Original Article

Comparative assessment of aquifers in a typical karst sedimentary system, South-West Nigeria

S. A. Ishola[1] ©

Abstract

The necessity of hydraulic assessment of groundwater system for practical application in any lithospheric environment cannot be overemphasized. The subject matter includes formulae to quantitatively appraise the hydraulic parameters influencing the water-yielding capacity of boreholes which tap a typical sedimentary karst rock mass. Pumping test was carried in a total of 25 boreholes each from different autonomous residential communities around 4 towns within Ewekoro Local Government Area to quantitatively appraise the hydraulic parameters influencing the water-yielding capacity of boreholes abstracting water from a typical sedimentary karst rock mass. The measurements were carried out at a controlled rate and water-level response was measured separately from Wasinmi, Itori, Ewekoro and Papalanto. The rise in water levels was recorded as residual drawdowns´, and the water level measured at a residual time t´ after the pump has been turned off. Hydraulic properties were estimated with discharge, drawdown and specific capacity data. The values of the hydraulic parameters are consistent with what obtains in the sedimentary aquifer. The average measured values of the basic and estimated hydraulic parameters are: borehole depth, 51, 50.36, 60.32, 95.36 m; specific discharge, 4.0×10^{-2}, 5.0×10^{-2}, 4.0×10^{-2}, 5.0×10^{-2} l/s; specific capacity, 6.3×10^{-3}, 7.0×10^{-2}, 6.0×10^{-3}, 5.0×10^{-2} m^2/s; well loss constant, 5.98×10^4, 4.30×10^5, 6.16×10^2, 5.19×10^3 s^2/m^5; transmissibility, 94.8 m^2/s respectively recorded for Wasinmi, Itori, Ewekoro and Papalanto. Further research should employ precise, quantitative data concerning requisite geologic information about sedimentary rock aquifer system.

Key words: Pumping; karst; drawdown; transmissibility; residual; permeability soil geochemistry

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1. Introduction

Water bearing rocks in large quantity are found in 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. Comparative assessment of aquifers in a typical sedimentary system is crucial for understanding groundwater resources, vulnerability to contamination and optimizing water management strategies. This analysis helps to identify variations in aquifer properties like storage, permeability, and recharge rates allowing for tailored resource extraction and protection measures[1]. By comparing the hydrogeological characteristics of different aquifers, scientists can assess their susceptibility to contamination. Factors like the presence of confining layers, the depth of the water table and the type of geological formations all influence how easily pollutants can reach groundwater. Comparative analysis provides the data needed to make informed decisions about groundwater extraction, recharge and protection. Understanding the storage capacity, recharge potential and potential for contamination in different aquifers allows for better planning and management of resources. Comparative assessments help to delineate different aquifer types within a sedimentary system. For example, some sedimentary units may be more permeable and thus better suited for groundwater extraction while others might be prone to contamination. Comparative assessments can highlight the geological controls on aquifer behavior. For instance, certain rock types or formations may naturally act as barriers to pollutant migration while others might be more susceptible[1-2]. It 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[3]. Previous work shows that sedimentary aquifers give higher groundwater yield than the basement complex aquifer. The evaluation of depth, yield and specific capacity of tube wells which tap the Abeokuta and Ewekoro formations (Dahomey Basin) and coastal plain sands with recent alluvium, in the Niger delta get complex[4]. 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/hrs are common as a result of lateral changes in lithology of the Abeokuta formation and coastal Plain sands. The evaluations of the various aquifer units in the Anambra basin, and on the basis of grain-size distribution were carried out in 1983 by Egboka[5]. The Ajali sandstone is identified to have great potentials for groundwater with a total discharge of 9.6×10^5 m^3 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. By understanding the strengths and weaknesses of different aquifers, managers can develop strategies for sustainable groundwater use. This could involve prioritizing extraction from more robust aquifers implementing measures to protect vulnerable aquifers and promoting sustainable recharge practices considers accurate estimation of aquifer properties from grain-size distribution data crucial for successful groundwater development and management practices[2-7]. However, this method is inadequate as its ability to define precisely, aquifer geometry and hydraulic boundaries is limited to sedimentary basins. Offodile is of that the idea that more productive aquifers occur in sedimentary geologic formations than in weathered and fractured crystalline rocks[8]. Some researchers employed textural characteristics to define the hydraulic conductivity of the Ajali sandstone in the Anambra basin[9]. Classical analytical method of pumping test is expensive and depends on aquifer's hydraulic boundaries and geometry, but remains the only reasonable procedure for obtaining accurate transmitting properties in the basement aquifer. In hydrogeological literature, the petrology of the basement complex has a considerable influence on flow direction and potential zones of groundwater. Offodile shows that over 50 % failure rates have been recorded from the boreholes drilled so far in the basement complex area[10]. The Abeokuta group, coastal plain sand, Ewekoro formation and recent sediment constitute aquifers in the Dahomey basin in which the study area is found. Sand and Gravel constitute materials in the aquifer of recent sediment, coastal plain sand and Abeokuta formation while limestone forms the aquifer material in Ewekoro formation. Most wells in the area for domestic water supply are shallow hand–dug wells. These wells make use of generally small, discrete bodies of groundwater in the weathered zone; their yield varies enormously and many fail completely towards the end of the dry season. Also, Limestone is a sedimentary rock composed largely of the minerals calcite and aragonite, which are different crystal forms of calcium carbonate ($CaCO_3$). Many limestones are composed of skeletal fragments of marine organisms such as coral or foraminifera. Limestone makes up about 10 % of the total volume of all sedimentary rocks. The solubility of limestone in water and weak acid solutions leads to karst landscapes, in which water erodes the limestone over thousands to millions of years. Most cave systems are through limestone bedrock. Limestone is a very common sedimentary rock consisting of more than 50 % calcium carbonate. Although it occurs in many different forms, its origins can be traced back to either chemical or biochemical processes that occurred in the geological past, often tens to hundreds of millions of years ago. Many different types of marine organisms have developed the ability to precipitate calcium carbonate from seawater to serve as a protective shell or exoskeleton. For example, scallops have a two-piece outer shell that can be opened to allow the scallop to feed and closed to give protection, whereas bryozoans produce an outer casing within which they live. When these organisms die, their shells accumulate on the seafloor. The soft parts decay, leaving only the hard shells (exoskeletons or tests), which typically become broken down by current action and biological predators. Over long periods of time, the loose skeletal sediments are transformed into bioclastic limestone by the addition of chemically precipitated carbonate cement between the shell fragments. In the warm low-latitude waters of the tropics, these are called tropical bioclastic limestones, while in the cooler waters, at mid to high latitudes, they are known as temperate bioclastic limestones. In the case of large congregations of tropical marine organisms, like reef-building corals, the normally very large structure remains intact as it is transformed into tropical limestone reef rock. Limestone is the primary constituent raw material for cement manufacturing. Physical observation of Ewekoro limestone deposit reveals the rock to be highly fossiliferous with the identified fossils indicating deposition in an open shelf environment. Moreover, the limestone deposit was equally observed to be principally mud supported which is indicative of rocks deposited in quiet water and a low energy environment[11]. Groundwater in the study area is recharged from, and eventually flows to, the surface naturally. Water flows directly between the surface and the saturated zone of an overburden aquifer, which is unconfined. The deeper parts of unconfined aquifers are usually more saturated since gravity causes water to flow downward. Aquifer characteristics vary with the mode of geological formation, mineralogical composition and structure of the substrate as well as the topography in which they occur. Generally, fractured crystalline rocks yield smaller quantities of groundwater in many environments in comparison with sedimentary aquifer. This makes it an important resource which can act as a natural storage that can buffer against shortages of surface water, as in during times of drought. Groundwater is naturally replenished by surface water from rivers when this recharge reaches the water table.

However, favourable geophysical and geological evidences improved the chances of locating joints and fracture zones in order to obtain a considerable amount of water from this source. This is evident as most crystalline rocks in Nigeria are located in high relief areas where runoff is high and infiltration rate is low. These are complemented by tropical climatic condition, as the crystalline rocks weather more easily and deeply only under humid condition. High cost of drilling tube wells hindered intensive research on hydrogeology of crystalline rocks in Nigeria. However serious research began in recently times, due to rapidity in urban development and improved economy. In this research work emphasis is placed on the quantitative evaluation of the practical yields of wells and aquifer by field and analytical methods[12]. The hydraulic properties of the aquifer and appropriate groundwater formulae are used to construct a mathematical model which provides a means of evaluating the performance of the sedimentary aquifer system. This will enable a workable data can be obtained from a considerable number of tube wells, which are widely distributed in the southwestern Nigeria. It is expected that this simple approach to organizing, conducting, and interpreting complex aquifer test data will turn into information that is understandable and useful to better explain the varying values of yield often reported for sedimentary aquifers in the literature. Nevertheless, recent experiences have shown that with appropriate knowledge of the geology and adequate hydro-geophysical surveys with improved drilling techniques much better results can be achieved. When compared with other areas in southern Nigeria with similar rainfall but different hydrogeological environments, the pattern of perennial streams is close. The greater part of the Ewekoro depression is a potential artesian basin but this swampy belt is only sparsely settled and the source of groundwater has been little developed. However, with the growing demands of industry and the need for uncontaminated domestic supplies, an increasing number of water wells are being drilled in the sedimentary rocks. Therefore, in this work comparative analyses were carried out for the Hydraulic evaluations of Sedimentary Karst auriferous System of Ewekoro communities namely Wasinmi, Itori, Ewekoro and Papalanto, South-West Nigeria in order to provide a foundation for making informed decisions about groundwater resources particularly in the context of the complex and varied geological environments of sedimentary system.

2. Theoretical background

The determination of specific yield of a given aquifer is the primary objective of pumping tests aquifer which are often undertaking by field hydrogeologists for the purpose of evaluating the hydraulic attributes of auriferous zones[13-14]. It encompasses pumping water from a given well and consequent measure of the rate of pumping and the corresponding drawdown level of the pumped well, where the output of measurement can be integrated with the appropriate empirical formula for the establishment of the hydraulic parameters of the aquifer[15-17]. During the pumping process, the volume of dewatered material found in the cone of depression can be obtained. The specific yield can then be established by comparing the volume of dewatered material with the total volume of discharged water. The solution of an exponential series that converges very slowly serves as the requirement for the computations of the volume of dewatered material which can be challenging in terms of time consumption and the tasks involved[12-18].

Earlier research reported that it may be quite easy to directly apply the standard formulae to pumping test field data obtained in a water–table aquifer that are shallow as a result of slow state of the drainage system and (or) variable state of discharge[13-15]. Nevertheless, we can apply the general equilibrium formula if a constant pumping rate Q is experienced for a sufficient period of Time T such that so that the cone of depression reaches approximate equilibrium form is attained by the cone of depression and the decline encountered in the process is also in a slow state. As pumping process progresses, the establishment of a hydraulic gradient which essentially serves as an equilibrium gradient would be found closer to the pumped well, and water would then be transmitted to the well via the auriferous zone in an approximate amount closer to the amount that is being pumped if not in exact proportion. The declined level of the water table as well as the resulting unwatered material in this area would consequently be much slower[14]. The basic assumptions adopted in configuration of the general equilibrium formula and reported by authors from published literature of other works are applied here[12-21]. Although, the decline in water table decline progresses slowly, the assumption that the attainment of steady-state conditions involves only, little error not greater than that observed as fluctuation encountered in pump discharge. An isotropic cum homogeneous water-bearing bed of infinite areal extent is assumed to lie on a relatively impervious formation[14-15]. The discharging well, equipped with a pump, is fully screened to the bottom of the water-bearing material. Furthermore, it is assumed that the mobility of water from the outer radius of the screen to the pump intake occurs without loss of head or with a head loss that is insignificant compared with the drawdown in the well. Also, the potentiometric surface of the aquifer is horizontal or nearly horizontal prior to the start of the pumping. The potentiometric surface of the aquifer is horizontal prior to the start of the pumping. The potentiometric surface is not changing with time prior to the start of the pumping rather all changes in the position of the potentiometric surface are the resultant effects of the pumping well alone. Darcy's law is valid and groundwater flow is horizontal[15]. The water table before pumping, and the underlying impervious bed, are assumed to be horizontal and infinite horizontal extent. Groundwater has a constant viscosity and density. It is assumed also that there is no recharge to the aquifer during the test and that all the water pumped is removed from storage.

The following terms and representations are utilized in the mathematical derivations for this study where K represents the hydraulic conductivity (LT^{-1}), $\frac{\rho}{\gamma}$ represents the hydrostatic pressure potential (L) and Z represents the gravitational potential (L). The negative sign observed in the equation is an indication that the flow mobility follow the direction of decreasing head, v_s defines the rate of flow which can follow any direction via a porous medium and is proportional to the negative rate of change of head in that direction. Q represents the discharge rate of the pumped well in gallons per day, P represents the field coefficient of permeability of the aquifer in gallons per day per square foot under a unit hydraulic gradient occurring at the prevailing water temperature, r is the horizontal distance from the axis of the pumped well to a point on the cone of depression, in feet, s is the drawdown at distance r, in feet, s_w is the drawdown just outside the screen of the pumped well, in feet while m represents the thickness of the zone of saturation before pumping or the height of the static water table above the aquifer bottom, in feet

T is the coefficient of transmissibility of the aquifer in gallons per day per foot. It is the measured flow through a vertical strip of the aquifer 1 foot wide and extending via the saturated height of the aquifer, at unit hydraulic gradient. T is technically equal to Pm. Darcy's law can be expressed in a differential form where the velocity of the flow in this direction is given as v_s.

$$v_s = \frac{K\partial(\frac{\rho}{\gamma}+Z)}{\partial s} \quad 1.0$$

If the head; h(x,y,t) = $\frac{\rho}{\gamma} + Z$ is differentiated with respect to s, we obtain equation (2.0)

$$\frac{\partial h}{\partial s} = \frac{\partial(\frac{\rho}{\gamma}+Z)}{\partial s} \quad 2.0$$

If equation (2.0) is substituted into equation (1.0), we obtain equation (3.0)

$$v_s = \frac{K\partial h_{22}}{\partial s} \quad 3.0$$

From Darcy's law, groundwater discharge is expressed in equation (4.0) as:

$$Q = 2\pi P(-\frac{\partial s}{\partial r})\,(m - s) \quad 4.0$$

$$\frac{\partial r}{r} = -\frac{2\pi P}{Q}\,(m - s)\,\partial s \;= -a(m - s)\partial s \quad 5.0$$

Where a = $\frac{2\pi P}{Q}$

Integrating, $\ln r = -\text{ams} + \frac{as^2}{2} + \ln\beta$ 6.0

Where β is the constant of integration.

Then $r = \beta e^{-\text{ams}} + \frac{as^2}{2}$ 7.0

The description of the cone of depression when it has virtually attained an equilibrium shape or position is expressed in Equation (7.0) while the volume of dewatered material in cubic feet, V within the cone of depression is expressed in equation (8.0)

$$V = \int_0^{s_w} r^2\,\partial s \quad 8.0$$

The limits of integration are being chosen at zero drawdown (for example, the extent of the cone at equilibrium) and at the drawdown outside the screen of the pumped well. The value of r in equation (8.0) may therefore be substituted in equation (5.0) thereby resulting to equation (9.0).

$$V = \pi\beta^2 \int_0^{s_w} e^{-2ams + \frac{as^2}{2}} \partial s \qquad 9.0$$

the exponent in equation (9.0) may be written in the equivalent form $[-2ams + (1 - \frac{s}{2m}]$, $\frac{s}{2m}$ may be ignored because it is generally small compared to unity; therefore, equation (9) becomes

$$V = \pi\beta^2 \int_0^{s_w} e^{-2ams} \partial s \qquad 10.0$$

$$V = \frac{\pi\beta^2}{-2ams} \left[e^{-2ams}\right]_0^{s_w} \qquad 11.0$$

$$V = \frac{\pi\beta^2}{2am}\left[1 - \frac{1}{e^{2ams_w}}\right] \qquad 12.0$$

For values found during field pumping tests, $2ams_w > 1$

Hence, $\frac{1}{e^{2ams_w}}$ is very small and can be ignored[14]. Therefore, equation 9.0 results to

$$V = \frac{\pi\beta^2}{2am} \qquad 13.0$$

β can be obtained from from equation (7.0) as $\beta = re^{ams} - \frac{as^2}{2}$

Which when the value of β is substituted in equation (13.0), equation (14.0) is derived as

$$V = \frac{\pi r^2 e^{2ams} - as^2}{2am} \qquad 14.0$$

If the exponent of e is re-modified, in the manner shown in equation (10.0), equation (15.0) can be expressed in a simplified form

$$V = \frac{\pi r^2 e^{2ams}}{2am} \qquad 15.0$$

Equation (15.0) fully represents the volume of dewatered material as expressed in terms of permeability, drawdown, horizontal distance, aquifer thickness, and pumping rate.

It is often necessary to accomplish pumping tests in hydro-geological site investigations by harnessing wells that only penetrate the aquifer completely or for which insufficient data are available. Therefore, it may be not be possible to determine the coefficient of permeability, ***P*** or the full aquifer thickness, m under such circumstances; equation 7.0 cannot be used to determine the volume of dewatered material in the cone of depression[12-22]. However, if the drawdown, **s** at the point of observation is small compared to suspected thickness of the zone of saturation, the thickness may be assumed to remain uniform and Transmissibility, **T** may be used in lieu of the unknown permeability and aquifer thickness ($T = Pm$).

Several standard groundwater formulae are permitted the direct computations and consequent determination of the coefficient of transmissibility. Therefore, equation (15.0) may re-modified further by substituting therein the equivalents $\frac{2\pi P}{Q}$ for a and T for the product Pm, which yields

$$V = \frac{\pi r^2 e^{4\pi \frac{T_S}{Q}}}{\frac{4\pi T}{Q}}$$

$$V = \frac{Q r^2 e^{4\pi \frac{T_S}{Q}}}{4T} \qquad 16.0$$

Taking the logarithm of both sides of equation (16.0) produces

$$\text{Log } V = \text{Log } \frac{Qr^2}{4T} + \frac{4\pi T_s}{Q} \text{ Log e}$$

$$\text{Log } V = \text{Log } \frac{Qr^2}{4T} + \frac{5.45\ T_S}{Q} \qquad 17.0$$

The specific yield can therefore be obtained as the volume of water pumped during the test divided by the gross volume of dewatered material within the cone of depression[12-22].

$$S_Y = \frac{Qt}{7.48V} \qquad 18.0$$

Where S_Y = specific yield

Q = average discharge rate of the pumped well in gallons per day

T = time in days, since pumping began

V = volume of dewatered material in cubic feet delivered from either equation 15.0 or 17.0

It is worthy of note that observed formulae derived in this work may be applied only on the condition that the data from an equilibrium pumping test and the test itself should be granted sufficient time long enough for the allowance of the greatest possible dewatering status in the cone of depression without it being affected by prospective recharge[12-14].

3. Materials and methods

3.1 Location and accessibility of the study area

Ewekoro community in Ogun State is one of the mills of West African Portland Cement Company (WAPCO) and Dangote group Cement Company. It is a sleepy neighbouring town to Papalanto, a name known for sugarcane plantation. It lies between latitude $6^0 53^1$N and longitude $3^0 14^1$E. The sedimentary rocks of Ogun State consist of Ewekoro formation and Abeokuta formation. The Ewekoro formation is fossiliferous and consists of economic deposits of limestones that is quarried by WAPCO[23]. WAPCO being a public limited liability company registered in Nigeria with its corporate headquarter originally located in Ikeja in Lagos State but later relocated to Ewekoro and Shagamu in Ogun State. The factory occupies approximately 0.4 hectares of land and it was incorporated by the West African Portland Cement Company in March 1959. Production started in 1960 with only one kiln. The initial production was 200,000 tons per annum. The second kiln was constructed in 1967 and this has increased the total annual production 450,000 tons.

3.2 Weather, climate and vegetation

The study areas is generally a low lying to gentle undulating terrain that falls within the humid tropical climate characterized by two distinct seasons predominant in the tropics in the southern part of Nigeria namely, the wet and dry seasons. The wet season usually occur from March to October, the climate is dominated by the tropical maritime air mass or moisture laden Southwest winds from the Atlantic Ocean that produces heavy rainfall; most of the rainfall comes in torrential showers resulting in high run-off while the dry season occurs from November to late February or early March under the influence of the dry continental air mass or North-Easterly winds from Sahara desert. The little dry season in the mid-west season of July/August months is dominant in the area[24-25]. The haematin season, a season of dusty high winds, unusual cold and extremely dry conditions, lasts from November to February. It is caused by the tropical continental air from the Sahara Desert which displaces the tropical Maritime air from the Gulf Guinea[26]. Ewekoro has no distinct temperature seasons; the temperature is relatively constant during the year. The wet season ensures adequate supply of water and continuous presence of moisture in the air. Hence, the study area experiences high diurnal and annual temperature, lack of cold season, high precipitation, low pressure, high evapotranspiration and high relative humidity[25-27]. The temperatures at night are cooler than during the daytime. November is an average, the month with most sunshine. February is the warmest with an average monthly temperature of 33.5^{0}C at noon. August is coldest with an average temperature of 21.9 ^{0}C. Rainfall and other precipitation peaks around June. The time around January is the driest.

The study area has a mean annual temperature of 27 ^{0}C in July and 32 ^{0}C in February, and the average monthly temperature of 25.7 ^{0}C. It has relative high humidity of 71.09 % and long wet season that ensures adequate supply of water and continuous presence of moisture in the air. The annual rainfall is estimated to be 1194.33 mm[24-29]. Cold and hazy conditions are usually prevailing especially towards the end of the year while hot and dusty conditions are experienced during dry season. Hence, the study area is characterized by high diurnal and annual temperature, high precipitation, low pressure, high evapo-transpiration and high relative humidity. The major water bodies in the region are Yewa and Ogun rivers which flow into Lagos lagoon while their tributaries are found in Ewekoro Local Government Area as Alaguntan River, Akinbo River and Eshe River. There are however streams running parallel in the area. Also ponds are not left out. Due to the alternation of wet and dry seasons, the water table fluctuates in response to the seasonality of rainfall. During the wet season, groundwater level rises towards the surface and drops as the dry season sets in.

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. The forest vegetation is of two types, namely, the fresh water swamp forest and the lowland rain forest. The savanna found in the State is mainly of the derived savanna type. The rainforest vegetation is typified by perennial trees which may vary in height forming storey with characteristics thick vegetation due to high rainfall. The vegetation changes with seasons with the incoming of the rains, the green grasses are back to life and the foliage of the trees becomes green and thick. Where the soil is wet due to river drainage denser fringing forest are found. During dry season some of the trees, which develop umbrella shaped canopies shed their leaves in order to minimize loss of water by transpiration[30]. The river and the river-fed wetlands support a large number of plants. The wetlands are main sources of freshwater for drinking, domestic and agricultural uses. In the recent years it cannot be considered for drinking and domestic purposes due to variety of pollutants and contaminants from multiple sources such as industrial outputs, irrigation return flow, domestic discharges and hospital disposals, aggregating the situation water pollution and contamination. Most of these wetlands get dried in dry season and serves as a dumping yard for garbage and industrial wastes. Water-borne diseases have reported in many places of the area where proper sanitation facilities are lacking.

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 is deforestation. This simply means the loss of vegetation cover that is necessitated by the need to move equipment to the 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 have ornamental values, that can hold the soil structure well and could cover the exposed land well. Limestone mining in Ewekoro had resulted into the conversion of many farmlands and settlements into quarry sites. The house types on the site 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 no longer to farm as it was before now. The West Africa Portland cement according to the management made frantic effort at re-settling the landowners in the estate built very close to the factory. But since this was rejected, a programme of gradual takeover of the old farm site had started. 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 from within the Limestone deposit ordinarily should serve as habitat to fresh water fish, this has however not been developed. The ammonium compound washed into the lake from its primary source (explosive materials) may serve as manure and may encourage the growth of plankton, algae and 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 pose a serious hazard on the lives of the aquatic animals[19]. 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[31].

3.3 Deposit geology and hydrogeological setting

Ewekoro formation which is the geology of the study area is an integral part of the sedimentary rocks of Ogun State typically comprising of Ewekoro formation and Abeokuta formation. The Ewekoro formation serves as economic deposits of limestones quarried by WAPCO and it is highly fossiliferous[14]. It is generally consistent in line with the regional geology of Eastern Dahomey Basin where non-crystalline and highly non-fossiliferous limestone and thinly laminated fissile and little non-fossiliferous shale were dominant[32]. The composition of the limestone at the type locality is about 11m to 12m with varying thickness and resistivity; sandy at the base with downward grading towards Abeokuta formation, overlain by phosphoric glauconitic grey shale with some of the well information revealing a thick overburden of between 3m and 16m consisting of silt, clay, sand shale with some alluvium and lateritic deposits in some places[19-29]. The limestone thickness ranged between 3m and 40m; the thickest section was found at Fashola community (38.3m) while the thinnest section was identified at Jaguna (1.6m). The overburden thickness varied between 2m to 16m. The reserve estimation the limestone deposit was estimated to be 7.75 x 10^8 cubic meters and adjudged to be of economic value if exploited especially around Fashola autonomous community in Papalanto. The limestone classifications based on microfacies revealed biomicrosparite, shelly biomicrites, algal biosparite and phosphoric biomicrites in stratigraphic sequence[31]. The rock is relatively soft and friable but in some places cemented by ferruginous and siliceous materials. The lithological units in Ewekoro formation are clayey sand, clay, shale, marl, limestone and sandstone[33]. On the lithostratigraphic setting, the lithology of Ise and Afowo formations were identified by[34] revealing a reasonable level of similiarity essentially in sands and sandstones, but with thick shaly interbedings. It was later observed that the Ise, Afowo and Abeokuta formations share similar lithology and electric log signatures. The uppermost sections of Abeokuta formation cropping out in Ijebu Ode and in shallow boreholes at Itori, Wasimi and Ishaga onshore were found to primarily consist of fine to coarse grained sand and shale, mudstone, limestone and silt as interbeds; there were good correlations of these lithofacies with the upper section of the neostrato type in Ojo-1 borehole[35]. Jones and Hockey (1964) revealed that Ewekoro limestone and the overlying Akinbo shale to be of lateral equivalents to the Imo formation of eastern Nigeria. The stratigraphy, depositional characteristics of limestone lithofacies and their corresponding hydrogeological characteristics in South-Western Nigeria were equally investigated by other researchers[33-37]. Although, the more prolific water bearing rocks are the sedimentary rocks but the basement rocks though hydrogeologically challenging appears also serves as potential groundwater sources meeting the domestic needs of small scale village, institution, industries and other water supply schemes.

Furthermore, Some study reported that the crystalline rocks display poor groundwater yield with recorded with recorded mean yield of 880gph (3960 liters /hrs) at mean depth of 123ft (37.3m) and well over 30% failure rate were recorded for borehole drilling[3]. Sedimentary aquifers have been reported to possess higher rate of groundwater production than the basement complex aquifer[14]**.** Figure 1 shows the Geological Map of the investigated Location within the Nigerian Part of Dahomey Embayment, the map of Ogun State displaying the geology of the study areas is presented in Figure 2, the inset map showing political divisions of the study area within Nigerian continental environment is shown in Figure 3 while Figure 4 is the data acquisition map showing the investigated locations in Ewekoro LGA, Southwest Nigeria[19].

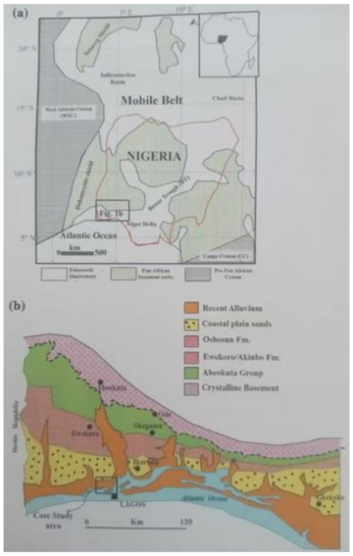

Figure 1. Geological map showing the selected locations of the study area within the Nigerian, part of Dahomey Embayment[19 & 38]

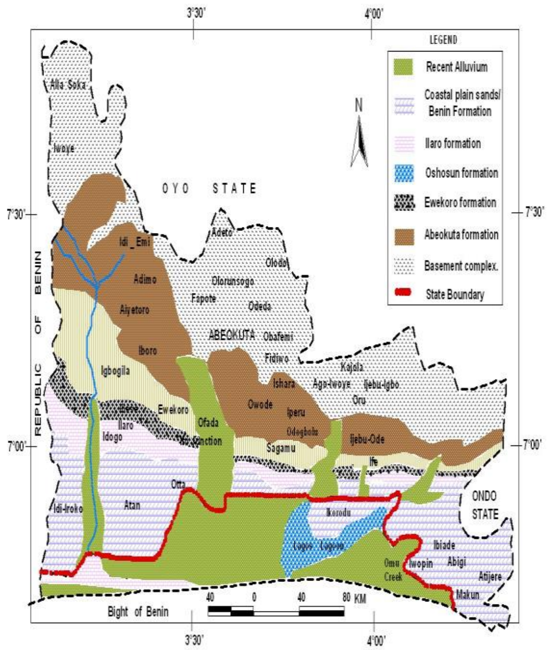

Figure 2. A map of Ogun State showing the geology of the study areas (after Kehinde-Phillips and Obiora & Onwunka)[39-40]

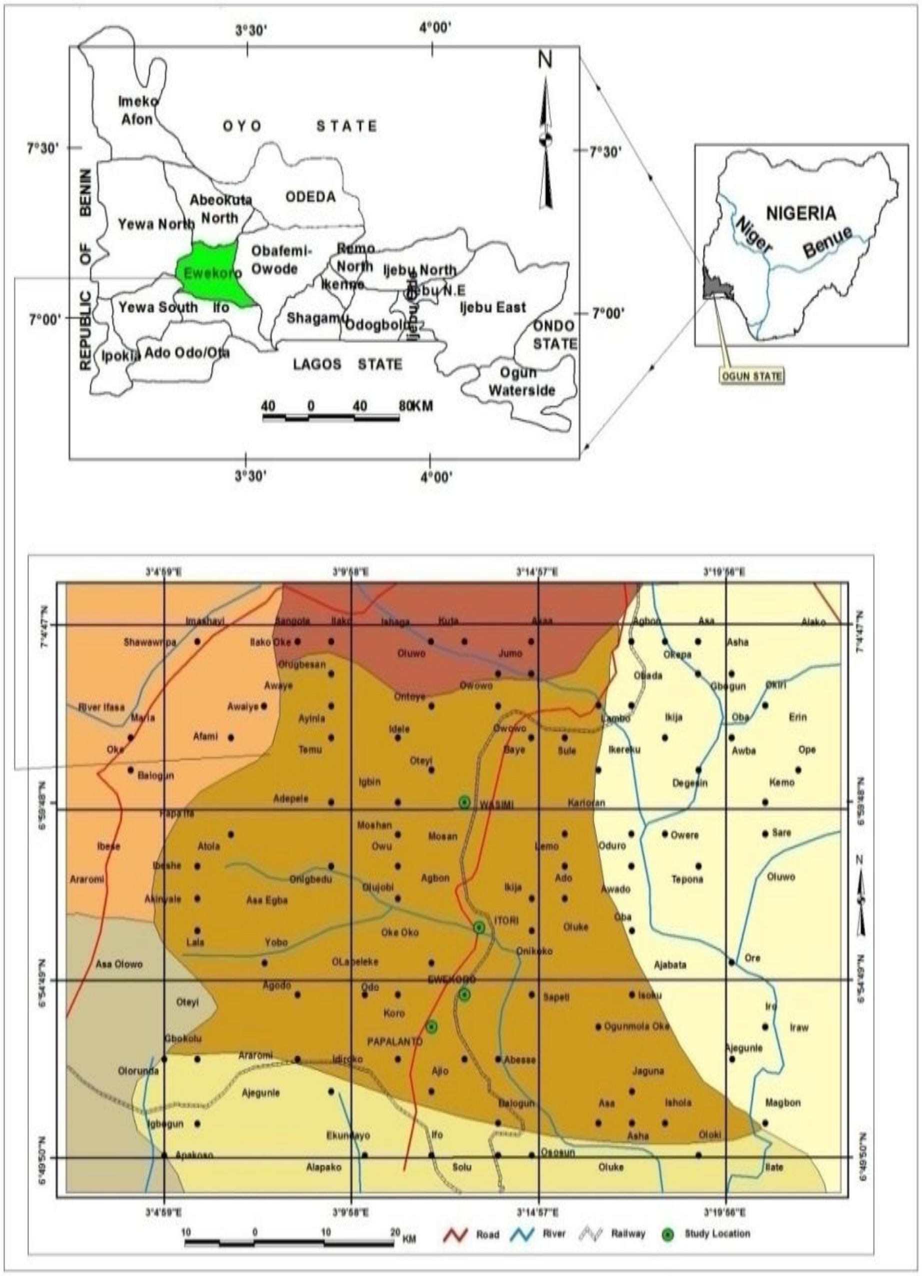

Figure 3. Inset map showing the study areas in Ogun State within Nigeria continental domain using Esri - data/nigeria political information in Arcview GIS 3.2A environment[19]

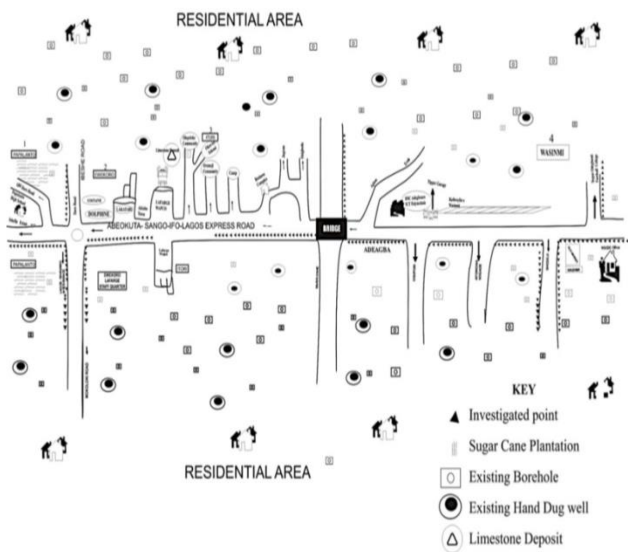

Figure 4. Base map showing the existence, location and accessibility of the investigated points in Ewekoro LGA, Southwest Nigeria[19]

4. Field data acquisition

Two major sources of data were used in this study. These are primary and secondary data. The primary data consisted of reconnaissance survey and personal visits to locations of existing boreholes and hand-dug wells in the study area, identifying sampling points and collecting well inventory. Practicing consultants on borehole drilling in Ewekoro Local Government Area were also contacted for information on the boreholes drilled in the study area. The secondary data consisted of published and unpublished documents for relevant information, such information were extracted from journals, conference papers and available textbooks. Existing drilled boreholes were identified across the study areas and where there were no boreholes and well inventories of hand-dug wells were collected. The depth of the boreholes and the overburden thickness were measured using dip metre[41].

5. Constant rate pumping test

Constant rate pumping tests were conducted on the selected boreholes. The materials used for these tests included; 60-litre gallons as a standard measure, generating set to power the pump, stop watch to record time intervals and rubber hose connected to the pipe from the borehole to discharge the water into the gallons. In conducting this test, the initial or static level of the water in the boreholes was measured using a dip metre. The generating set was thereafter switched on to start the pumping. The pumping was allowed to run continuously for a long period of two hours before the rate of pumping was adjusted for the boreholes to maintain constant discharge. At this point, the water level was measured to know the drawdown and a calibrated 60-litre gallon was then filled from the constant discharge from the boreholes while a stopwatch was simultaneously set to record the time taken, in seconds, to fill the bucket. This process was repeated for four hours for each of the selected boreholes. It was therefore observed that the water level and the drawdown in the boreholes were constant throughout the four hours pumping. With the constant discharge from the boreholes, a state of equilibrium was maintained between the rate of discharge and the rate of recharge from the aquifer. In this condition of equilibrium, the rate of pumping or discharge is directly proportional to the yield of the borehole or well at the constant drawdown. In other words, the discharge per unit time in litres per second gives the yield of each of the selected boreholes at the constant drawdown[19].

6. Results

The classification standards of transmissibility Potentials of Aquifer System and the outputs of the basic well inventories and hydraulic properties of the aquifers via boreholes in the study area are presented as summary in Table 1 and Table 2 respectively. In the evaluation of the aquifer characteristics in the study area, groundwater supply to boreholes were abstracted from fractured sandstone/limestone whose depth ranged from 35 to 75m with mean value of 51m; 35 to 85m with mean value of 50.36 in; 35 to 100m with mean value of 60.32m; 38m to 108m with a mean depth of 75.36m respectively recorded for Wasinmi, Itori, Ewekoro and Papalanto. The static water level ranged from 8.45 to 37.4m with mean value of 17.7m to 27.1m with a mean value of 15.1m; 4.41 to 48.1m with a mean value of 22.1m and 3.43 to 54.3m with a mean value of 33.8m respectively recorded for Wasinmi, Itori, Ewekoro and Papalanto. The well-heads varied from 0.04 to 0.61m with a mean of 0.33m; 0.33 to 0.52m with a mean of 0.13m; 0.58m to 1.38m with a mean of 0.15m and 0.33 to 0.46m with a mean of 0.30m respectively recorded for Wasinmi, Itori, Ewekoro and Papalanto. The observed residual drawdown varied between 3.67 to 11.4m with a mean value of 8.17m; 3.28 to 11.3m with a mean value of 8.41m; 3.53 to 11.6m with a mean value of 7.48m and 2.84m to 12.0m with mean value of 8.10m respectively recorded for Wasinmi, Itori, Ewekoro and Papalanto while the recovery time varied from 850 to 3431s with a mean value of 2254s; 1015 to 8352s with a mean value of 2391; 1566 to 3150s with a mean value of 2483 and 1030 to 3110s with a mean value of 2218s respectively recorded for Wasinmi, Itori, Ewekoro and Papalanto.

Table 1. Transmissibility potentials of the aquifer system[19, 49 & 56-57]

Transmissibility (T) Range (m^2/day)	Aquifer Potentiality Classification
> 500	High Potentials
100−500	Good Potentials
50−100	Moderately Potentials
5−50	Low Potentials
0.5−5	Very Low Potentials
<0.5	Negligible Potentials

Table 2. Summary of basic and estimated hydraulic parameters of studied aquifer systems of boreholes in selected locations in Ewekoro communities

BASIC HYDRAULIC PARAMETERS							**ESTIMATED HYDRAULIC PARAMETERS**				
Locations	**Well Head (m)**	**Borehole Depth BHD (m)**	**Borehole diameter BHDT (mm)**	**Static Water Level SWL (m)**	**Residual Draw-Down DD (m)**	**Recovery Time (s)**	**Specific Discharge Q (l/s)**	**Specific Capacity Cs (m^2/s)**	**Well Loss WLC (s^2/m^5)**	**Transmissibility T (m^2/s)**	**Optimum Operating Capacity OOC**
Wasinmi Boreholes											
MEAN	0.33	51	84.80	17.8	8.17	2254	4.0×10^{-2}	6.3×10^{-3}	5.98×10^{4}	4.5×10^{-1}	02.52×10^{-4}
MAX	0.61	75.00	125.00	37.4	11.4	3431	11.0×10^{-2}	2.0×10^{-2}	2.73×10^{6}	9.2×10^{-1}	2.20×10^{-3}
MIN	0.04	35.00	25.00	8.45	3.67	850	1.0×10^{-2}	1.0×10^{-4}	4.77×10^{4}	1.00×10^{-2}	1.00×10^{-6}
S.D	0.11	11.58	46.18	8.47	2.49	838	2.0×10^{-2}	5.0×10^{-2}	5.60×10^{4}	2.6×10^{-1}	1.00×10^{-4}
CV (%)	33	23	55	48	31	37	50	79	94	58	40
Itori Boreholes											
MEAN	0.33	50.36	87.60	15.1	8.41	2391	5.0×10^{-2}	7.0×10^{-2}	4.30×10^{5}	1.00×10^{-2}	3.50×10^{-3}
MAX	0.52	85.00	140.00	27.1	11.3	8352	11×10^{-2}	48.0×10^{-2}	1.28×10^{4}	7.00×10^{-2}	5.28×10^{-2}
MIN	0.13	35.00	25.00	3.25	3.28	1015	3.0×10^{-2}	1.0×10^{-2}	8.57×10^{4}	1.00×10^{-4}	3.00×10^{-4}
S.D	0.11	15.07	44.70	7.53	2.51	1418	2.0×10^{-2}	9.0×10^{-2}	3.69×10^{5}	2.00×10^{-2}	1.80×10^{-3}
CV (%)	33	30	51	50	30	59	40	12	86	200	51
Ewekoro Boreholes											
MEAN	0.58	60.32	109.40	22.1	7.48	2483	4.0×10^{-2}	6.0×10^{-3}	0.616×10^{4}	9.00×10^{-3}	2.40×10^{-4}
MAX	1.38	100.0	140.00	48.1	11.6	3150	6.0×10^{-2}	1.0×10^{-2}	1.189×10^{4}	8.00×10^{-2}	6.00×10^{-4}
MIN	0.15	35.00	25.00	4.41	3.53	1566	3.0×10^{-2}	1.0×10^{-4}	0.196×10^{4}	1.00×10^{-4}	3.00×10^{-6}
S.D	0.41	19.15	34.41	14.3	2.45	555	1.0×10^{-2}	3.0×10^{-2}	0.365×10^{4}	1.5×10^{-2}	3.00×10^{-5}
CV (%)	71	32	32	65	33	22	25	50	59	166	13
Papalanto Boreholes											
MEAN	0.30	75.36	86.600	33.8	8.10	2218	5.0×10^{-2}	5.0×10^{-3}	0.519×10^{4}	9.00×10^{-3}	2.50×10^{-4}
MAX	0.46	108.0	140.00	54.3	12.0	3110	9.0×10^{-2}	1.0×10^{-2}	1.137×10^{4}	4.00×10^{-2}	9.00×10^{-4}
MIN	0.33	38.00	25.00	3.43	2.84	1030	3.0×10^{-2}	1.0×10^{-4}	0.085×10^{4}	1.0×10^{-4}	3.00×10^{-6}
S.D	0.084	20.73	48.62	16.9	2.65	673	2.0×10^{-2}	3.0×10^{-3}	0.307×10^{4}	7.00×10^{-3}	6.00×10^{-5}
CV (%)	28	28	56	50	33	30	40	60	59	78	24

7. Discussion

In Wasinmi Boreholes, the studied rock mass aquifer system yields (Q) up to 11.0×10^{-2} l/s with Residual Drawdown (S′) ranging between 3.67m and 11.4m. Average Static Water Level (SWL) is 17.8m within a range of 8.45m – 37.4m, while its Depth ranges between 35m and 75m. Mean specific capacity (Cs) and well loss constant (WLC) are 6.30×10^{-3} m^2/s and 5.98×10^4 s^2/m^5 respectively, with maximum Transmissibility (T) of $9.2\times10^{-1}m^2/s$ (79,488m^2/day). Among the tested aquifer properties, Borehole depth (BHD) is the least variable parameter, having coefficient of variation (CV) of 23% followed by Residual Drawdown (S′) with CV of 31%. In general, all other parameters have coefficient of variation above 10 %. This implies that the variation caused by the aquifer system on DD, SWL, BHD, Q, Cs, WLC, OOC and T is high enough to be significant in hydrogeological system of Wasinmi Boreholes[49-59].

In Itori Boreholes, the studied rock mass aquifer system yields (Q) up to 11.0×10^{-2} l/s with Residual Drawdown (S′) ranging between 3.28m and 11.3m. Average Static Water Level (SWL) is 15.1m within a range of 3.25m – 27.1m, while its Depth ranges between 35m and 85m. Mean Specific Capacity (Cs) and Well Loss Constant (WLC) were 7.02×10^{-2} m^2/s and 4.30×10^5 s^2/m^5 respectively, with maximum Transmissibility (T) of $7.0\times10^{-2}m^2/s$ (6048m^2/day). Among the tested aquifer properties, Borehole Specific Capacity (Cs) is the least variable parameter, having coefficient of variation (CV) of 12%; this is in agreement with findings of Knopman and Holliday[60] followed by Residual Drawdown (S′) with CV of 30%. In general, all other parameters have coefficient of variation above 10 %. This implies that the variation caused by the aquifer system on DD, SWL, BHD, Q, Cs, WLC, OOC and T is high enough to be significant in hydrogeological system of Itori Boreholes[49-59].

In Ewekoro Boreholes, the studied rock mass aquifer system yields (Q) up to 6.0×10^{-2} l/s with Residual Drawdown (S′) ranging between 3.53m and 11.6m. Average Static Water Level (SWL) is 22.1m within a range of 4.41m – 48.1m, while its Depth ranges between 35m and 100m. Mean Specific Capacity (Cs) and Well Loss Constant (WLC) were 6.00×10^{-3} m^2/s and 6.16×10^5 s^2/m^5 respectively, with maximum Transmissibility (T) of $8.0\times10^{-2}m^2/s$ (6912m^2/day). Among the tested aquifer properties, Optimum Operating Capacity (OOC) is the least variable parameter, having coefficient of variation (CV) of 13% followed by Period of Recovery (t) in seconds with CV of 22%. In general, all other parameters have coefficient of variation above 10 %. This implies that the variation caused by the aquifer system on DD, SWL, BHD, Q, Cs, WLC, OOC and T is high enough to be significant in hydrogeological system of Ewekoro Boreholes[49-59].

In Papalanto Boreholes, the studied rock mass aquifer system yields (Q) up to 9.0×10^{-2} l/s with Residual Drawdown (S′) ranging between 2.84m and 12.0m. Average Static Water Level (SWL) is 33.8m within a range of 3.43m - 54.3m, while its Depth ranges between 38m and 108m. Mean Specific Capacity (Cs) and Well Loss Constant (WLC) are 5.0×10^{-3} m^2/s and 0.52×10^4 s^2/m^5 respectively, with maximum Transmissibility (T) of $4.00\times10^{-2}m^2/s$ (3456m^2/day). Among the tested aquifer properties, Optimum Operating Capacity (OOC) is the least variable parameter, having coefficient of variation (CV) of 22% jointly followed by Well Head (WH) and Borehole Depth (BHD) with CV of 28%. In general, all other parameters have coefficient of variation above 10 %. This implies that the variation caused

by the aquifer system on DD, SWL, BHD, Q, Cs, WLC and T is high enough to be significant in hydrogeological system of Papalanto Boreholes[49-59] (Table 2**).**
The coefficient of variation provides some measure of departure from normality. It is a standardized measure of dispersion of a probability distribution or frequency distribution. A coefficient of variation greater than 100% indicates that the variable in question is not normally distributed. In contrary, a coefficient of variation less than 100% indicates that the data is normally distributed. The coefficient of variation is calculated as follows:

$$CV\ (\%) = \frac{\sigma}{\mu} \times 100\% \qquad 1.4$$

Where CV is the coefficient of variation, σ is the standard deviation, and μ is the arithmetic mean of the distribution.

The data for each tested hydraulic parameter in selected parts of Ewekoro Local Government Area were statistically analyzed by applying the homogeneity test and the results presented in Table 2 alongside with the arithmetic mean and Standard deviation for each hydraulic property.
By applying the normality test and calculation of coefficient of variation for every Hydraulic parameter, it was observed that all the hydraulic units (Basic and Estimated) had normal distribution in all the investigated study area except Transmissibility that exhibited abnormal distribution with Coefficient of Variation of 200% in Itori Boreholes and 166% in Ewekoro Boreholes. When the depths of penetration obtained from the field data were compared to the total depths of the shallow wells dug close to the measurement locations, the results revealed with clear distinction that all the wells at this section were not drilled to the aquifer level; the wells were terminated just slightly above the overburden and some within the overburden. Also, due to the unavoidable irregularities in the size of the borehole and water losses into the fractured rock that occurred in many wells because each construction method adopted has advantages related to the ease of construction, cost factors, character of the formations to be penetrated, well diameter and depth, sanitary protection and intended use of the well itself. Therefore, a careful study of the operating history of the deteriorated and abandoned boreholes and wells in the region should be made in order to reveal some logical steps in devising the maintenance and rehabilitation procedures to be adopted.

8. Conclusions

Evaluation of aquifer properties is often possible with methods of measurement by devising approximate methods of analysis based on idealized models of an aquifer system. Diverse results and variations arise in the attempt to force the application of ideal conditions formulae to sedimentary aquifer situations. Variations of estimated aquifer parameters indicate that the sedimentary nature of the aquifer actually does coincide rather closely with what may be predicted theoretically with model aquifers and mathematical models. It is apparent that quantitative answers to explain the behaviour of the sedimentary rock mass aquifer system depend primarily upon the geologic and hydrologic controls. As the general technique of groundwater resource evaluation is inadequate, a need for more precise, quantitative data concerning requisite geologic information about typical sedimentary aquifer is strongly recommended.

The varying residual drawdown, high recovery transmissivity, and high specific capacity represent locations that were considered to delineate the potential groundwater zones for development. The aquifer hydraulic characteristics play a major role in the identification of groundwater potential zones, because they reflect the rock structures through which the water flows. In general, transmissivity values greater than 100 m^2/day are considered good in hard rock terrains. Basic and estimated aquifer parameters were hydraulically determined based on the existing boreholes in the study areas. Aquifer parameters, such as transmissivity, Specific Discharge and Time required for full recovery, have been analyzed to evaluate the groundwater potential of the study area. Itori borehole has the highest Optimum Operating Capacity with the mean value of 3.50×10^{-2} m^2/s. The recovery transmissivity and specific yield are also very high in the study area notably Ewekoro boreholes and Papalanto boreholes with the mean values of 5.02×10^{-2} l/s and 4.02×10^{-2} l/s and 9.00×10^{-2} m^2/s . The varying residual drawdown and recovery time observed are due to the structural displacements in the hydrogeological formation of the study area. Low recovery and optimum operating capacity may reflect a lack of secondary porosity, compaction of lithologic units and a shallower weathered layer. The results of the test of normality using the coefficient of variation showed that the field acquired data comprise a highly representative and statistically comparable dataset. The results of the Well loss coefficient reveal most of the studied Boreholes to be either mildly deteriorated or severely deteriorated while few studied wells were unaffected. However, there is availability of groundwater all over the investigation locations in Ewekoro Local Government area that can support domestic and industrial uses. Aside from the expected yield of the studied aquifer system, during the percolation processes potential contaminants from the surface water are removed by filtration, adsorption, reduction and biodegradation while the capacity of self-purification depends mainly on flow velocity, hydraulic residence time and the covered distance determined by the permeability and the hydraulic potential in the aquifer. This hydraulic attempt at assessing the aquifer parameters of this typical sedimentary terrain has revealed the groundwater resource potentials of the study area. The evaluation of the aquifer performance assessment through the constant discharge of the recovery method has provided information regarding the construction and design of discharge wells and development of groundwater in the study area.

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Data availability

The data that support the findings of this study are available from the author upon reasonable request.

Declaration of competing interest

The author declares that he has no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Use of AI tools declaration

The author declares that he has not used Artificial Intelligence (AI) tools in the creation of this article.