

Hydrogeochemical Characterization and Groundwater Quality Assessment for Irrigation and Associated Purposes using Piper Trilinear Diagram in Papalanto District South-West Nigeria

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Abstract

The significance of quality groundwater for daily societal usage cannot be overemphasized. Papalanto district in Ewekoro Local Government area is one of the carbonaceous sub-basins of Dahomey embayment and supplies water to the neighbouring autonomous communities in this part of Ogun State, South-West Nigeria. Currently, it is susceptible to pollution from point and near point sources due to an increase of unplanned urban developments, industrial, agricultural and domestic activities thereby compromising its quality. Having subjected the collected water samples to varying standard laboratory tests, the results were consequently analyzed. Major hydrochemical facies were identified; the dominant water types patterned in the following order based on the abundance of major ions in relation to its corresponding cation abundance is $K^+ > Na^+ > Ca^{2+} > Mg^{2+}$. Emerging cationic concentrations indicate about 70% of the samples to be lower than or well within the present allowable limit of 200, 150, 200 and 12 mg/L respectively of the approved National and International standards including WHO and NESREA. The dominant water types are in the order of Chloride (Cl^-) type $> HCO_3^- + CO_3^{2-} > SO_4^{2-} + Cl^-$; $(Na^+ + K^+) > (Ca^{2+} + Mg^{2+})$ with further analyses revealing that 2% are of $NaHCO_3$ type, 68% are of $NaCl$ type while the remaining 30% are of mixed $CaNaHCO_3$ type with no geochemical contribution from the $CaHCO_3$, mixed $CaMgCl_2$ and $CaCl_2$ types. The vast majority of samples in both groundwater sources (boreholes and wells) are mixed $CO_3^{2-} + HCO_3^- - Cl^-$ dominant fluids. The mechanism controlling groundwater chemistry originally regulated by the geochemical contribution of weathered limestone formation and evaporation process as dominated by mixing of low salinity water and carbonate rock constituents caused from surface and possible underground contamination sources, such as the liquid and solid waste discharged into the nearby land and channels, domestic wastewater, septic tank effluents, and irrigation return flow with existing underground minerals followed by ion exchange process while $HCO_3^- + CO_3^{2-} - Cl^-$ and $Na^+ + K^+$ water types suggesting dissolution of mineralogical constituents; an interaction between rock and water within the matrix of subsurface hydrogeological compartment and recharge of freshwater.

Keywords: Groundwater quality, Water pollution, Hydrochemical facies, Papalanto, cation

INTRODUCTION

Inadequate quantity, substandard and poor quality of water has serious impacts on sustainable development of any given society

(Ishola, 2019; Ishola *et al.*, 2021). Groundwater has become the major source of water supply for drinking, household, agricultural, industrial, recreational, and environmental activities etc. This has led to

an increase in daily demand for water supply which is met principally from the exploitation of groundwater resources. Nowadays groundwater is a very important concern for mankind since it is directly linked with human safety being the most vital natural resource that forms the core of the entire ecological system. Determination of physical, chemical and bacteriological quality of groundwater is important for assessing its various usages both for specific and general applications. Variation in groundwater quality observable in any area has been a primary function of physical and chemical parameters which are greatly controlled by natural processes such as the underlying geological formations and anthropogenic activities in an area. Notably, industrial and municipal solid wastes have emerged as one of the leading causes of pollution of surface groundwater system (Gupta *et al.*, 2009). Globally, many researchers have carried out different studies in different locations and at different times on groundwater quality and pollution sources controlled by industrial and natural process [Massoud *et al.*, 2006; Sue *et al.*, 2013; Mehdi *et al.*, 2014; Mohamad *et al.*, 2016; Nasrabadii and Abbasi, 2014; Ying *et al.*, 2014]. The underlying rationale governing the chemical characteristics of groundwater and possibly enhancing the varying observable anthropogenic activities are well documented in many urban and peri-urban areas of the world [Homocik *et al.*, 2010, Marjani *et al.*, 2009, Ikem *et al.*, 2002, Cruikshank *et al.*, 1980, Eisen and Anderson (1980), Katz *et al.*, 1980, Kakar and Bhatnagar (1981), Flipse *et al.*, 1984, Cavallero *et al.*, 1985, Foster (1988),

Dummer and Van Straaten (1988), Gosk *et al.*, 1990, Somasundaram *et al.*, 1992, Nazari *et al.*, 1993, Asubiojo *et al.*, 1997, Philips *et al.*, 1997, Mohan *et al.*, 2000; Majudeswaran and Ramachandran, 2005; Yusuf, 2007; Mondal *et al.*, 2009; Joshi *et al.*, 2009; Srinivasamoorthy *et al.*, 2009; Jain *et al.*, 2010; Brinda *et al.*, 2012; Magesh *et al.*, 2012; Rajesh *et al.*, 2012; Sharma *et al.*, 2014; Selvan, 2015]. Groundwater contamination has been a major issue in any inhabited environment, especially in industrial urban centres (Ishola *et al.*, 2021). Papalanto is one of the growing industrialized districts and major cement producing and product marketing location as well as the major sugar cane plantation for the entire South-West Nigeria. In due course, its industrial and agricultural glory gets fluctuated in terms of production due to various internal and external diseconomies which were adversely affected by the emerging government policies (Ishola *et al.*, 2019). On parity with cement industry, engineering industry mostly iron steel production also dominated the economy of the district in the past. As against the receding trend of the clay blocks industry, cement industry, ceramics and engineering industry still hold its unique position in spite of tremendous growth experienced in the country for the past few decades by different sectors of the economy (Ishola *et al.*, 2019). Papalanto has been very busy due to aforementioned industrialization alongside with the predominant agricultural activities and rapid urbanization due to the daily increase in population in its surroundings autonomous communities within the district (Ishola, 2019). The increased population, industrial mining and quarry operations

make it essential to assessing the quality of groundwater system as well as ensuring the long-term sustainability of resources of the district (Uday *et al.*, 2018; Ishola, 2019). In this region, there is no proper or adequate drainage system. Hence, the sewage is discharged into the river. Consequently, the polluted water reaches the diverse channels and flow paths which form the part of the Akinbo River, Alaguntan River and Eshe River systems. A decrease in various quality characteristics clearly indicates the possibilities of pollution due to industrial activities such as mining, fertilizer application, and foundries in and around Ewekoro Local Government Area, has not only a strong influence on surface water but also unprecedented implications on the underground water system. Earlier before now, most of the studies focused their attention on drinking and irrigation suitability on a few other regions of Ogun State thereby making the evolution hydrochemistry of groundwater system in Papalanto region inadequate or grossly unavailable. These aforementioned rivers; as they receive waste water discharge from point sources such as slurry discharges, foundry mills, small scale industries, and congested residential areas with unrestricted domestic sewage effluents, as the higher pollution load discharged its content into streams and rivers ultimately resulting in deterioration of surface water, as well as underground water system (Dineshkumar *et al.*, 2015; Ishola, 2019). Jeyaraj *et al.*, 2016 has accounted that a domestic and untreated industrial discharge is probably responsible for the high concentration values of Electrical Conductivity, COD, Alkalinity,

and Turbidity. Furthermore, many of the earlier works in the area provide a preliminary and superficial assessment of groundwater quality without due characterization of the exact causative factors controlling the water quality. But this present study has taken the large extent of the region covering the autonomous communities in this urban settlement, industrial zone, irrigational zones, for better revelation and understanding of the water quality changes due to anthropogenic influences through tabular and geometrical representations and accompanied multivariate statistical techniques. The varieties of pollutants and contaminant seepages from multiple sources such as industrial outflows, agricultural cum irrigation return flow, domestic discharges and medical disposals aggregated the situation to be of water pollution and contamination impacts. Moreso, most of the wetlands in the district get dried up in dry season and serves as dumping yards for industrial wastes alongside the garbage dumping and other encroachments that have led to degradation of water bodies and ultimate depletion of the subsurface aquiferous zone. Lack of proper waste management infrastructure and deterioration of water bodies are the inferred environmental problem in the Papalanto district.

Study Area

Hydrogeological Setting

Papalanto district of Ewekoro Local Government Area is approximately bounded by longitude $3^{\circ}13'E$ and $6^{\circ}54'N$ and harbours one of the largest outcrops of Ewekoro limestone that easily attracts global attention (Ishola *et al.*, 2019). The study area is located within the sedimentary terrain of southwestern Nigeria and extends from Ibesse, 4km east of Papalanto along Papalanto-Shagamu road to Ogun River, 5km east to Iro community. The Ewekoro formation at the type locality is composed of 11m to 12m of limestone. It is sandy at the base grading downward into Abeokuta Formation. The Ewekoro formation is overlain of phosphatic glauconitic grey shale (Jones and Hockey, 1964). Subsurface investigation buttressed by some well information revealed a thick overburden of between 3m and 16m made up of silt, clay, sand shale with some alluvium and lateritic deposits in some places (WAPCO, 2001; Ishola *et al.*, 2019). Limestones occur below this rock sequence with varying thickness and resistivity. The thickness of the limestone is between 3m and 40m; the thickest being at Fashola community (38.3m) and the thinnest at Jaguna (1.6m). The range of overburden thickness is between 2m to 16m while the limestone thickness ranges between 1.5m to 38.2m. The reserve estimation was calculated to be 7.75×10^8 cubic meters and adjudged to be of economic value if exploited especially around Fashola town. The limestone is classified (based on microfacies) into biomicroparite, shelly biomicrites, algal biosparite and phosphatic biomicrites in that stratigraphic order (Fidelis *et al.*, 2014). The Ewekoro formation is the local geology in the

study area which is generally consistent with the regional geology of eastern part of the Dahomey Basin; predominantly comprises of the non-crystalline and highly non-fossiliferous limestone and thinly laminated fissile and probably non-fossiliferous shale (Ushie *et al.*, 2014). It is the sedimentary terrain of southwestern Nigeria. Ewekoro formation consists of intercalations of argillaceous sediment. The rock is soft and friable but in some places cement by ferruginous and siliceous materials. The lithological units in Ewekoro formation are clayey sand, clay, shale, marl, limestone and sandstone (Ishola *et al.*, 2021).

On the lithostratigraphic nomenclature, the lithology of Ise and Afowo formations were defined by Omatshola and Adegoke (1981) which reveals a high degree of similarity; both as essentially sands and sandstones, but the latter contains thick interbeds of shales. This difference is not sufficient to warrant the establishment of separate lithostratigraphic units. The two formations were later considered synonymous by Okosun (1998). In that study, it was observed that the Ise, Afowo and Abeokuta formations have similar lithologic and electric log characters. The uppermost beds of Abeokuta formation which crop out in Ijebu Ode area and in the shallow boreholes at Itori, Wasimi and Ishaga onshore consist mainly of fine to coarse grained sand and interbeds of shale, mudstone, limestone and silt. These lithofacies correlate well with the upper portion of the neostatotype in Ojo-1 borehole Okosun (1998).

The Abeokuta formation was defined by Jones and Hockey (1964) to consist of grits,

loose sands, sandstones, kaolinitic clay and shale and was further characterized as usually having a basal conglomerate or basal ferruginized sandstone (Archibong, 1978; Okosun, 1998 and Chene, 1978). On the analyses of surface outcrops, Abeokuta formation comprises mainly sand with sandstone, siltstone, silt, clay, mudstone and shale interbeds. It usually has a basal conglomerate which may measure about 1m in thickness and usually consists of poorly rounded quartz pebbles with silicified and ferruginized sandstone matrix or a softly gritty white clay matrix. Coarse, poorly sorted pebbly sandstone with abundant white clay have been found to constitute the basal bed in other outcrops lacking conglomerates. The overlying sands are coarse grained clayey, micaceous and poorly sorted; indicative of short distances of transportation or short duration of weathering and possible derivation from the granitic rocks located to the north. The formation possesses a thickness value of 849m, 898m, 624m, 54.4m and 888m in Ise-2, Afowo-1, Ileppawi, Itori and Ojo-1 boreholes respectively as obtained from the subsurface data on the Abeokuta formation as obtained from Ise-2, Afowo-1, Orimedu-1, Bodashe, Ileppawi, Ojo-1 and Itori boreholes by Okosun (1998). In the Ise-2 borehole, the essentially arenaceous sequence between 1261.5m and 2142.1m which consists of sands, grits, sandstone, siltstone, clay and shale constitutes the formation. The interval 1076m - 1907m which is made up of very coarse loose sands with sporadic thin intercalations of multicoloured shale and limestone represents the formation in Ojo-1 borehole. The strata from the 44m to 98.4m in the Itori borehole,

which consists of coarse-fine and medium-grained sand, silt and sandy clay horizons, constitutes the upper portion of the formation. The Ise-2 borehole also penetrated a basal conglomerate.

Jones and Hockey (1964) revealed Ewekoro limestone and the overlying Akinbo shale to be lateral equivalents of the Imo formation of eastern Nigeria. The stratigraphy, depositional characteristics of limestone and clay/shale deposits with hydrogeological settings in South-Western Nigeria were equally investigated by other authors such as Omatshola and Adegoke (1991), Oladeji (1992) and Ishola *et al.*, 2021. Ewekoro formation belongs to tertiary formed Paleocene and Eocene; and the greater part of the depression is a potential artesian basin where groundwater can be sourced (Ishola, 2019). Kogbe (1976) and Adegoke *et al.*, 1972 described the stratigraphic and palaeogeography of different sedimentary basins. Also, Adegoke *et al.*, 1976 outlined the Albian and younger Palaeographic history of Nigeria and summarized the nature and extent of transgressive, regressive phases as well as the nature of the sediment which also consists of intercalations of argillaceous sediment. The rock is soft and friable but, in some places, cemented by ferruginous and siliceous materials.

Although the water bearing rocks, in large quantity, are the sedimentary rocks, the basement rocks which underlies the area though hydrogeologically problematic appears to present relatively good ground water potential thought to be the reliable aquifers for small scale village, institution, industries and other water supply schemes.

Offodile (1983) explained that the crystalline rocks are poor ground water regions with recorded average yield of 3960 liters /hrs (880gph) at average depth of 37.3m (123ft) and over 30% failure rate in water borehole drilling. Previous work shows that sedimentary aquifers give higher groundwater yield than the basement complex aquifer. Jones and Hockey (1964) evaluate depth, yield and specific capacity of tube wells which tap the Abeokuta formation, Ewekoro formation (Dahomey Basin) and coastal Plain sands with recent alluvium, in the Niger delta complex. These are important aquifer units in the Dahomey basin and Niger delta complex respectively. It is revealed that yields in excess of 10,000 l/hr are common as a result of lateral changes in lithology of the Abeokuta formation and coastal Plain sands. Egboka (1983) evaluates the various aquifer units in the Anambra basin, and on the basis of grain-size distribution. The Ajali sandstone is identified to have great potentials for groundwater with a total discharge of $9.6 \times 10^5 \text{ m}^3 \text{ yr}^{-1}$. Although the water bearing rocks in large quantity are the sedimentary rocks, the basement rocks though may be hydro-geologically problematic appears to present relatively good ground water potential thought to be the reliable aquifers for small scale village, institution, industries and other water supply schemes. Uma *et al.*, 1989 considers accurate estimation of aquifer properties from grain-size distribution data crucial for successful groundwater development and management practices. However, this method is inadequate as its ability to define precisely, aquifer geometry and hydraulic boundaries is limited to sedimentary basins. By

comparison, Offodile, (1992) is of that the idea that more productive aquifers occur in sedimentary geologic formations than in weathered and fractured crystalline rocks. Hydraulic conductivity of the Ajali sandstone in the Anambra basin was defined by employing the textural characteristics techniques (Yusuf, 2007; Tijani and Nton (2009). Nevertheless, recent experiences have shown that with the appropriate knowledge of the basic subsurface geology, detailed reconnaissance cum hydro-geophysical survey, and adequate hydrochemical evaluation with improved drilling techniques much better results of subsurface water quality status can be determined.

Site Description and Natural Vegetation

The natural vegetation of Ogun State which the study areas belong consists of the forest and the savanna which affect the floristic composition of the plant communities. Human activities on the natural vegetation have reduced the original forest to secondary forest bush, regrowth and thickets. One very important impact of the quarry and mining activities in the area is deforestation which has led loss of vegetation cover necessitated by the need to move equipment to the quarry site, removal of the topsoil or (overburden) stemming of explosives and removal of blasted limestones. These effects are normally reduced by appropriate mitigating actions such as massive reclamation of the mined areas using new overburden materials and a forestation programme that involve planting of varieties of trees that can hold the soil structure well and could cover the exposed land well. Furthermore, Limestone

mining in the entire Ewekoro Local Government Area of which Papalanto is a part had resulted into the conversion of many farmlands and human settlements into quarry sites. The house types on these sites are mainly the makeshift type built for use on no permanent basis. The few landowners on the factory site are resident on site to participate in cement business and could no longer engage in farming activities as it was before now. The West Africa Portland cement according to the management made frantic effort at resettling the displaced landowners in the estate that were built very close to the factory. Afterwards a programme of gradual takeover of the old farm site had started with some inhabitants completely relocated to new location far away from Papalanto while some others completely rejected the resettlement efforts. Since the resettling efforts were rejected by some of the landowners. In the course of using the quarry, farmers had been stopped from the site and the cutting/felling of the trees continued, resulting into a large expanse of land exposed to rain water and wind. The lake created as a result of blasting of limestone and release of water within the weathered limestone deposit ordinarily should serve as habitat to fresh water fish, this has however not been developed. Aside from this, the ammonium compound consequently washed into the lake from its primary source (explosive materials) may serve as manure and may encourage the growth of plankton, algae, aid the liming of the lake and encourage fish production. However, the possibility of having an excess

quantity of the ammonium compound washed into the lake may not only pose a serious hazard on the lives of the aquatic animals but much more virulent and debilitating hazards on the consumers of those aquatic animals if the lake is harvested for aquatic food (WAPCO, 2000; Ishola, 2019).

Fig. 1 shows the Geological Map of the Selected Locations of the Study Area within the Nigerian Part of Dahomey Embayment, Fig. 2 Displays the Google Earth imagery of the selected Investigated study area within in Ewekoro Local Government Area, Southwest Nigeria, the map of Ogun State showing the geology of the study areas is presented in Fig. 3, the inset map showing political divisions of the study area within Nigerian continental environment is shown in Fig. 4, the maps of the investigated locations in the study area are shown in Fig. 5, and Fig. 6 is a basemap showing the location and accessibility of the study areas amidst the investigated points in Ewekoro LGA.

The entire study area is generally accessible by major roads and several footpaths, although the road from Abeokuta town to the investigated area is tarred. In addition to Ewekoro-Papalanto road, the survey locations can equally be accessed through a major road from Lagos State through Sango-Ifo express road. The Global Positioning System (GPS) receiver was used in the field to obtain the spatial locations of the study area during sampling.

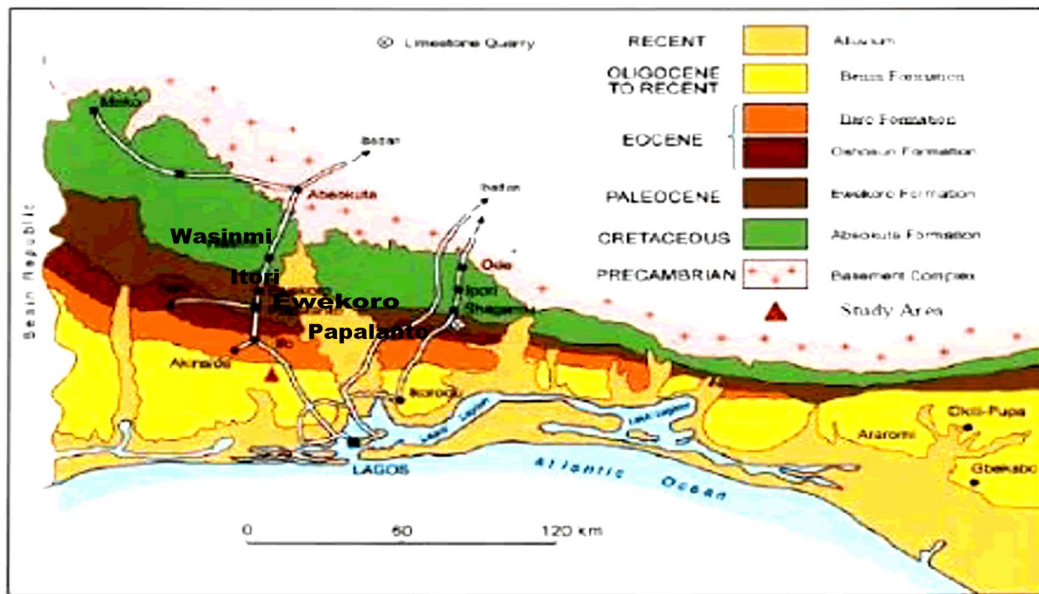


Figure 1: Geological Map Showing the Selected Locations of the Study Area within the Nigerian Part of Dahomey Embayment (Billman, 1992; Modified by Ishola, 2019).



Figure 2: Display of Google Earth Imagery of the selected Investigated study area within Ewekoro LGA, Southwest Nigeria (Ishola, 2019).

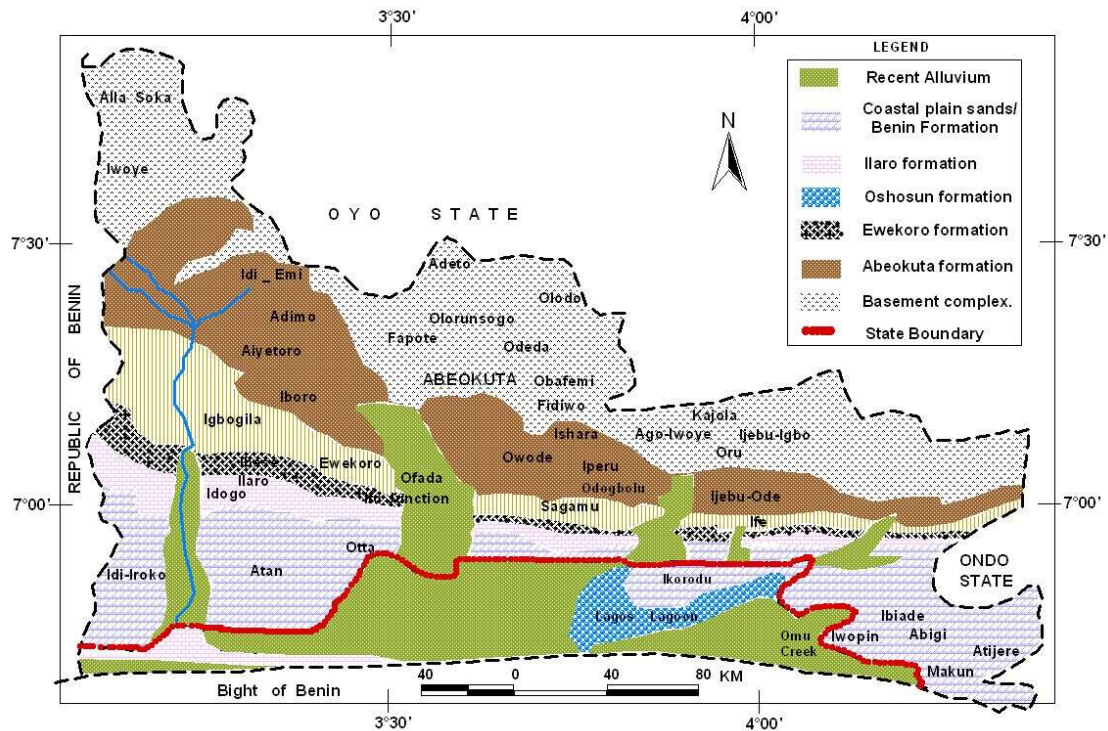


Figure 3: A Map of Ogun State showing the Geology of the Study Areas after Kehinde-Phillips (1990); Obiora and Onwuka (2005)

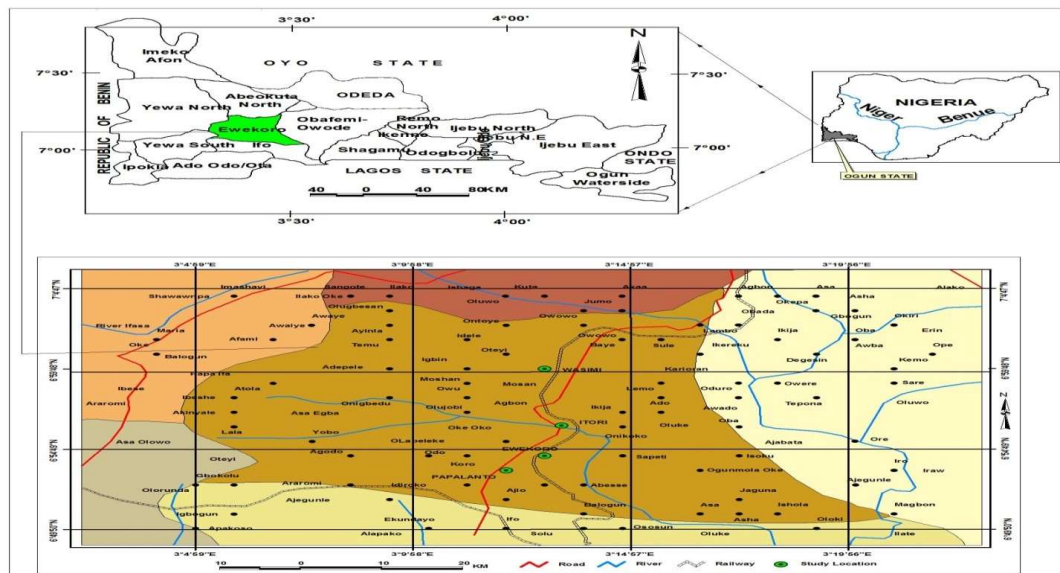


Figure 4: Inset Map showing the Study Areas in Ogun State within Nigeria Continental Domain using Esri Data/Nigeria Political Information in ArcView GIS 3.2A (Ishola, 2019).

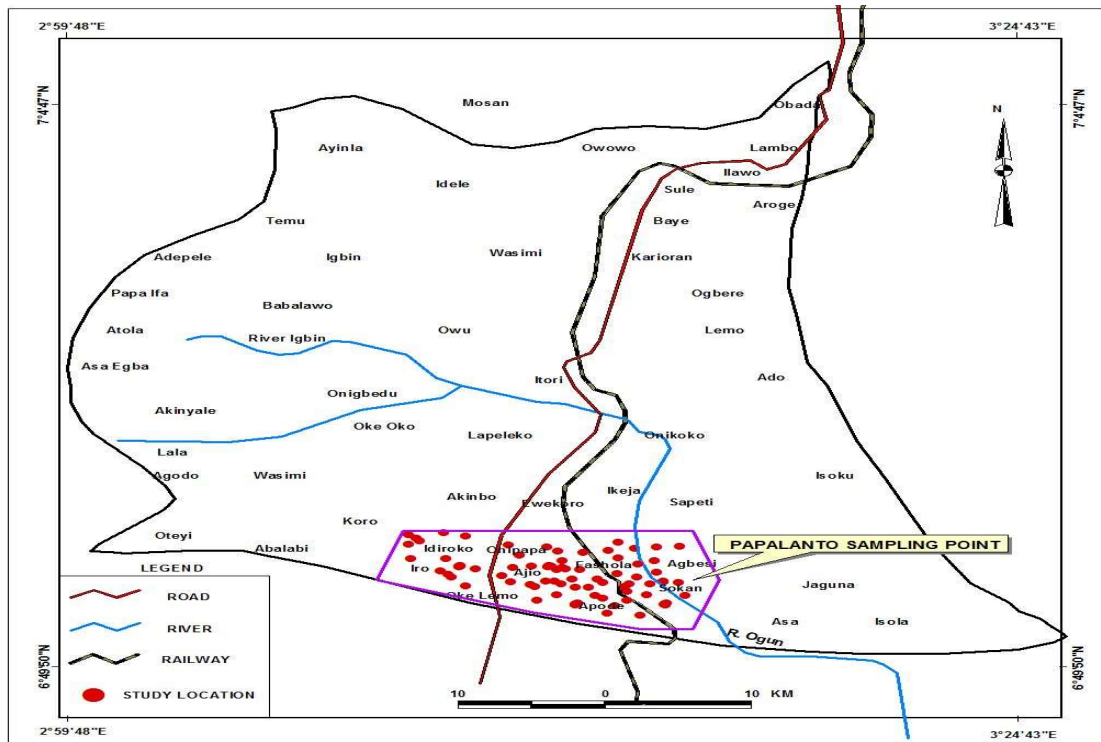


Figure 5: Data Acquisition Map showing the Investigated Locations in Papalanto Study Area in Ewekoro LGA, Southwest Nigeria (Ishola, 2019).

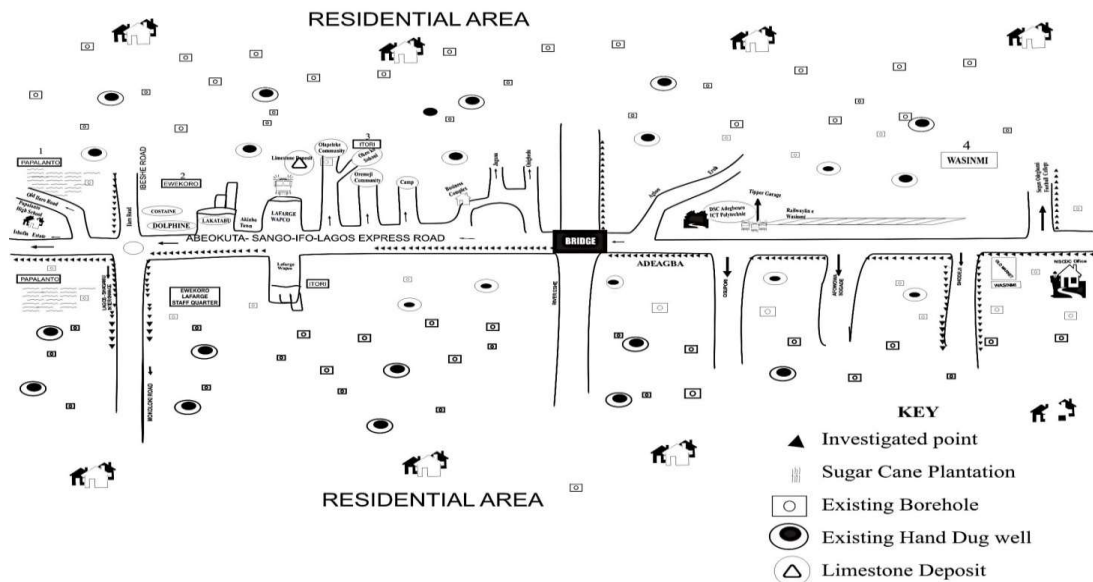


Figure 6: Basemap showing the Location and Accessibility of the Investigated Points in Ewekoro LGA, Southwest Nigeria (Ishola, 2019)

Sample Collection and Hydrogeochemical Analyses of Groundwater

The study identified existing and functional boreholes and hand-dug wells as one that are frequently in use greater than 30 persons per day based on the level of usage while the procedure for data collection started with a reconnaissance survey to the area. Through this approach, 50 functional groundwater sources in dry season (25 boreholes and 22 wells) were randomly and strategically selected, with their coordinates recorded. Water samples were collected in 1 litre plastic bottles. All plastic bottles were rinsed thrice with the sampled water prior to sample collection, after sampling, the containers were tightly covered. In addition, Physico-chemical analyses of the water samples were carried out to identify and quantify the physical properties and chemical components of water. This includes pH, TSS, Turbidity, Chloride Cations, Anions, Trace Elements, Total Hardness and so on were determined using standard methods (APHA, 1998). The samples collected were appropriately labelled and stored in clean air tight, leak proof plastic bottles in an ice-packed cooler, and immediately taken to the laboratory for analyses for heavy metals. Physico-chemical properties (Electrical Conductivity (EC), Total Dissolved Solids (TDS), Temperature, Dissolved Oxygen (DO) and pH were determined insitu using Hannah Combo TDS/pH/EC/Temperature meter series multi-parameters (model HI991300), whereas Hannah (model HI9147) equipment was used for DO in order to ensure that they are not subjected to alteration such as temperature. Water samples from the wells and boreholes were collected in a neat container (or that

which the water samples to be tested has been rinsed with) and the sensor on the meter was dipped in it while the metre displayed the values it measured on a digital screen. The same procedures were repeated for other water samples. Preparation of samples was carried out using acid digestion before 2ml of sample was injected into the machine by flow method. Detection limit set for each element varied from 0.02–0.1 µg/ml. These measured parameters were compared with WHO and other specification. The geographical coordinates of sample points were also taken with GPS mete and their location is indicated on the data acquisition map. Water samples for anion determination were collected in 500 ml bottles, unfiltered and unpreserved, and stored below 8 °C prior to analysis. Ion Chromatography (IC) was used for anions. Nitrate, phosphates, bicarbonate, chloride and sulphate were measured after chromatography separation using conductivity detectors.

Major metals and trace metals were determined using the Inductively Coupled Mass Spectrometer (ICP-MS) and Inductively Coupled Optical Emission Spectrometry (ICP-OES). In order to improve accuracy and to prevent cloudiness of the water, water samples were filtered to less than 0.45 µm using a Pall Corporation GN-6 metricell sterilized membrane. Minute particles of clay sizes were removed before analysis. ICP-OES is useful in measuring higher concentrations, such as high levels of contamination. When lower levels of contamination are present, ICP-MS provide lower detection limits for measurement. In addition, cell-based ICP-MS provides an

additional tool for the removal of interferences that might prevent detection of a contamination incident. The trace elements analyzed were Mn, Cr, Zn, Pb and Cd. These analyses were carried out in order to study how concentration of elements in water samples has been affected by the activities in the study area. The analytical results using charge-balance error checked for major ionic contents was calculated using Microsoft Excel and Aq.Qa GroundWater Chart Software Package, did not exceed 6%. The irrigation suitability of groundwater was examined based on Total Hardness (TH), Sodium Adsorption Ratio (SAR) in association with electrical conductivity values, Sodium Percentage (Na%), Permeability Index (PI) and Magnesium Ratio (MR) as calculated by the following formulas,

$$TH (CaCO_3) = (Ca^{2+} + Mg^{2+}) \text{ meq/L} \times 50$$

$$SAR = \frac{Na}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$$

$$Na\% = \frac{(Na^{2+} + K^{+})}{(Ca + Mg + Na + K)} \times 100$$

$$PI = \frac{(Na + \sqrt{HCO_3})}{(Ca + Mg + Na)} \times 100$$

$$Mg \text{ Ratio} = \frac{(Mg^{2+})}{(Ca^{2+} + Mg^{2+})} \times 100$$

Piper trilinear diagram, USSSL (United State Salinity Laboratory) diagram and Sodium versus Electrical Conductivity Plots were performed to recognize the various hydrogeochemical characters in the

groundwater for drinking and irrigation suitability. The acquired results were subjected to analysis of variance (ANOVA) and Multivariate statistical methods such as correlation matrix, principal component analysis, and hierarchical cluster analysis were performed using IBM SPSS 20 software.

RESULTS AND DISCUSSION

Geochemistry and Water Quality Status

In addition to the pH, Electrical Conductivity, and TDS, chemical characteristics of the groundwater were statistically analyzed with the outcomes compared with the approved drinking water suitability standards as given in Table 1 and Table 2 respectively for boreholes and wells. The mean value of PH for Papalanto borehole was 6.78 ± 0.11 while that of temperature was 26.56 ± 0.87 . The standard deviation values for both parameters showed that the variation between the measured values was not much. The pH of the groundwater in the study area varies from 6.4 to 6.87 with an average value of 6.78 ± 0.11 in boreholes and 6.70 to 7.85 with an average value of 7.11 ± 0.40 in hand-dug wells indicating alkaline nature of the samples; this was confirmed by the very high detected values of Alkalinity in the study area with a value range of 180.74 to 1481.11 and a mean value of 487.75 ± 515.95 in boreholes and a value range of 286.78 to 1711.11 with a mean value of 408.85 ± 391.94 in wells. The EC values varied from 645.00 $\mu\text{S/cm}$ to 911.00 $\mu\text{S/cm}$ with an average value of $487.75 \pm 515.95 \mu\text{S/cm}$ in boreholes and 630.00 $\mu\text{S/cm}$ to 845.00 $\mu\text{S/cm}$ with an

average value of 757.16 ± 56.61 $\mu\text{S}/\text{cm}$ in wells which is directly related to the ionic concentrations present in the groundwater and its lower values contribute to lower salinity and total dissolved concentration. The TDS values are very low in the study area and vary between 6.90 to 8.98 mg/L with a mean value of 8.41 ± 0.71 mg/L in boreholes and between 7.80 to 10.40 mg/L with a mean value of 8.08 ± 0.66 mg/L in well for drinking purpose the maximum allowable TDS guideline value prescribed by the WHO (WHO, 2012) is 1000 mg/L. All the groundwater samples (both boreholes and wells) come under fresh water type (Table 1 and Table 2) and very much suitable for drinking purpose; as the value of TDS in them is far lower than 1000 mg/L. Suggestively, the lower TDS may be due to lack of serious percolation of channel water containing varying solids, agricultural wastes, and industrial seepages; most important sources of increasing dissolved solids in the groundwater could be traceable to the weathered country rocks. DO ranges from 6.70 to 7.84 with a mean value of 7.00 ± 0.32 in boreholes and 7.20 to 8.98 with a mean value of 8.56 ± 0.52 in wells making well water higher than the set permissible standards. The values of BOD ranges from 16.90 to 21.65 with a mean value of 20.02 ± 1.84 in boreholes and from 17.90 to 22.75 with a mean value of 19.76 ± 1.848 in wells thereby making both groundwater sources to be above the recommended limits of WHO standards. The recorded values of COD ranges from 25.00 to 38.88 with a mean concentration value of 32.38 ± 3.05 in boreholes and from 31.40 to 36.83 with a mean value of 34.38 ± 1.38 in wells (Table 1

and Table 2). The concentrations of Ca^{2+} , Mg^{2+} , Na^+ , and K^+ ions vary from 12.10 – 28.72 (mean value of 24.02 ± 4.17 mg/L), 1.94 – 4.47 (mean value of 3.47 ± 0.66 mg/L), 38.40 – 45.8 (mean value of 42.58 ± 2.04 mg/L) and 48.60 – 23 (mean value of 55.17 ± 2.60 mg/L) respectively for Papalanto boreholes and from 9.61 – 11.95 (mean value of 11.10 ± 0.75 mg/L), 4.24 – 9.99 (mean value of 7.42 ± 1.26 mg/L), 34.40 – 52.64 (mean value of 4.53 ± 4.03 mg/L) and 41.61 – 61.44 (mean value of 45.37 ± 4.94 mg/L) respectively for Papalanto wells. Thus, $\text{K}^+ > \text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+}$ represents the ordered pattern of cation abundance. Not only that, but Cationic concentrations also indicate about 70% of the groundwater samples to be lower than the provisional allowable limit of 200, 150, 200 and 12 mg/L respectively. Among the anions, the chloride is the most dominant ion in the groundwater. The concentration of chloride in the study area ranges in value from 71.80 to 382.04 mg/L and with an average value of 314.80 ± 88.05 in boreholes making it above the highest allowable standard of WHO and 70.61 to 226.39 with an average value of 196.40 ± 56.00 in wells; making Papalanto wells lower than the allowable set standards. Chloride has been found to be one of the most important and contributive inorganic anions present in groundwater. Relatively, the higher concentration of chloride observed from the groundwater samples contributes approximately to about 85% to the total anionic concentration; most probably due to an influence of poor sanitary conditions, chemical fertilizers, irrigation return flow and industrial effluents. According to WHO (WHO, 2012), the maximum permissible

limit of chloride value is 250 mg/L, from the study area, the mean concentration of the samples exceeds the permissible limit and unsuitable for drinking purpose. The concentration of bicarbonate is observed from 90.37 to 778.62 mg/L with a mean value of 403.81 ± 318.40 in boreholes and 143.38 to 855.11 mg/L with a mean value of 203.94 ± 196.01 in wells making samples from both groundwater sources higher than the approved set standards; higher concentration of HCO_3^- when compared with chloride concentration in the groundwater infers that mineral dissolution must have also occurred in subsurface aquiferous zone. The concentrations of SO_4^{2-} were noted to range in values between 0.03 to 11.88 mg/L with an average value of 9.60 ± 3.65 mg/L in boreholes and 9.37 to 14.62 mg/L with an average value of 10.31 ± 1.32 mg/L in wells, which is a very significant environmental problem in many irrigated agricultural regions. Since the sulphate concentration is less than 400 mg/L in the groundwater samples; it indicates a lower impact of soluble salts accumulation in the soil, anthropogenic activity and lower sulphate fertilizer application. The range of NO_3^- is 0.12 – 0.14 mg/L with an average of 0.12 ± 0.008 mg/L in boreholes and 0.11 – 0.14 mg/L with an average of 0.13 ± 0.007 mg/L in wells making both results falling below the WHO recommended a value of 45 mg/L. The highest mean value of 403.81 ± 318.40 was recorded for HCO_3^- followed by 314.80 ± 88.15 for Cl^- while the lowest mean value of 0.0001 ± 0.0003 was recorded for Al^{3+} . COD, BOD and DO exhibit an increasing order of value concentrations of and $\text{COD} > \text{BOD} > \text{DO}$

respectively. The high value of standard deviation over the mean revealed a wide variation in the distribution of elemental constituents of the sampled parameters in the hydrogeologic environment of the study area. Very high variability in the concentration of both the physico-chemical and elemental parameters (e.g. HCO_3^- , Ni, Cr, Co, Al^{3+} , Pb^{2+}) resulted in the standard deviation being higher than the mean values for such elements (Table 1 and Table 2). The concentration of NO_3^- does not exceed 10 mg/L in groundwater under natural conditions; beyond 10 mg/L is an indication of anthropogenic pollution; principally due to poor sanitary conditions, indiscriminate application of fertilizers for higher crop yields (SubbaRao *et al.*, 2012; Ishola, 2019). The plotting of major ions in the Piper trilinear diagram is highly essential for effective understanding of the hydrogeochemical evolution of the subsurface aquiferous zone in the study area (Piper, 1944) (Fig. 7). The cation region of the piper plot of the groundwater samples of the study area reveals the 100% of the analyzed sampling points to lie within the ($\text{Na}^+ + \text{K}^+$) zone with none found on the non-dominant zone, Calcium and Magnesium zone. In the anion region of the plot, about 48% of the point lies within the ($\text{HCO}_3^- + \text{CO}_3^{2-}$) while 52% lies in the Chloride (Cl^-) type it was further revealed that the hydrogeological formation of the study area is typically characterized as alkalis ($\text{Na}^+ + \text{K}^+$) exceeding alkaline earths ($\text{Ca}^{2+} + \text{Mg}^{2+}$). In terms of acidic strength, weak acid versus strong acids, the plot reveals about 32% of the dominant presence of strong acids ($\text{SO}_4^{2-} + \text{Cl}^-$) exceeding Weak acids ($\text{HCO}_3^- + \text{CO}_3^{2-}$) while

68% of dominantly Weak acids ($\text{HCO}_3^- + \text{CO}_3^{2-}$) exceeding strong acids ($\text{SO}_4^{2-} + \text{Cl}^-$). Further analyses of the piper plot reveals that 2% are of NaHCO_3 type, 68% are of NaCl type while the remaining 30% are of mixed CaNaHCO_3 type with no geochemical contribution from the CaHCO_3 , mixed CaMgCl_2 and CaCl_2 types (Fig. 7) supported by bubble plot showing the dominance of HCO_3^- (Fig. 8)

The vast majority of samples are $\text{HCO}_3^- + \text{CO}_3^{2-}$ and Cl^- dominant fluids. It indicates, mixing of high salinity water and carbonate rock constituents caused from surface and possible underground contamination sources, such as the liquid and solid waste discharged into the nearby land and river channels, domestic wastewater, septic tank effluents, and irrigation return flow with existing underground minerals followed by ion exchange process (Jeyaraj *et al.*, 2016). However, the presence of $\text{HCO}_3^- + \text{CO}_3^{2-} - \text{Cl}^-$ and $\text{Na}^+ + \text{K}^+$ water types suggest probable mineral dissolution, an interaction between rock and water as well as the influence of freshwater recharge (Mondal and Singh, 2012). Bubble plot is mainly used

in this study to understand the ranking relationship between water compositions and respective aquifer characteristics such as rock-water interaction for better understanding and interpretation of dominant groundwater chemistry. Bubble plot with a 3D- effect resembles a scatter chart but compares sets of three values instead of two. The third value determines the size of the bubble marker which is displayed with a 3D effect (Fig. 8). It gives an indication of chemical weathering in rock-forming minerals influencing the groundwater quality by dissolution of weathered rock through which subsurface circulations take place (Selvakumar *et al.*, 2015); the chemistry of groundwater in the Ewekoro geological formation in which the study area belongs is mainly controlled by geochemical mechanisms of a typical limestone formation (Sajikumar and James, 2016; Ishola, 2019; Ishola *et al.*, 2021). The display of samples falling outside these plots may be due to other processes of anthropogenic activities outside natural geological conditions, which addressed the similar observation of (Srinivasamoorthy *et al.*, 2008).

Table 1: Descriptive Statistics showing the Concentration Values of Physico-Chemical and Elemental Parameters of Papalanto Boreholes (N=25)

Parameters	Min	Max	Range	Mean±SD	WHO (mg/L)	NESREA (mg/L)	NSDWQ (mg/L)	USEPA (mg/L)	NAFDAC (mg/L)
PH	6.40	6.87	0.47	6.78±0.11	6.5 – 9.5	7.00-8.50	6.50-8.50	6.50-8.50	6.50-8.50
TEMP (°C)	25.00	28.00	3.00	26.56±0.87	27	NA	NA	27	27
EC (μScm^{-1})	645.00	911.00	266.00	703.48±92.31	1200	NA	900	1200	1000
DO (mg/L)	6.70	7.84	1.14	7.00±0.32	7.5	NA	7.5	NA	NA
BOD (mg/L)	16.90	21.65	4.75	20.02±1.84	10	NA	10	NA	NA
COD (mg/L)	25.00	38.88	13.88	32.38±3.05	NA	NA	NA	NA	NA
TDS (mg/L)	6.90	8.98	2.08	8.41±0.71	100	1500	500	500	500
TSS (mg/L)	0.12	0.31	0.19	0.23±0.05	> 10	>10	NA	NA	NA
TS (mg/L)	0.66	0.99	0.33	0.86±0.10	1500	NA	NA	NA	NA
TURB (NTU)	0.10	1.11	1.01	0.24±0.33	< 4	5.0	5.0	5.0	5.0
ALK (mg/L)	180.74	1481.11	1300.37	487.75±515.95	200	500	100	100	100
TH (mg/L)	12.06	29.96	17.90	26.91±4.91	< 200	100 -300	500	NA	100
THC (mg/L)	0.12	0.21	0.09	0.19±0.03	NA	NA	NA	NA	NA
Na ²⁺ (mg/L)	38.40	45.87	7.47	42.58±2.04	< 200	NA	200	NA	200
K ⁺ (mg/L)	48.60	58.47	9.87	55.17±2.60	12	200	NA	200	10
Ca ²⁺ (mg/L)	12.10	28.72	16.62	24.02±4.17	75	NA	NA	75	75
Mg ³⁺ (mg/L)	1.94	4.47	2.53	3.47±0.66	20	15	NA	20	20
Cl ⁻ (mg/L)	71.80	382.04	310.24	314.80±88.05	250	200	250	100	100
NO ₃ ⁻ (mg/L)	0.12	0.14	0.02	0.12±0.008	50	45	NA	10	10
NO ₂ ⁻ (mg/L)	0.01	0.02	0.01	0.02±0.003	< 3.0	NA	NA	NA	NA
SO ₄ ²⁻ (mg/L)	0.03	11.88	11.85	9.60±3.65	400	500	200	250	100
NH ₄ ⁺ (mg/L)	0.80	1.78	0.98	1.47±0.28	1.50	NA	NA	NA	NA
PO ₄ ³⁻ (mg/L)	8.70	10.77	2.07	10.14±0.57	NA	NA	NA	NA	NA
HCO ₃ ⁻ (mg/L)	90.37	778.62	688.25	403.81±318.40	100	NA	NA	NA	NA
MgCO ₃ (mg/L)	8.72	13.98	5.26	11.54±1.40	10	NA	NA	NA	NA
Cu ²⁺ (mg/L)	0.00	0.03	0.03	0.02±0.01	2.0	NA	1.0	1.3	1.0
Pb ²⁺ (mg/L)	0.00	0.0006	0.0006	0.0006±0.0005	0.01	0.01	0.01	0.01	0.01
Cd ²⁺ (mg/L)	0.00	0.0004	0.0004	0.0004±0.0005	0.003	0.003	0.001	0.005	0.005
Mn ²⁺ (mg/L)	0.01	0.03	0.02	0.02±0.009	0.1	0.2	0.5	0.4	2.0
Zn ²⁺ (mg/L)	1.11	1.85	0.74	1.43±0.25	0.01	NA	NA	NA	NA
Fe ³⁺ (mg/L)	0.03	1.17	1.14	0.40±0.42	0.3	0.3	0.3	0.3	0.3
Cr (mg/L)	0.00	0.0004	0.0004	0.0004±0.0005	0.05	0.05	0.05	0.05	0.05
Ni (mg/L)	0.00	0.0003	0.0003	0.0003±0.0005	0.02	0.05	NA	NA	0.05
S (mg/L)	0.38	2.47	2.09	1.41±0.65	250	NA	NA	NA	NA
Al ³⁺ (mg/L)	0.00	0.0001	0.0001	0.0001±0.0003	0.2	NA	NA	0.2	0.5
I (mg/L)	0.02	0.04	0.02	0.03±0.008	NA	NA	NA	NA	NA

Drinking Water Standard Specifications given by WHO (2004), NESREA (2010), NSDWQ (2007), USEPA (2007) and NAFDAC (2011) and Statistical Information of ion Concentrations.

KEY

NA – NOT AVAILABLE IN THE NATIONAL GUIDELINES AND STANDARDS
DRINKING WATER QUALITY
WHO – WORLD HEALTH ORGANISATION
NESREA – NATIONAL ENVIRONMENTAL STANDARD REGULATION AGENCY
USEPA – UNITED STATE ENVIRONMENTAL PROTECTION AGENCY
NSDWQ – NATIONAL STANDARDS FOR DRINKING WATER QUALITY
NAFDAC – NATIONAL FOOD AND DRUG ADMINISTRATION AND CONTROL

Table 2: Descriptive Statistics showing the Concentration Values of Physico-Chemical and Elemental Parameters of Papalanto Hand-Dug Wells (N=25)

Parameters	Min	Max	Range	Mean±SD	WHO (mg/L)	NESREA (mg/L)	NSDWQ (mg/L)	USEPA (mg/L)	NAFDAC (mg/L)
PH	6.70	7.85	1.15	7.11±0.40	6.5 – 9.5	7.00-8.50	6.50-8.50	6.50-8.50	6.50-8.50
TEMP (°C)	22.00	31.00	9.00	25.12±1.99	27	NA	NA	27	27
EC (µScm ⁻¹)	630.00	845.00	215.00	757.16±56.61	1200	NA	900	1200	1000
DO (mg/L)	7.20	8.98	1.78	8.56±0.52	7.5	NA	7.5	NA	NA
BOD (mg/L)	17.90	22.75	4.85	19.76±1.48	10	NA	10	NA	NA
COD (mg/L)	31.40	36.83	5.43	34.38±1.38	NA	NA	NA	NA	NA
TDS (mg/L)	7.80	10.40	2.60	8.08±0.66	100	1500	500	500	500
TSS (mg/L)	0.35	0.53	0.18	0.45±0.04	> 10	>10	NA	NA	NA
TS (mg/L)	0.61	1.04	0.43	0.90±0.10	1500	NA	NA	NA	NA
TURB (NTU)	0.11	0.34	0.23	0.24±0.05	< 4	<5.0	<5.0	<5.0	<5.0
ALK (mg/L)	286.78	1711.11	1424.33	408.85±391.94	200	500	100	100	100
TH (mg/L)	14.84	29.76	14.92	19.34±3.61	< 200	100 -300	500	NA	100
THC (mg/L)	0.00	0.43	0.43	0.04±0.12	NA	NA	NA	NA	NA
Na ²⁺ (mg/L)	34.40	52.64	18.24	41.53±4.03	< 200	NA	200	NA	200
K ⁺ (mg/L)	41.61	61.44	19.83	45.37±4.94	12	200	NA	200	10
Ca ²⁺ (mg/L)	9.61	11.95	2.34	11.10±0.75	75	NA	NA	75	75
Mg ³⁺ (mg/L)	4.24	9.99	5.75	7.42±1.26	20	15	NA	20	20
Cl ⁻ (mg/L)	70.61	226.39	155.78	196.40±56.00	250	200	250	100	100
NO ₃ ⁻ (mg/L)	0.11	0.14	0.03	0.13±0.007	50	45	NA	10	10
NO ₂ ⁻ (mg/L)	0.01	0.05	0.04	0.03±0.009	< 3.0	NA	NA	NA	NA
SO ₄ ²⁻ (mg/L)	9.37	14.62	5.25	10.31±1.32	400	500	200	250	100
NH ₄ ⁺ (mg/L)	0.11	0.75	0.64	0.17±0.17	1.50	NA	NA	NA	NA
PO ₄ ³⁻ (mg/L)	8.60	9.85	1.25	9.25±0.42	NA	NA	NA	NA	NA
HCO ₃ ⁻ (mg/L)	143.38	855.11	711.73	203.94±196.01	100	NA	NA	NA	NA
MgCO ₃ (mg/L)	10.43	14.64	4.21	11.25±1.04	NA	NA	NA	NA	NA
Cu ²⁺ (mg/L)	0.03	0.06	0.03	0.05±0.01	2.0	NA	1.0	1.3	1.0
Pb ²⁺ (mg/L)	0.00	0.02	0.02	0.007±0.005	0.01	0.01	0.01	0.01	0.01
Cd ²⁺ (mg/L)	0.00	0.0009	0.0009	0.0009±0.0003	0.003	0.003	0.001	0.005	0.005
Mn ²⁺ (mg/L)	0.02	0.06	0.04	0.04±0.01	0.1	0.2	0.5	0.4	2.0
Zn ²⁺ (mg/L)	0.84	4.23	3.39	2.31±1.26	0.01	NA	NA	NA	NA
Fe ³⁺ (mg/L)	0.05	1.52	1.47	0.80±0.38	0.3	0.3	0.3	0.3	0.3
Ni (mg/L)	0.00	0.00	0.0006	0.0006±0.0005	0.02	0.05	NA	NA	0.05
S (mg/L)	1.14	5.25	4.11	3.28±1.41	250	NA	NA	NA	NA
Al ³⁺ (mg/L)	0.00	0.01	0.01	0.002±0.004	0.2	NA	NA	0.2	0.5
I (mg/L)	0.00	0.06	0.06	0.04±0.02	NA	NA	NA	NA	NA
Si (mg/L)	0.00	0.04	0.04	0.01±0.01	NA	NA	NA	NA	NA

Drinking Water Standard Specifications given by WHO (2004), NESREA (2010), NSDWQ (2007), USEPA (2007) and NAFDAC (2011) and Statistical Information of Ion Concentrations.

KEY

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Geochemistry and Suitability for Irrigation Purpose

The osmotic pressure in the root zone which affects agricultural soil and hence plants physically and chemically leading to reduced yield and consequently hindering the plant growth can be altered by the dominant presence of excessive amount of dissolved salts such as Sodium, Magnesium, Chloride and Bicarbonate that are primarily meant for irrigation purposes (Bob *et al.*, 2016). Also, the growth and continuation of successful irrigation projects does not only depend on the supply of irrigation water to the land but also aim in controlling the solutes and alkali status of the soil (Oster, 1994). Thus, further analysis using the United States Salinity Laboratory (Doneen, 1964 and USSI, 1954 and Paliwal, 1992) have been applied for better classification and characterization of groundwater parameters, as the suitability of groundwater for irrigation application depends among others on the mineralization of the concerned water and its possible effects on the soil and plants. Hardness is an important factor in determining the suitability of water samples for various purposes; domestic, and irrigation purposes as is involvement in overall physico-chemical constituents of the water among others cannot be overemphasized. Sawyer *et al.*, 2003 reported the classification of water as soft, hard, moderately hard and very hard. Based on this classification scheme, total hardness of the groundwater samples indicates in the study area are very soft in nature while the maximum permitted limit of total hardness for drinking is specified as 500 mg/L (Sawyer *et al.*, 2003). However, for

irrigational purposes, more than 1000 mg/L of hardness is also accepted. The correlation between SAR and EC were plotted as shown (Fig. 9a and Fig. 9b). The EC values of the groundwater acquired from the study area simply measures up to 911 $\mu\text{S}/\text{cm}$ in boreholes and 842 $\mu\text{S}/\text{cm}$ in hand-dug wells making it to fall in the class of good to permissible (Table 3 and Table 4). The alkalinity of the water is high with corresponding low salinity level making it very conducive for irrigation purposes; high sodium content and high salinity levels are bad for irrigation because sodium is a component of a harmful salt and also causes poor physical conditions of the soil. A high amount of salts in irrigation water can also modify the osmotic pressure in the root zone, which in turn limits the amount of water absorbed by the plant and consequently hindering the effective and healthy growth of the affected plant (Ying *et al.*, 2014). Furthermore, the presence brownish to reddish soil and the absence of black cotton soil, less rocky landform coupled with the low topography of the study areas are jointly responsible for the quality status of the water. The good quality persists till the bottom of the highly weathered zone, which is noted up to 35 m below ground level (Selvakumar *et al.*, 2015; Ishola, 2019). C2S2 and C2S1 could be of acceptable water quality for standard irrigation activities of the study area from boreholes and hand-dug wells respectively (Table 4). C4S1 and C3S1 groups, representing the high salinity and low sodium hazard has been reported for the groundwater in the rapid urban development areas of Coimbatore, India which indicates the acceptable quality for

irrigation of the area (Selvakumar *et al.*, 2015). This is corroborated with the results of the computed relationship of Na% versus EC values (Fig. 10a and Fig. 10b). Groundwater status belonging to these groups can be used for irrigation activities with salinity control and Sodium percent versus Electrical conductivity chart (Fig. 9a and Fig. 9b). This reveals that all the groundwater samples (both boreholes and hand-dug wells) fall in the category of very good and good to permissible condition with no samples falling into the doubtful to unsuitable field. Notably, Permeability index (PI) is a significant parameter for groundwater quality standardization in relation to the soil for better yield and overall agricultural improvement. Sodium, Bicarbonate, Calcium, and Magnesium content in the soil go a long way in influencing soil permeability. Magnesium ratio also serves as an important parameter to assessing the suitability of water

quality conditions for the desired irrigation requirement. Excessive Magnesium content damages soil structure when water contains comparably more of sodium and high salinity (Chidambaram *et al.*, 2013). It has been reported that when magnesium ratio exceeds the value of 50, the water associated with such content could be considered to be harmful. Hence, it is unsuitable for irrigation, because it could harmfully affect the crop yield as the soils become more alkaline (Elango *et al.*, 2003). In the study area, the recorded PI is 89.45% and 92.94% for boreholes and hand-dug wells respectively while the mean magnesium hazard values ranged from 12.55 to 41.25 in boreholes which are very suitable for irrigational purposes and 26.87 to 63.48 in wells where 3 well water samples exceed the value of 50 in entire groundwater samples, which are not suitable for irrigation.

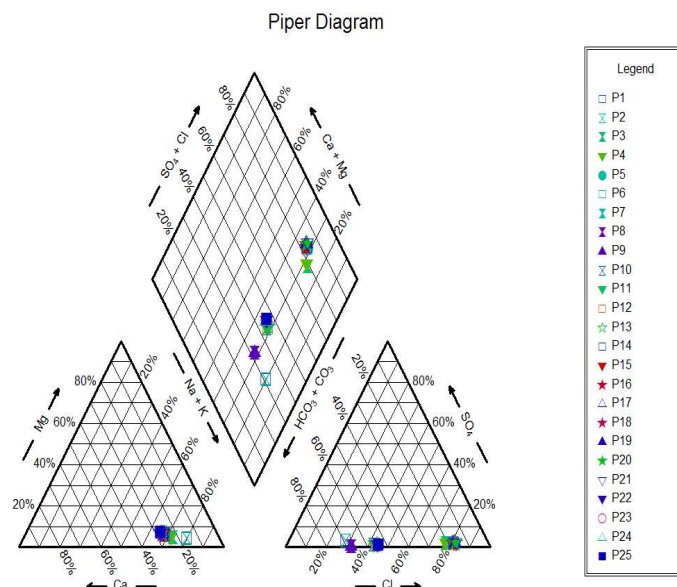


Figure 7: Piper Trilinear plot showing the ionic characterization of Groundwater of Papalanto.

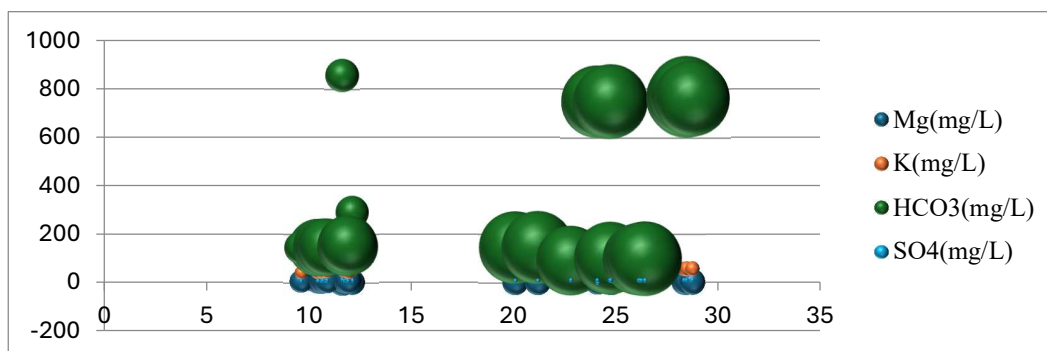


Figure 8: Bubble plot showing Dominant Hydrogeochemical Parameters of Papalanto (Ishola, 2019).

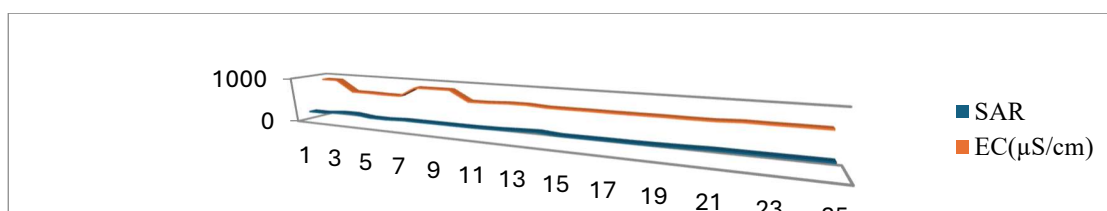


Figure 9a: SAR versus EC of Papalanto Boreholes

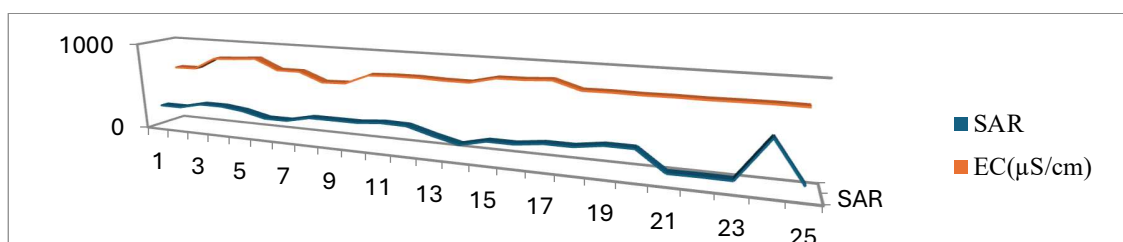


Figure 9b: SAR versus EC of Papalanto Hand-Dug Wells

Table 3: Groundwater Classification of Papalanto according to Total Dissolved Solids (Selvakumar *et al.*, 2017).

S/NO	Groundwater Class	TDS Range (mg/L)	Number of Samples (Boreholes and Wells)		Samples No
			In No	In %	
1	Fresh Water	< 1000	1-50	100%	1-50
2	Slightly Saline	1000 – 3000	–	–	–
3	Moderately Saline	3000 – 10,000	–	–	–
4	Very Saline	10,000 – 30,000	–	–	–
5	Brine	≥ 30,000	–	–	–

Table 4: US Salinity and Permissible Classification for Irrigation (Selvakumar et al., 2017).

Sodium Hazard	Salinity Hazard	EC($\mu\text{S}/\text{cm}$)	Quality Classification
S1: Low	C1: Low	0 - 750	Very Good
S2: Medium	C2: Medium	750 - 2000	Good to Permissible
S3: High	C3: High	50 - 100	Permissible but Doubtful
S4: Very High	C4: Very High	2000 - 3000	Doubtful to Unsuitable
S5: Extremely High	C5: Extremely High	3000 - 4000	Unsuitable

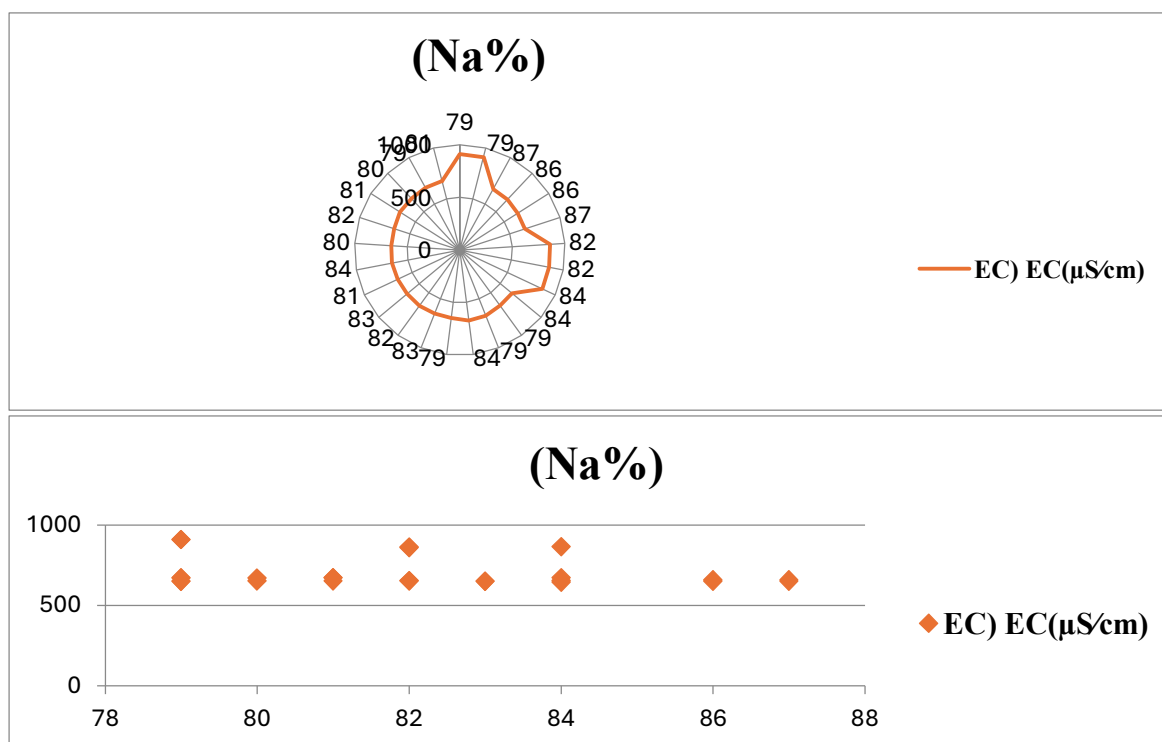


Figure 10a: Layout of Sodium Percent versus Electrical Conductivity of Papalanto Boreholes

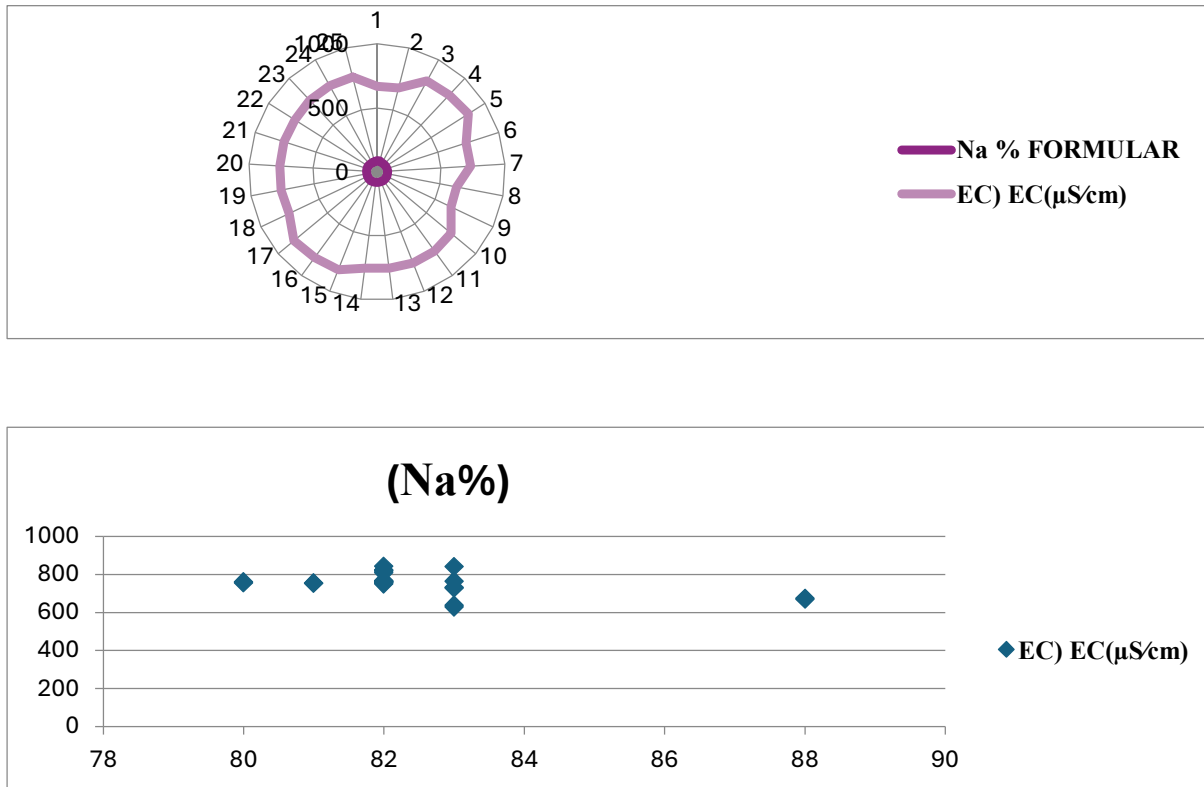


Figure 10b: Layout of Sodium Percent versus Electrical Conductivity of Papalanto Hand-Dug Wells

CONCLUSIONS

This study gave a comprehensive hydrogeochemical characterization to examining the groundwater quality status and for understanding of pollution sources in Papalanto District. The result of the physicochemical parameters indicates that the groundwater in the study area is generally alkaline, fresh and naturally soft. The abundance of major ions is in the following ordered pattern of cation abundance of $K^+ > Na^+ > Ca^{2+} > Mg^{2+}$. Cationic concentrations revealed that about 70% of the groundwater samples have lower concentration value than the provisional permissible limits of 200, 150, 200 and 12 mg/L respectively of the approved national and international standards

including WHO and NESREA while the dominant water types were in the order of Chloride (Cl^-) type $> HCO_3^- + CO_3^{2-} > SO_4^{2-} + Cl^-$; $(Na^+ + K^+) > (Ca^{2+} + Mg^{2+})$ with further analyses revealing that 2% are of $NaHCO_3$ type, 68% are of $NaCl$ type while the remaining 30% are of mixed $CaNaHCO_3$ type with no geochemical contribution from the $CaHCO_3$, mixed $CaMgCl_2$ and $CaCl_2$ types. This dominant fluids which indicate, mixing of low salinity water and carbonate rock constituents caused from surface and possible underground contamination sources, such as the liquid and solid waste discharged into the nearby land and channel (Jeyaraj *et al.*, 2016). For irrigation suitability based on USSSL, Sodium Percent versus Electrical

conductivity plot, SAR, and Magnesium hazard calculation, it was observed that groundwater in the study areas may cause low to very low salinity and medium to high alkalinity hazard when used for irrigation. Since groundwater chemistry is principally controlled and regulated by mixing of saline water caused by surface contamination with invading impacts on the subsurface water and gradual dissolution of rock-forming minerals. Also, the clustering of urban settlement with the rapid increase in population of the urban dwellers coupled with the accompanied multifaceted activities in one way or the other increases the urban heat which influences soil

moisture and groundwater status. The results of this study provide better and improved information that can be useful for the water resource management not only in Papalanto but also in the entire Ewekoro Local Government Area particularly with respect to anthropogenic stress. Therefore, it is advisable at this point, that advanced inorganic removal treatment such as Nano-filtration and Reverse Osmosis should be provided to avoid using the groundwater in these areas for drinking and irrigation purposes directly before the required treatments are made.

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