes divided into early rain, peak rain and late rain; early dry and late dry seasons. Different thematic datasets were adequately processed and digitized with root mean square error of <0.00002 while mid-resolution Landsat image was classified using ENVI 4.7 with an accuracy of 0.994 and 99.5% respectively. The results obtained from the different data processes and laboratory analysis were geo-spatially analysed to determine the distribution, trend and inter-relationship among the observed differences in water quality index. The observed differences in water quality index in the study area are closely linked and determined by several factors of which well depth, Landuse, seasonal dynamics and presence or absence of coliform remain predominant. The increase in coliform was observed to be directly proportional to decrease in water quality index in the study area. The water quality index was observed to fall between 0 and 65. The groundwater in the study area is classified into four categories of bad, fair and excellent. However, none of the borehole or well samples fell within the excellent category.

**Keywords :** Groundwater, Geo-spatial, Water Quality Index, Inter-relationship, Landuse, Coliform.

## I. INTRODUCTION

Water is life. It is required by all living things for metabolism (Ayedun *et al.*, 2011). It is second only to air as the most essential natural resource for the survival of man. According to the World Health Organization (WHO), the minimum water requirements for developing and developed countries per person per day are 120 and 400 litres respectively due to difference in infrastructure for water development (WHO, 2012, GLAAS, 2012). There are different sources of water namely; atmospheric, surface and groundwater. Surface water occurs as either fresh or saline. Saline water is found mainly in seas, oceans and occasionally as fossil water trapped within rocks. It constitutes about 97% of total earth water. Fresh water, which constitutes less than 3%, occurs either as solid in ice caps (68.70%), or liquid found as groundwater (30.10%). Surface water (1.20%) which occurs as streams, rivers, lakes etc. is readily available for daily use, while groundwater is available and accessed through wells, springs and boreholes (Oyebode, 2005; Ajewole, 2005; Hefkes *et al*., 1981).

Besides, the current level of urbanization and development has placed additional pressure on water quality even in those areas where surface water is available. As a result of this, there is a need for alternative sources. Groundwater sources provide the most readily available alternative due to its widespread occurrence, drought reliability, pure natural quality and consistent temperature (Ranjana, 2009).

Naturally, groundwater contains mineral ions. These ions are slowly dissolved from soil particles, sediments and rocks as the water travels along mineral surface in the pores or fractures of the unsaturated zone into the aquifer. Generally, metals associated with the aqueous phase of soils are subject to movement with soil water, and may be transported through the vadose zone to groundwater (Pierce *et al*., 1998). They are referred to as dissolved solids. Such contamination from anthropogenic factors is increasingly affecting the quality and limiting groundwater use. It has been established that once pollutant enters the subsurface environment, it may remain concealed for many years, becoming dispersed over wide areas of groundwater aquifer and rendering groundwater supplies unsuitable for consumption and other uses (Sunder *et al*., 2010). Therefore, understanding the potential influences of human activities and the impact of natural interaction on groundwater quality is important for protection and sustainable use of groundwater resources (Jehangir *et al*., 2013).

Evaluation of water quality prior to its use will assist in water treatment and disease prevention. It will also guide farmers in preventing probable deleterious effects on plant productivity as well as protecting industrial equipment against incrustation and corrosion.

Previous groundwater assessment involves various elemental analyses which are subjected to different statistical computations either aimed to check for variance or trend. This method, though still in use produces numerous results that are sometimes difficult to interpret and inadequate for spatial analysis. Based on this, the Water Quality Index Computation and the use of GIS (Geospatial techniques) have been introduced to provide an easy assessment of spatial distribution of water quality in different areas (Kavita, 2010). Geospatial techniques for water quality index have not been carried out in Nigeria especially in the Jos Plateau area which has a peculiar geology in Nigeria. Surface water sources are generally seasonal in this area for which reason most residents depend on groundwater.

## II. MATERIALS AND METHODS

**Study Area**

The study area is located within Latitudes 9°- 10° North and Longitudes 8.5° - 9.0° East (Figures 1a, b & c). It has an area of 510 Km² and a population of 306,716 as at the 2006 census. Bukuru is the LGA headquarters of Jos South. As part of the Jos plateau and due to its high altitude of 1200m above the surrounding plains, Bukuru-Jos experiences low temperature and high rainfall. The climate is the wet and dry type classified as tropical rainy climate by Alkali *et al*., 1993. It is characterized by a mean annual rainfall of 1,050-1,400mm, at its peak between July and August. The mean annual temperature is about 22°C and 24.5°C in the hottest months of March and April.

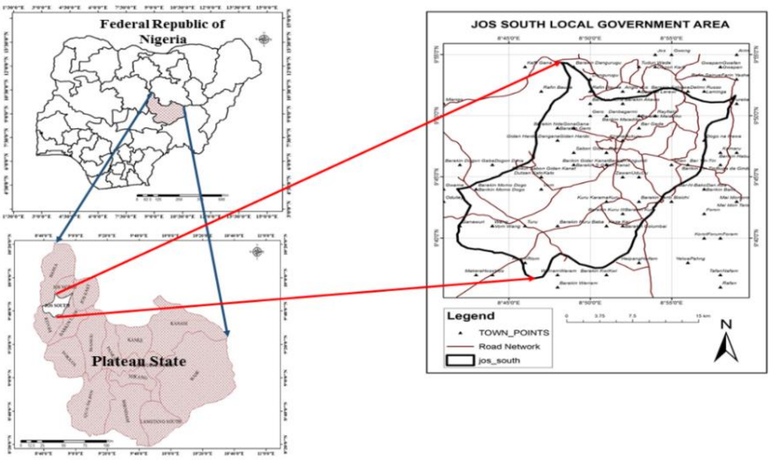



**Figure 1 a, b & c.** Study Area

The study area consists of Precambrian and Cambrian Basement rocks (Williams, 1956; Alkali and Yusuf, 2010) of the older granite suite. These have been eroded to expose the younger granites. It has an elevation of about 1200 m above sea level. The landscape is characterized by rough terrain and a wide expanse of rocky hills.

Bukuru has a generally poor soil with shallow profile due to the rocky environment. The soil is lateritic which is commonly found in the middle belt of Nigeria. The soil moisture regime is uniform while the temperature regime is referred to as Isothermic (Eswarn *et al.*, 1997). The major types of soil in the area include: Lithosols, Acrisols, Cambisols and Luvisols.

### 2.1. Data

Datasets used for this research comprise of primary and secondary data that have both spatial and non-spatial attributes. The primary data include: mid resolution Landsat satellite images of 2015, coordinate value of sample stations and selected points which were acquired with the use of handheld GPS, well/borehole data, water parameter value acquired with automated instruments used during field work and via laboratory analysis. The secondary data include: maps (topographic, soil, geology and administrative), demographic data and Digital Elevation Model (DEM). The borehole and well depth, water temperature and conductivity were measured in the field using Solinst model 107 TLC (Temperature / Level / Conductivity) Meter, with 250 m tape reel while the water sample pH were measured using Milwaukee uP-based pH Meter model MW102 with sensitive prober of ±0.02 pH / ±0.5°C accuracy.

Software packages include: ENVI, ArcGIS, Arc Scene, PAST, Arc Modular Builder, SPSS, Microsoft Office with Excel and Visio extensions and Algorithm for water Quality Index calculation.

### 2.2. Methodology

The existing geology map and other related literature coupled with information derived from field work across the study area were used to review the geology of the study area as thematic data and baseline information for the study). Digital Image Processing Technique which includes: False Colour Composite (CFC) Combination, haze reduction, de-stripping, stretching and onscreen supervised classification was used to process the Landsat satellite images in order to produce the Landuse/Landcover maps of the area.

The study area was gridded into 75 equal measurements of about 9 $km^2$ /grid to ensure that all boreholes and wells were captured as shown in Figure 2.

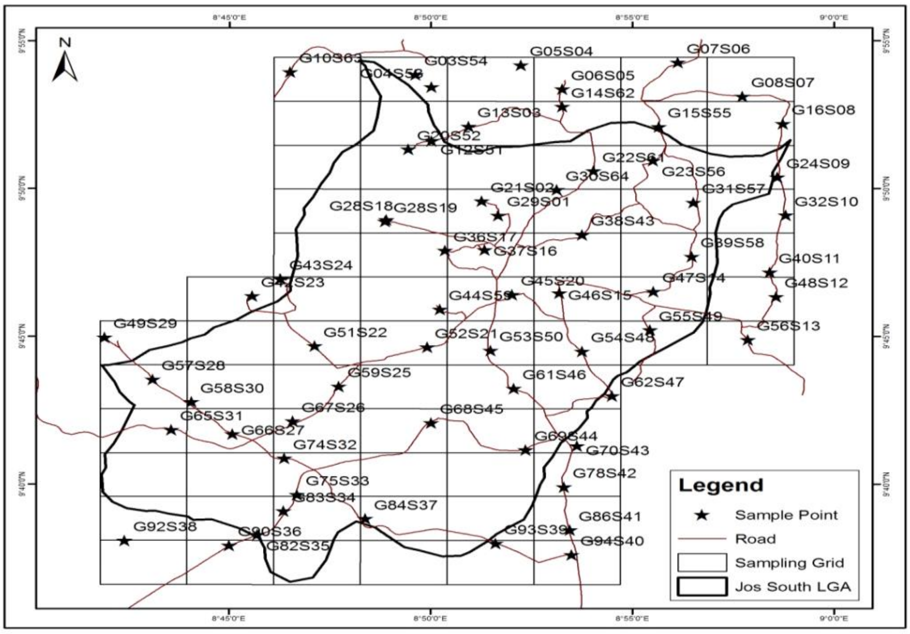



**Figure 2.** Grid Division and Sample Station Distribution

Using accessibility as a major exclusive criterion, nine grids were eliminated. Within each of the remaining 64 grids, one borehole/well was randomly selected. The number of stations was chosen to give consideration to the point-area Root Mean Square Error (RMSE) and Inverse Distance Weighted (IDW) interpolation quality of the selected stations. Field measurements include Borehole & Well depth, water temperature, pH & conductivity while handheld GPS receiver was used to acquire the spatial coordinates and elevation of each point.

The sample collection lasted for two years. Within these years, samples were collected at five intervals divided within the wet and dry seasons. These intervals include: Late dry season (January – March), Early Rain (April –June), Peak Rain (July – August), Late Rain (September – October) and Early Dry (November – December. Standard water samples collection method was employed with strict adherence to quality assurance.

The acquired results from the different thematic data and laboratory analysis were built into a work geo-database from where different geo-spatial analysis such as overlay, interpolation and geo-statistics were applied to determine the distribution, trend and inter-relationship between the observed physico-chemical properties and other thematic data for the overall water quality index.

In addition, multi-criteria weighting and computation of participating thematic datasets and water parameters were utilized to determine the water quality index of each sample station. The output result was also built into the work geo-database from which the water quality index map of the study area was produced (Figure 5).

## III. RESULT AND DISCUSSION

### 3.1.0. Thematic Layers.

In order to achieve the set objectives for this work, different data processing and analysis were carried out. The study area was mapped and delineated to the region of interest. The different thematic data sets which include topographic, soil, geology and administrative maps were adequately processed and digitized with root mean square (RMS) error of <0.00002 while the 30m resolution Landsat image acquired in December, 2015 was classified using ENVI 4.7 with an average kappa coefficient and overall accuracy of 0.994 and 99.5% respectively.

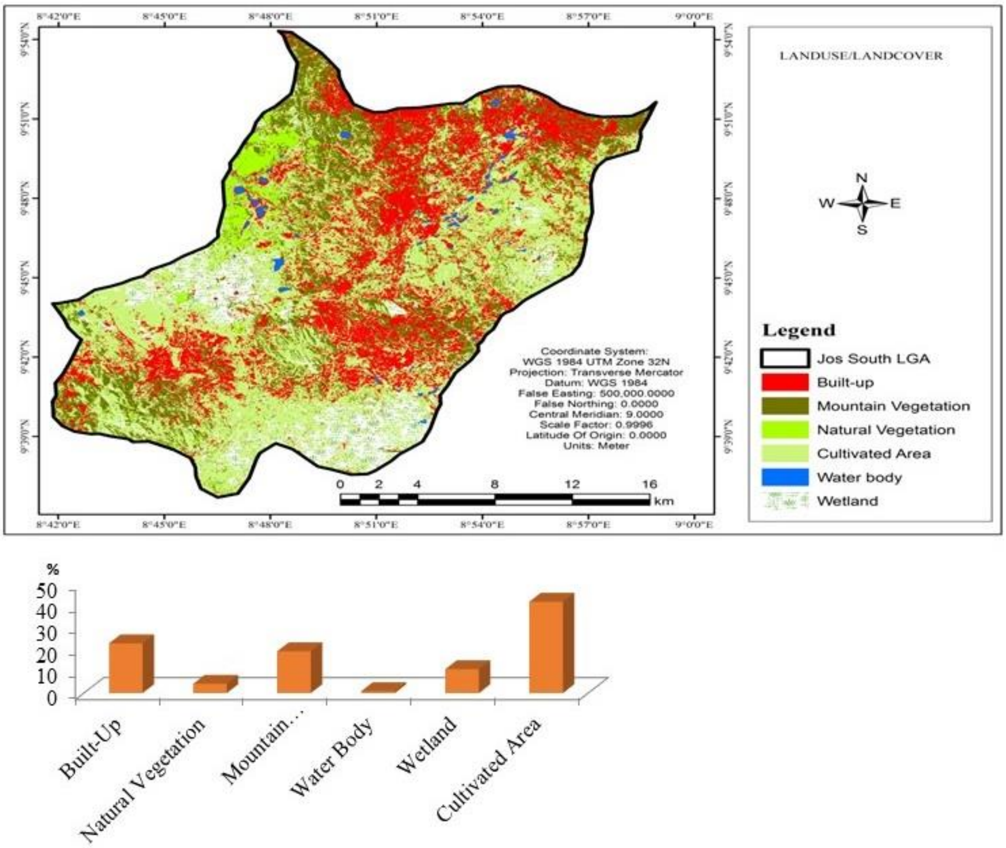



**Figure 3.** Classified Land Use Land Cover Map of Jos South LGA

Analysis of the nature of landuse is very important in predicting the groundwater quality (Krishna *et al.*, 1996). The classified output was vectorized into different Land Use Land Cover thematic classes. The class statistics (see Table 1) shows that the total area under study is 509.8km$^2$. The built-up area shown in Figure 3 above covers 116.4 sq. km representing 22.8% of the study area. It spans from North to South with a linear pattern influenced by the topography and Road network. The water bodies that are present in the study area mostly in Rayfield, Bukuru and Giro areas are majorly abandoned mine ponds.

**Table 1**. Class Statistics of the Different Land Use Land Cover Themes of Jos South LGA.

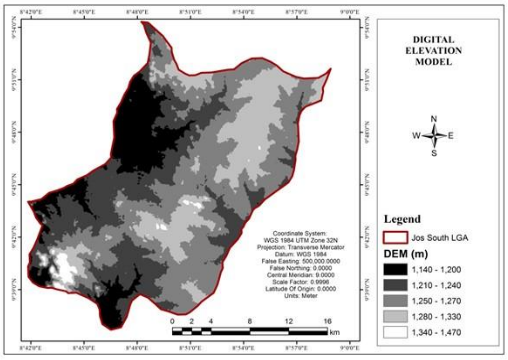
| LULC | Area (sq. m) | Area (sq. km) | Area (%) |
|---|---|---|---|
| **Built-Up** | 116350200 | 116.3502 | 22.81376471 |
| **Natural Vegetation** | 21491100 | 21.4911 | 4.213941176 |
| **Mountain Vegetation** | 97799400 | 97.7994 | 19.17635294 |

| | | | |
|---|---|---|---|
| **Water Body** | 4493700 | 4.4937 | 0.881117647 |
| **Wetland** | 56025000 | 56.025 | 10.98529412 |
| **Cultivated Area** | 213626700 | 213.6267 | 41.88758824 |
| **Total** | 509786100 | 509.7861 | 99.95805882 |

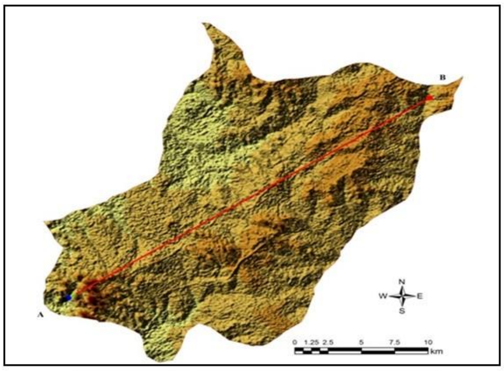
The entire water bodies cover 4.5% of the study area. Agricultural land occupies 213 km² representing 41.8% of the study area while, natural and mountain vegetation occupy 21.5 and 97.8 km² representing 4.2 and 19.2% respectively

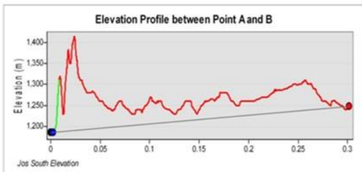
The geomorphologic relief and elevation analysis is an important factor and central to this study. With the elevation analysis and its output such as slope, elevation profile (cross-section plot), 3D rendering and draping; the terrain in relation to well depth, well water volume and distribution of groundwater are better appreciated.

Few areas are relatively flat, punctuated with knoll, stream channels and abandoned mine ponds and excavated debris. Such areas include part of Vom, Ray field, and Gero. In addition, the 3D visualization map and its associated elevation profile graph shown in Figure 4 below further provides the visual explanation of the terrain pattern.




**Digital Elevation Model of the Study Area**






**3D Visualization Map and Elevation Profile Graph of the Study Area**

**Figure 4.** Digital Elevation Model, 3D Visualization Map and Elevation Profile graph of the Study Area.

The elevation profile graphs are cross-sectional charts with elevation plotted against distance. This gives terrain explanation of selected line of site over a set distance. Analysis of the elevation profile highlights the relationship and the effect of terrain on the pattern, distribution and magnitude of groundwater. The satellite image covering the area added as a floating area in Arc Scene environment was draped on a 3D layer in order to provide the Digital Terrain Model (DTM).

**3.2. Spatial Distribution of Water Quality Parameters**

The WQI results obtained for the different sample sites were found to fall between 0 and 65. Based on the WQI rating, groundwater in the study area was classified into four categories of bad, fair, good and excellent as shown in Figure 5 below. None of the well samples fell within the excellent category. Insight from the spatial distribution of WQI shows slight fluctuations in distribution and variation in index value.

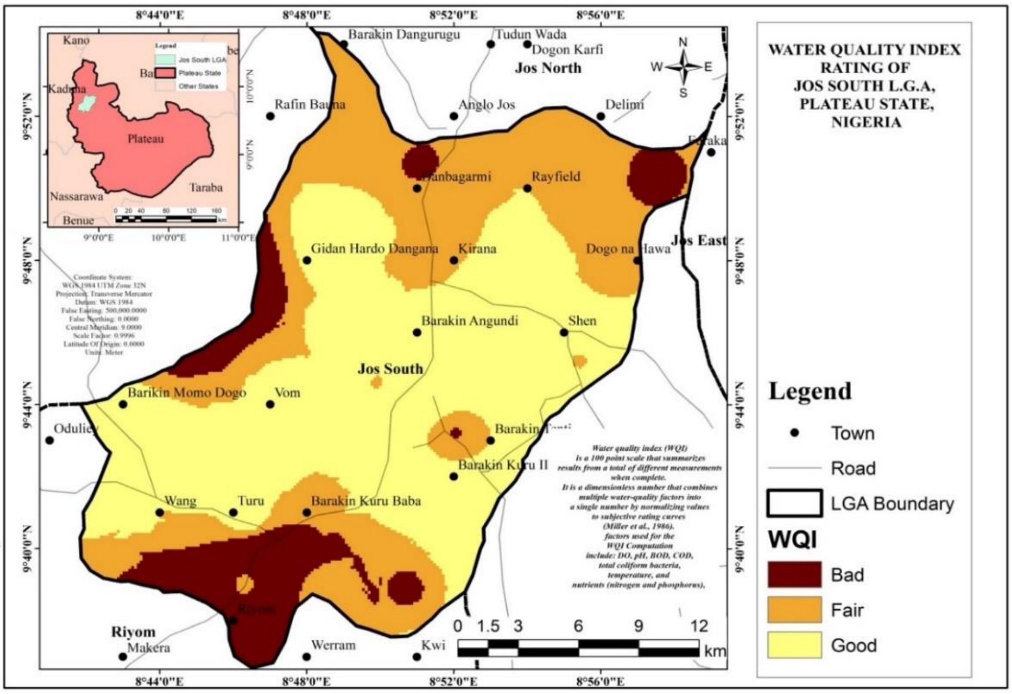



**Figure 5.** General Water Quality Index Rating Map of the Study Area.

However, high value of WQI was observed to be constant in areas like Wang, Bukuru low cost, Vom, Angundi and part of Rayfield. While lower values observed in surrounding areas of Kuru, Riyom, Gyel, Kuru Baba, Kugia, Danbagarmi, Dogon karfe etc. The observed differences in WQI across the study area are closely linked and determined by several factors of which Well depth, land use, seasonal dynamics and presence or absence of coliform remain prominent.

The overlay visualization of well depth and water quality index spatial distribution showed that areas/wells with shallow depth of < 5m tend to have poor water quality index while deeper wells tend to have better WQI. Most of the shallow wells are prone to infiltrated contamination. Outside the well depth, well location and protection such as the availability of concrete ring casing, lid, and fetching method affect the WQI irrespective of depth. This is the case with some of the deepest wells. Examples of such deep well with bad water quality include those located in Tundun wada, Dogon karfe, Bisichi etc. Wells in this location are majorly used for Abattoir, Poultry/Piggery and local beer processing.

The observed spatial distribution of water quality index of groundwater in the study area is closely related to the Landuse pattern and associated anthropogenic activity shown in Figure 6 below. Areas such as Riyom, Heipang, Danjuru, and Dan-gyel, known for animal husbandry (particularly piggery), Irrigation farming and mixed Landuse recorded poor water quality index. The land use in these areas in addition to other factors influences the WQI. Areas such as Rayfield, Nyengo Gyel, Dweidu, Barakin Kuru-Baba and Loyep etc. known with history of Tin mining, seasonal farming highly dependent on inorganic fertilizers and with mixed Land use recorded fair WQI. Areas such as Vom, Lahol, Shen, Geyro and Zawan which also have mixed Landuse comprising of residential, agricultural but characterized with dispersed surrounding settlement and abundant natural vegetation recorded good WQI. In addition, seasonal variation from wet to dry also influences the WQI of groundwater in the study area. The WQI values are high during the wet season than that of the dry season, the noticed variation and decrease in WQI index in dry season is attributed to decrease in well water volume and increase in coliform during the dry season.

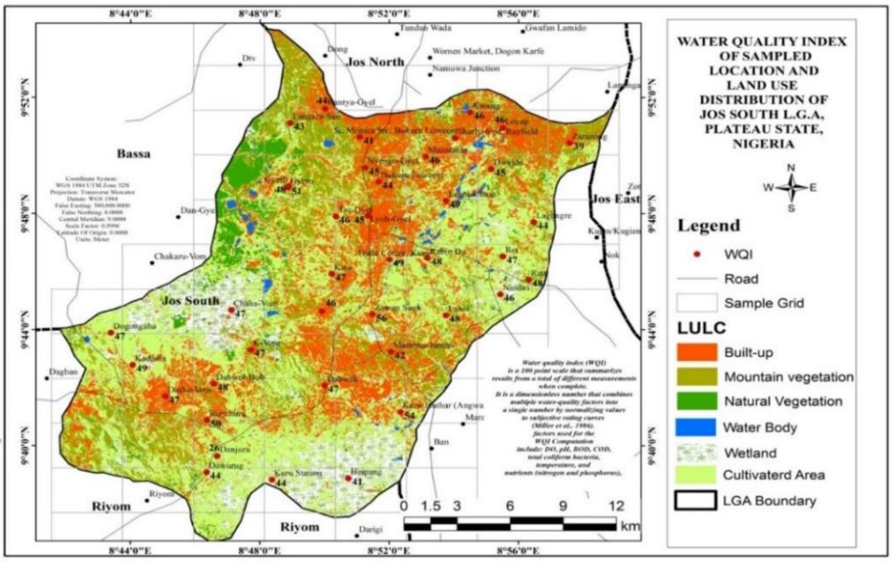



**Figure 6.** Water Quality Index of the various Sampled Location and their Associated Land Use and Land Cover

Of all the participatory parameters for the WQI computation, coliform had more influence on the outcome and value of ground water QI of the study area. The increase in coliform is directly proportional to decrease in water quality index, that is, well water with higher coliform count despite the input of other parameters tend to have lower WQI in the study area (Lar, *et* al.,). However, the dominance of coliform in the groundwater of the study area shown in Figure 7 is attributed to the balance of other elements which majorly fall within the permissible limit of different regulatory bodies.

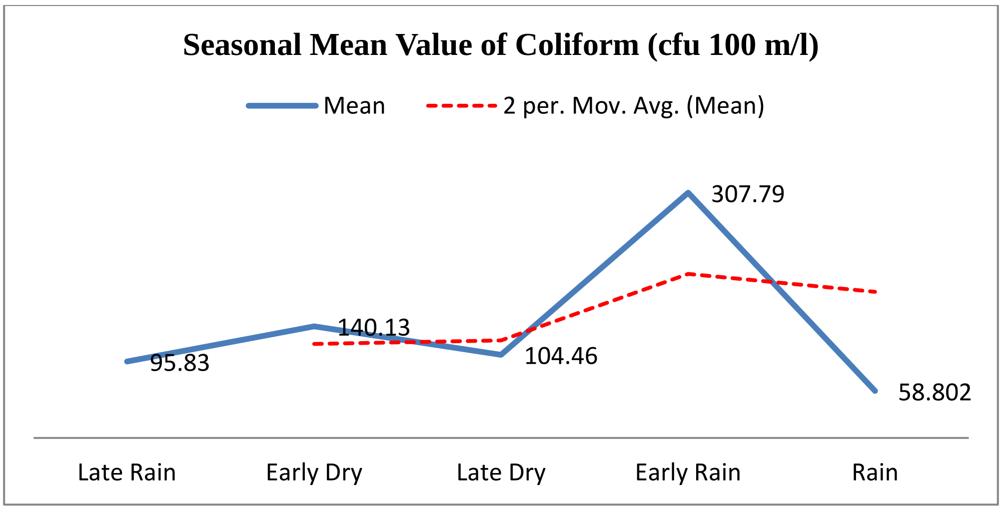



**Figure 7.** Seasonal Mean Value of Coliform

## IV. CONCLUSION

Based on the results of the present study, the study revealed that the concentrations of physico-chemical parameters of the water samples are comparable to results of other conventional studies (Jaji, *et al.,* 2007) conducted in other parts of Nigeria. The results also revealed that the values obtained were lower than the permissible limits recommended by the WHO for drinking water, groundwater from the study area needs proper treatment before use mostly for drinking.

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