Journal of Hydrogeology & Hydrologic Engineering

Research Article

A SciTechnol Journal

Geoelectrical Assessment of the Impact of Indiscriminate In-Stream Sand Mining on Hydrological System of Coastal Aquifers in Oron Local Government Area, Akwa Ibom State, Nigeria

Evans UF[1*], Okiwelu AA[2] and Udoinyang EP[3]

Abstract

Geoelectrical measurement using Schlumberger electrodes array was conducted to assess the impact in-stream sand mining on hydrological system of coastal aquifers. A total of 15 VES was carried out and results were interpreted using manual curve plotting and computer software. The VES results as well as the fluctuations in groundwater level for mining and non-mining sites were compared. The variation of in-situ resistivity of geounit shows that mining sites produced mostly AK and K curve types with comparatively higher values (1042-12827 Ωm). This was contrary to the HQ and H curves with relatively lower resistivity values (162-4736 Ωm) obtained for geolayer of non-mining sites. HQ and H curve types with the associated low resistivity values, complemented with observed low percolation groundwater level (0.22 mmd-1), and productive 4 m depth well indicate balance in hydrological level. However, AK and K curves, associated high resistivity values earth layer, high groundwater percolation (0.56 mmd-1) and non-productive 10 m deep-hand-dug wells within mining site, were pointers to unsaturated geolayer and groundwater imbalance. This means that, groundwater could only be abstracted from deeper aquifers in locations with intensive sand mining especially during dry season. To maintain balance in hydrogeological system of mining sites, a well-planned sand mining programme should be employed.

Keywords: Geoelectrical; In-stream; Sand; Mining; Groundwater and Hydrology

Introduction

Man in attempt to meet the challenges of life has increased his exploration of unconventional natural resources including mining of sand from the streams without considering the spatial variations in the hydrological system. Sand exploration in recent years is further intensified by the rapid development, which increases demand for river sand as a source of construction material. It is therefore pertinent to device means of maintaining a balance in the hydrological system of sand mining sites. A balance in the hydrological system of a place does not only sustain the groundwater resources but protect it from subsurface contamination [1-3]. This is particularly important in the face of the rising demands for potable water and the changes in rainfall patterns as witnessed in Nigeria.

***Corresponding author:** Evans UF, Department of Research & Statistics, Maritime Academy of Nigeria, Oron, Nigeria, Tel: +23417384132/7038236344; E-mail: egeosystems2@gmail.com

Received: January 28, 2019 **Accepted:** July 17, 2019 **Published:** August 07, 2019

The concept of hydrological balance underlines the fact that for a specific water body or geologic formation, there must be a balance between water input (precipitation) and water disbursed (discharge) by transpiration from plants, evaporation from the surface and run-off to ocean [4]. Besides, over certain periods, water can also be stored as soil water and groundwater (in aquifers) or in catchments. The water input, discharge and storage make it both renewable and limited. Basic principle of water conservation shows that, water balance of an aquifer is the relation between inflow, discharge and groundwater storage. In the storage and discharge of groundwater, local rock materials within a geological formation are essential in the hydrological balance of an area [5].

Groh et al. asserted that, rock fragments (sand) vary in size and shape, and are naturally endowed [6]. These rock fragments are useful in the construction of roads, dams, buildings and bridges, as well as in the manufacturing of glass wares. Today, there is high demand for sand nationwide [7] because of its economic importance. Sand mining in the Niger Delta is seen as lucrative business by the populace and a major source of employment for local dwellers. Therefore, sand mining operation is carried out in almost all the streams and Rivers. This operation is done either mechanically using dredgers or manually using steel pails. Besides in-stream mining, red earth mining is also going on ashore [8].

In-channel or near-channel sand mining is capable of changing the sediment budget of a site, which may result in substantial modifications of the hydrological potential of an area. Such modifications, according to Bruce PE et al. [9-13] depend on the mining methods, particle-size characteristics of the sediment, the characteristics of riparian vegetation and magnitude and frequency of hydrologic events. The negative effect of in-stream mining is further compounded by the effect of sea level rise [14,15]. Any volume of sand exported from streambeds or coastal areas is a loss to the system as well as threat to bridges, river banks and other nearby structures. In addition, it also threatens the adjoining rivers and their use by the local people. In the views of Alexander et al. [16-19] sand mining has the tendency of causing: loss of aquatic habitats (specially for fish), decreased species diversity due to loss of sensitive species, loss of spawning grounds (for aquatic species and river bank dwelling species), disturbances to food webs, habitat loss for bank dwelling species such as aquatic birds, reptiles, amphibians ecosystem stability and the exposure of the riverbed to solar radiation. Others are, undercutting and collapse of river banks, loss of adjacent land and structures, upstream erosion (due to increase in channel slope changes in flow velocity), downstream erosion due to increase in carrying capacity of the stream) which always begins with water table depletion. These modifications can substantially change the adjoining subsurface properties such as porosity, dissolved ion content, groundwater table fluctuation. These subsurface properties control the ground electrical resistivity, which is easily delineated by geoelectrical resistivity survey.

In the strength of the above, the study examines the impact of indiscriminate in-stream sand mining on hydrological potential so as to determine if there exists significant variation in the water table between mining and non-mining sites using geoelectrical resistivity survey. At present, the level of understanding of hydrological potential in the study area is generally not sufficient to enable the prediction of channel respond quantitatively and with confidence. Thus, it becomes difficult to make decisions on where to mine, how much and how often a particular stream should be mined. This study demarcates the hydrogeology of mining and non-mining sites for the ecosystem sustainability.

Study Area

Physiographic description of study area

The study area is within the tropical rain forest belt of the Nigerian Niger Delta. It is bounded by the Atlantic Ocean in the South and Imo River towards the North. The climate is equatorial, consisting of wet and dry seasons. The wet season is noted for heavy rainfall, which causes the water table to rise considerably [20,21]. In some cases, the water table rises to the ground surface. The wet season usually starts by March and ends in October of each year. The heavy rainfall witnessed during this season increases the level of leaching of soluble salts and their compounds. This renders the soil generally acidic and the rate of electrochemical reaction in the soil tends to increase. This influences the local subsurface electrical conductivity [22]. The dry season usually witnesses low rainfall and lowering of water table. Thus, the water table in the area is subject to spatial and seasonal variations, which also affects some of the streams in the area. Temperature is noted to be fairly higher during the dry season than the wet season, though there is no sharp boundary between the two seasons.

The study area comprises five geomorphic sub-environments: the undulating lowland of the coastal plain sands, the flood plain with extensive sand deposit, the meander belts consisting fresh water swamps, the mangrove swamps and estuary and the beach ridges [21,23]. The flood plains adjoin the major rivers in the area, while the meander belt is characterized by intensive river meandering and consists of silty clay and sands. Tidal creeks of saline water surround the mangrove swamp and estuary. The tidal variation ranges between 1.5 m to 1.8 m, and defines the limits of partial saturation of the superficial soil, which is significantly influenced by the hydrology of the rivers and series of seasonal streams [20]. The undulating lowland is characterized by extensive and irregular distribution of near shore coarse–fine grains permeable sands. These sands are subject to enormous seepage pressures, as they are often mined for local construction projects.

Geology of the study area

The targeted aquifer lies within the deltaic depositional environment of the Nigerian Niger Delta and forms parts of the Coastal Plain Sand (CPS) otherwise called Benin Formation. It is a heterogeneous succession of discontinuous, interbedded sandstones, siltstones, and shales with variable thicknesses. The near surface geology of the Coastal Plain Sand environment is well established from extensive drilling due to exploration for oil in the Niger Delta [24-26]. The Benin Formation is the uppermost unit of the Niger Deltaic lithofacies and has clastic sedimentary rocks formed either as terrestrial or marine deposits [27,28]. The sediments are predominantly sandy with minor shale intercalations [25]. has described the Benin Formation as a continental depositional environment having massive, poorly sorted sands and sandstones with thin shales, clay and gravel which grades downwards into the delta front Agbada lithofacies. The grains are sub-angular to well rounded; white or yellowish brown (when coated with limonite) and bear lignite, which occur in thin streaks or finely, dispersed fragments [29,30].

The Benin Formation is said to be overlain in many places by lateritic overburden and alluvial deposits of considerable thickness caused by the weathering and subsequent ferruginization of older rock sequences. This is underlain by impervious shale layer, which is also characterized by lateral and vertical variations in lithology [31]. This composition provides favourable condition for fresh-water bearing. The thickness of the Benin Formation is variable and may be more than 6,000 ft in some locations [26]. The coastal sediments of the Benin Formation develop frequent anticlinoid fault structure at depth of importance in search for oil traps [32-34].

The geologic map of the study area shows that, the area is of intense coastal sand/gravel and alluvial deposits,

(Figure 1) with high, permeability and porosity. The study area is underlain by Quaternary to Tertiary sediments of the Niger Delta. The near surface sediments in this region are typically sandy, clayey, silty, pebbly, loose, and are poorly sorted. Groundwater potentials are very high due to high permeability, high recharge potential and considerable aquifer thickness. Sediments within the southeastern part of the study area may be saline in nature due to its proximity to the Bight of Bonny which contains saline water. Depletion of sand in the streambed and along coastal areas could cause deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets, which may lead to saline-water intrusion from the nearby sea [35-39].

Methodology

The vertical electrical sounding (VES) using the Schlumberger array was employed to map the subsurface adjacent to selected sites (rivers) in Oron Local Government Area of Akwa Ibom State where in-stream sand mining activities are practised. These sites include: *Etim Inyang* beach, Benson beach and *Uya-Oron* creek. Nine VESs were carried out in mining sites along traverse close and parallel to the river channels using ABEM Terrameter (SAS 4000) and its accessories. In addition, six VESs were conducted at non-mining sites. For purpose of control and ground-truthing, additional data on seasonal groundwater level fluctuations were obtained from three hand-dug wells in both mining and non-mining sites, and the lithology log of a nearby mechanically drilled borehole was interpreted.

At every sounding point, current was injected into the subsurface by means of two current electrodes (AB). At the same time, a measurable potential was maintained by ensuring that, the potential electrodes separation was not greater than 1/5 of half the current electrodes spacing. The potential electrodes (MN) were situated near the centre of the array. The current electrodes separation was a step-wise increase to a maximum of 600 m to allow injected current to reach deeper layers. The measured earth resistance (ΔV) was combined with the geometrical factor for Schlumberger electrode array to compute the subsurface electrical apparent resistivity (ρ_a) using a standard equation given as,

$$\rho_a = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] * \frac{\Delta V}{I} \quad (1)$$

The obtained apparent resistivity values were manually plotted against half current electrodes spacing on double logarithmic paper produce geo-resistivity field curve. The achieved field curves were then manually smoothened to remove extraneous signatures and lateral heterogeneities from the field data. Therefore, at every crossover points the average to two readings was taken or any point which shows unconformity to the trend of the sounding curve was deleted. The manually processed data (curves) were then interpreted with the aid of IPI2Win (a computer software) to obtain geo-resistivity layering and depth limited to current penetration.

(Figure 2) The combination of data interpreted from VES and hydrogeologic information available from ground truthing, aided geo-interpretation of the hydrological potential of the area. The groundwater levels in the hand dug wells were measured using a calibrated wood and the difference between the water level in the rainy and dry seasons were computed. This was necessary to provide complementary data for the study. In addition, lithology log available from a nearby mechanically drilled water borehole provides information on the local geology of the study area.

In hydrologic cycle, a one-dimensional water (mass) balance equation for the fluctuations in groundwater level is given by,

$$P + Q_{in} = E + \partial M_{sw} + \partial M_{gw} + Q_{dis} \qquad (2)$$

Where P is precipitation (mmd^{-1}); E is recharged to surface or groundwater (mmd^{-1}), E is evapotranspiration (mmd^{-1}); M_{sw} is surface water storage (mmd^{-1}), M_{gw} is groundwater storage (mmd^{-1}) and Q_{dis} is discharged from surfac or groundwater (mmd^{-1}).

Results

The results of interpreted data for the study area are contained (Table 1)

Mining

"Yes" for site where sand/gravel is being mined; "No" indicates site where no mining activity is going on; %Er is the RMS error.

A maximum of 4 geoelectrical layers have been delineated, with resistivity values ranging between 42.4 and 12827 Ωm. The variation of in-situ resistivity of geounit shows that mining sites produced mostly AK and K curve types with comparatively higher values

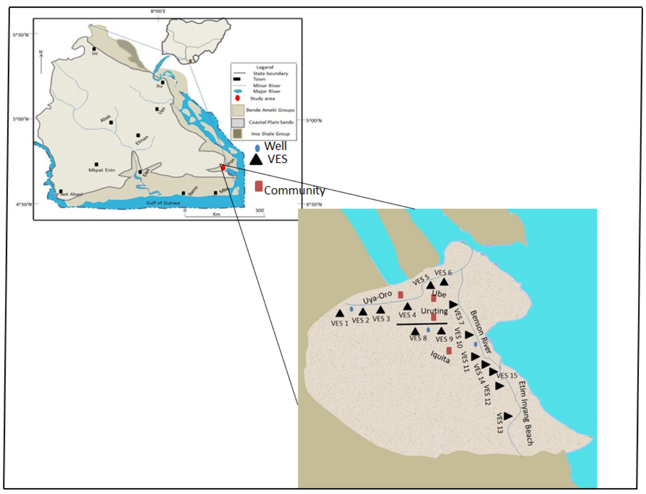

Figure 1: Map of Akwa Ibom State showing the study area, geology, towns and rivers.

(1042-12827 Ωm). This was contrary to the relatively lower resistivity value (162-4736 Ωm) which generates HQ and H curve types for geolayer at non-mining sites. The geoelectrical resistivity information obtained, complemented with borehole lithology log near (Figure 3) VES 11 and data from hand dug wells were used to construct the geoelectrical sections for non-mining and mining sites of the study area respectively (Figures 4 and 5). AK and K curves as well as the associated high resistivity values of earth layer were common with mining sites. Wells drilled within the mining sites were not productive at depth less than10.0 m depth during the dry season. The absence of water within this depth was considered the absence of phreatic zone at the superficial depth of about 10 m and yielded thick vadose zone, which was interpreted to mean deeply buried groundwater table. A relatively high groundwater percolation (0.56 mmd^{-1}) was noticed at mining sites. Meanwhile, non-mining sites were identified with HQ and H curve types, and the low resistivity values at superficial depth.

Wells drilled close to the non-mining sites were productive even at depth less than 5.0 m during the dry season. The presence of water within this depth suggested the presence of phreatic zone at the superficial depth of about 50.0 m and produced thin vadose zone. This was interpreted to mean shallow buried groundwater table. Low percolation (0.22 mmd^{-1}) of groundwater was observed at non-mining sites. The borehole lithology log and

(Figure 3) physical inspections of hand dug wells in the study area revealed that, the near surface geology comprised sand of different grains with little or no clay intercalation. This confirmed that, the relatively low resistivity values of the middle layer in (Figure 4) (non-mining site), mark the presence of groundwater. It was therefore, interpreted to mean near-surface buried aquifer, when compared with (mining site).

Discussion

Based on the results obtained for the study, resistivity values determine the curve types, which define the shapes, forms and patterns of vertical variation of resistivity in the study area. Basically, the A curve-type shows continuous raise in resistivity, literally interpreted to mean unsaturated subsurface condition. The K curve-type shows the low-high-low subsurface resistivity. The H curve-type is indication of high-low-high georesistivity. It describes a trough-like resistivity curve. This curve-type is always a pointer to subsurface saturation zone. However, Q curve-type is indication of continuous decrease in earth resistivity (Figure 6).

The combinations of two or more georesistivity curve-types are very possible. Therefore, the delineation of AK and K curves in areas identified with high resistivity values indicates low conductive rock materials. This is in support of Orellana et al. [40-42]. They asserted that, high resistivity rock materials are associated with poorly conductive media. The conductivity of earth materials is a function of dissolved salt, porosity, clay content, and degree of saturation of the pore space. This explains the non-production wells at depth about10 m in the mining site, and was considered to indicate groundwater depletion.

The delineated HQ and H curve types with its associated low resistivity obtained at non-mining site indicated the presence of groundwater. This was supported by productive wells at depth less than 5.0 m wells in non-mining site. It is worth noting that, groundwater levels respond to changes in precipitation with only a few months delay, indicating that, the mechanism of recharge is fast and that, the

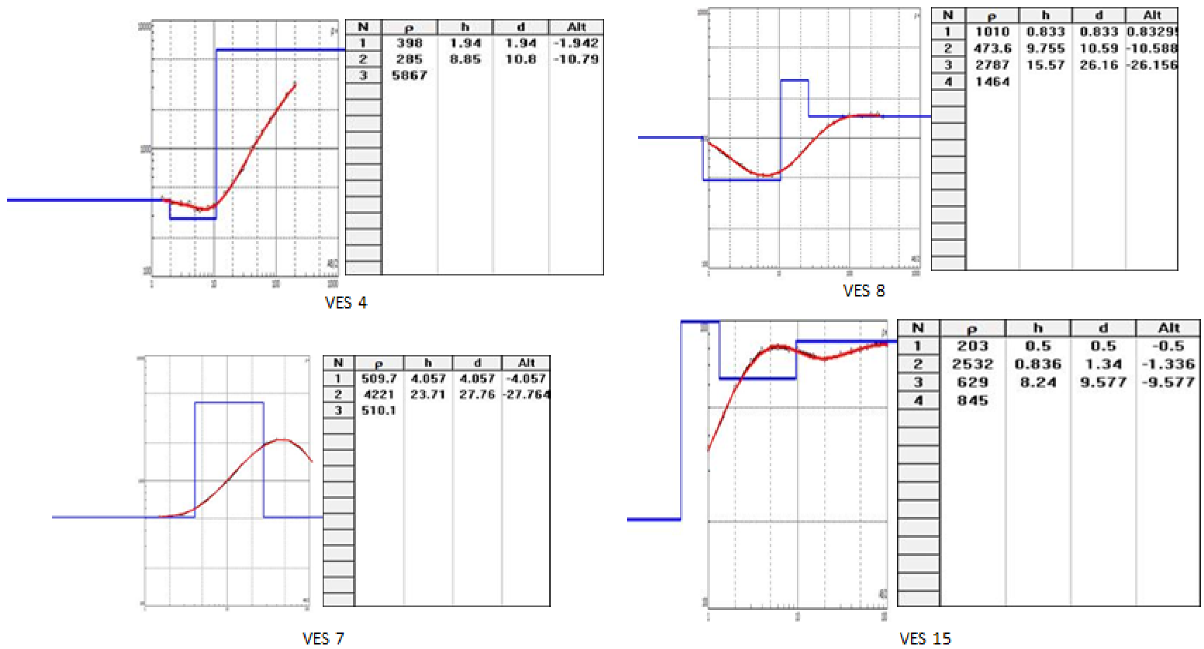

Figure 2: Typical electrical resistivity sounding data and best-fit layer model interpretations for the study area.

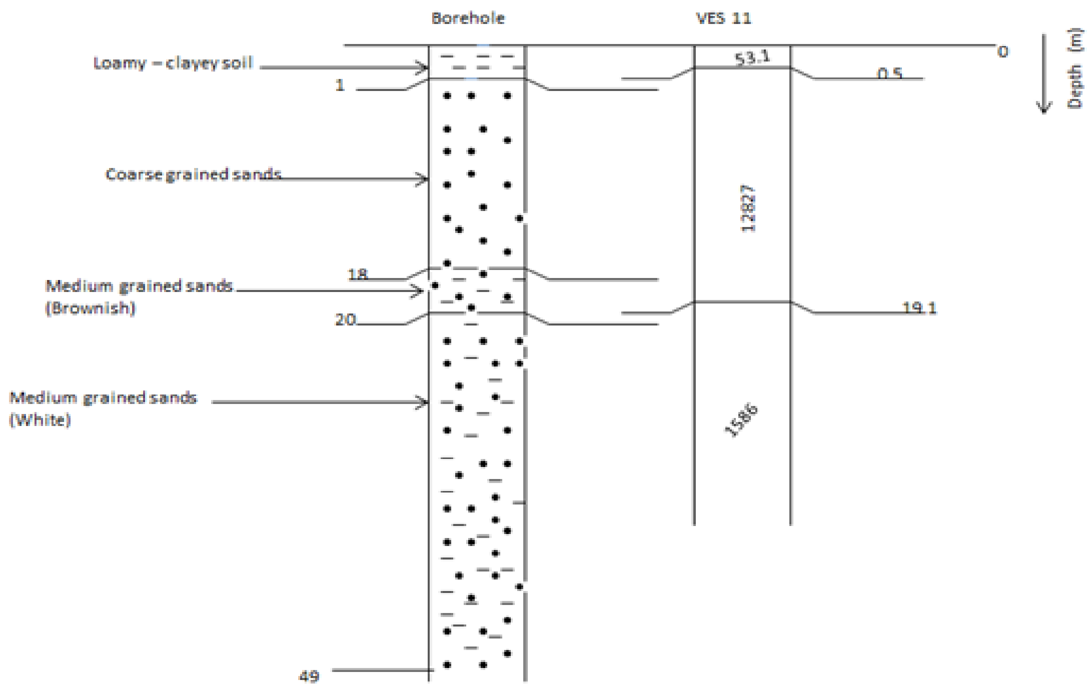

Figure 3: Ground truthing using the lithology log of a borehole drilled 20 m away from VES 11.

groundwater level variations should be mainly driven by weather and climate. Hence, the variation in groundwater level between the two sites should result from changes in recharge and/or discharge.

Generally, water infiltrates quickly (high infiltration rate) into granular soils but very slowly (low infiltration rate) into massive and compact soils. However, the lithology log and the wells dug at the mining and non-mining sites reveal that, the two sites had close similarities in subsurface structure. Therefore, in the absence of mining, the water levels in the wells should show good correlation. In addition, water infiltration should be faster (higher) in the mining

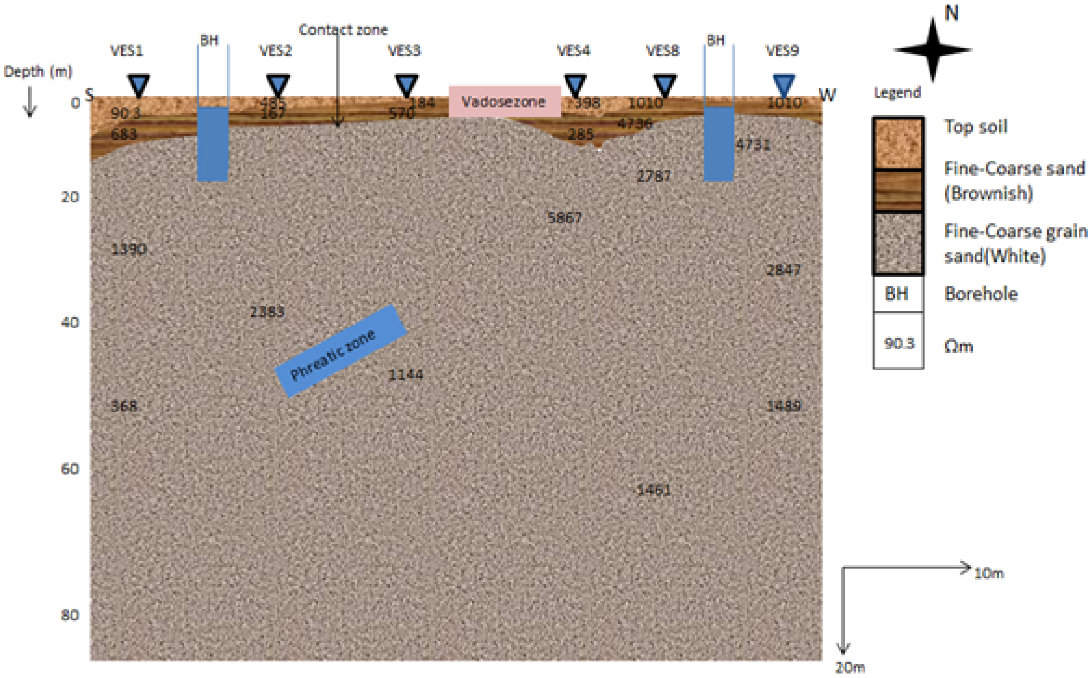

Figure 4: Geoelectrical section showing the subsurface unit for the non-mine sites studied.

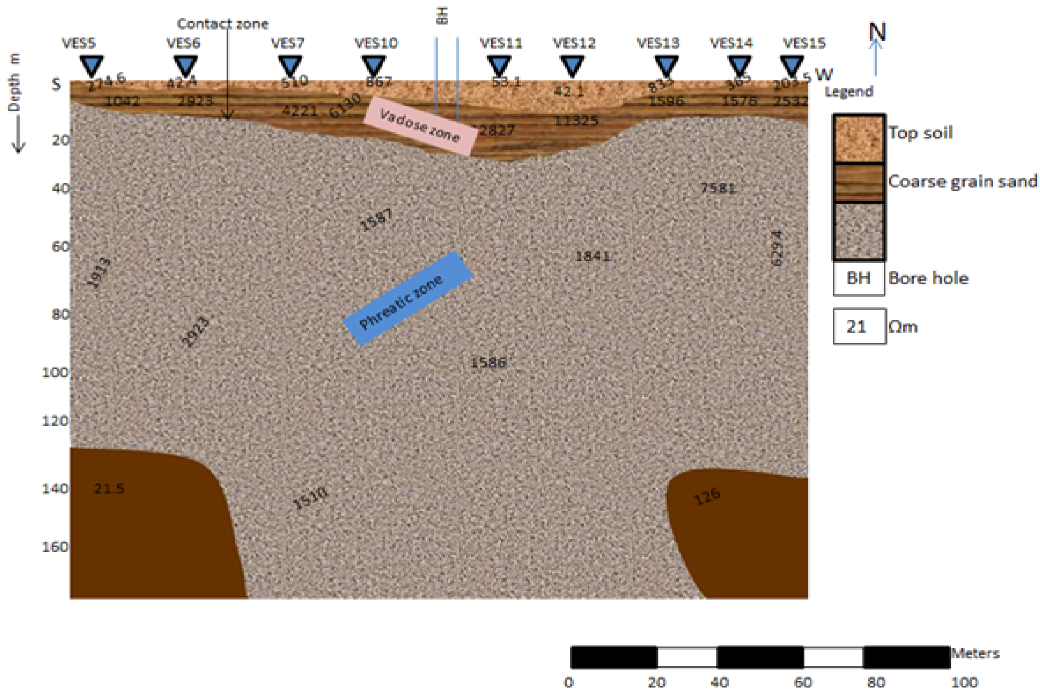

Figure 5: Geoelectrical section showing geolayers and their resistivity values for mining sites within the study area.

site because the soil is dry (evidence by high resistivity values), than the non-mining site, which is wet (evidence by low resistivity value without the presence of clay strata). This result is in support of Bashir et al. [43-45]. They posited that, stream mining has the capacity to transform riverbeds into large and deep pits with attendant effect of depleting groundwater table. This leaves drinking water wells on the embankments of the river dry, lowers stream flow elevation and floodplains water table as well as eliminates water table that depends on vegetation in the riparian area. Hence, it is only the tap rooted plants that can adapt to such environment, while the shallow-rooted plants may be extinct. The implication is that, shallow-rooted plants in the area may be deprived of the needed groundwater for their survival.

For cities such as Ibeno, Oron, Mbo, Eastern Obolo, and Ikot Abasi, groundwater table depletion could encourage saline water intrusion into fresh water. Mbipom et al. [46] noted that, the Southern Nigeria was prone to salt water ingress. This can result in serious groundwater pollution which is in line with the report by Sultana [19] that; continuous sand mining has the tendency of decreasing water volume thereby causing salt water ingress into rivers and groundwater. Besides, Lawal PO [7] and Aromolaran [8] noted that, sedimentation due to stockpiling and dumping of excess mining materials and organic particulate matter, oil spills from excavation machinery and transportation vehicles are very common sources of pollution in mining sites. This often informs short term turbidity, which impacts adversely on water users and aquatic ecosystems except where in-stream mining activities are well planned. Unfortunately, most sand mining (in-stream or land mining) in developing countries are unplanned, with poor stockpiling and uncontrolled dumping of overburden and chemical/fuel spill which reduce water quality for downstream users [7,15,35,47,48].

The contour plot categorizes the study area into active, passive, and non-mining sites. The active mining site shows high earth resistivity values, closely followed by the passive mining site, while the non-mining site showed low resistivity values is the spatial distribution of subsurface resistivity observed at various locations in the study

Table 1: Geoelectrical layer parameters for the study area.

VES	N	Location	ρ_2	ρ_2	ρ_3 (Ωm)	d_1	d_1	d_2	h_1 (m)	h_1	h_2	h_3	%Er	Curve	Mining	Lat	Long
1	4	Uya-Oro	90.3	683	1390	368	0.5	12.5	42.4	0.5	12	30.0	1.1	AK	No	4.653	8.314
2	3	Uya-Oro	485	167	2383	-	2.3	4.73	-	2.3	2.5	-	2.2	H	No	4.633	8.305
3	4	Utumong	1184	570	1144	1181	1.0	6.89	52.1	0.8	5.9	45.2	1.6	HA	No	4.645	8.302
4	3	Utumong	398	285	5867	-	1.9	10.8	-	1.9	8.9	-	2.2	H	No	4.638	8.286
5	4	Ube	279.2	1042	1913	21.49	0.3	7.0	138.9	0.3	6.7	131.8	2.3	AK	Yes	4.663	8.251
6	3	Ube	42.4	2923	5579	-	0.8	7.9	-	0.8	7.2	-	2.3	A	Yes	4.680	8.242
7	3	Uruting	510	4221	510	-	4.1	27.8	-	4.6	23.7	-	1.8	K	Yes	4.696	8.260
8	4	Uruting	1010	4736	2787	1464	0.8	10.6	26.7	0.8	9.8	15.6	1.4	HQ	No	4.703	8.245
9	4	Uruting	1010	473	2847	1489	0.8	10.1	24.6	0.8	9.7	14.0	1.5	HQ	No	4.684	8.263
10	3	Iquita	867	6130	1587	-	3.0	18.6	-	3.0	15.5	-	1.9	K	Yes	4.687	8.264
11	3	Iquita	53.1	12827	1586	-	0.5	19.1	-	0.5	18.6	-	2.0	K	Yes	4.711	8.260
12	3	Etim Inyang	42.4	11325	64.6	-	0.5	5.9	-	0.5	5.4	-	2.9	K	Yes	4.735	8.251
13	4	Etim Inyang	388	1596	8561	126	1.0	12.2	124.0	1.0	11.3	111.4	1.3	AK	Yes	4.804	8.219
14	4	Benson Beach	365	1576	7581	117	1.1	14.5	118.4	1.1	13.3	104	1.6	AK	Yes	4.803	8.256
15	4	Benson Beach	203.3	2532	629.4	845	0.5	1.34	9.58	0.5	0.8	8.2	1.0	AK	Yes	4.802	8.261

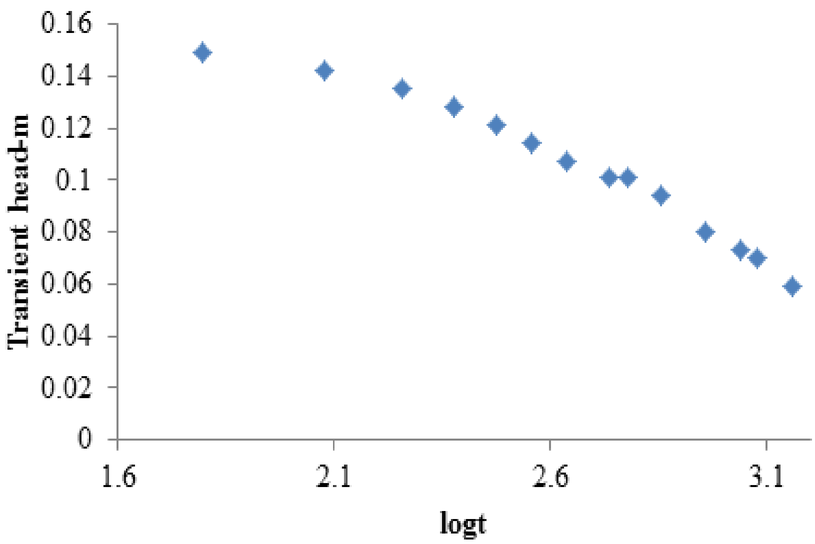

Figure 6: Interpretation of basic VES curve-types.

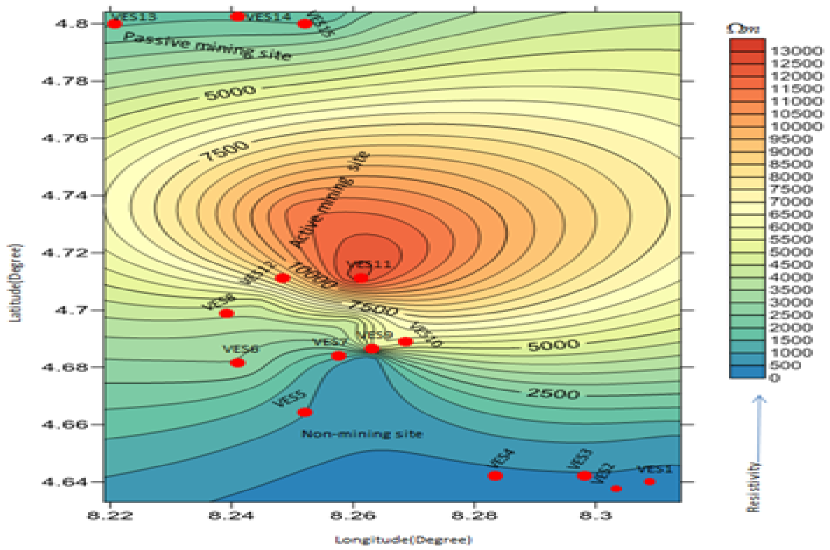

Figure 7: Geo-resistivity contour map showing spatial resistivity variation with survey stations.

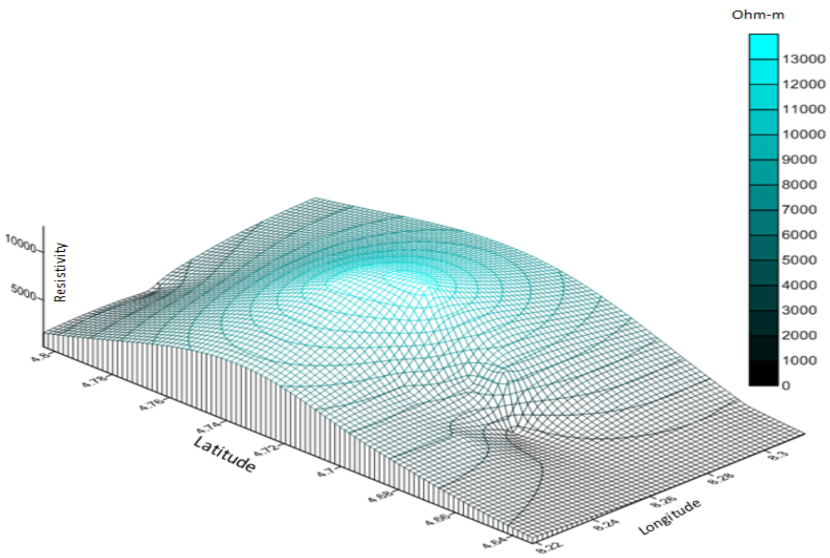

Figure 8: 3-D spatial distributions of geo-resistivity for the study area.

area. The region within the centre of the map shows high resistivity, with relatively thick unsaturated zone. This region is identified as groundwater table depletion zone, therefore should not be mined for sands. But should be given time for natural recovery (Figures 7 and 8).

In general, as water seeps into the ground, with gravity as the dominant driving force, it enters a zone which contains both water and air referred to as the vadose zone. The upper part of this zone (root zone or soil zone), supports plant growth and is crisscrossed by living roots, holes left by decayed roots, and animal and worm burrows may not have water at intense mining site especially during the dry season. Below the root zone lies a capillary fringe which results from the attraction between water molecules and rocks. As a result of this attraction, water clings as a film on the surface of rock particles. Water moves through the unsaturated zone into the saturated zone where all the interconnected openings between rock particles are filled with water. The groundwater is held within the interconnected openings of saturated rock. This zone is deeply buried at mining site, as opposed to non-mining site.

Conclusion

Geoelectrical measurement using Schlumberger electrodes array was conducted with the aim of assessing the impact of indiscriminate in-stream sand mining on hydrological system of coastal aquifers in Oron, Akwa Ibom State. 15 VES were conducted, and data obtained were interpreted quantitatively and qualitatively with the assistance of the lithology log from the study area. Results indicate that, high contact point between the phreatic zone and the overlying vadose zone achieved for and non-mining sites. While low contact point was achieved between the phreatic zone and the overlying vadose zone for mining sites. The results show that, the in-stream sand mining activities deplete groundwater level; thereby the groundwater location becomes lower than what was obtained at the non-mining site. The results specifically show that, sand mining had depleted the groundwater level, thus increased the thickness of the vadose zone in the study area. This may have attendant effects on drinking water wells and rivers embankment. It could lower stream flow elevation and floodplains water table, which may eliminate water table dependent vegetation in the riparian area.

Other impacts of indiscriminate in-stream sand mining include: increased short-term turbidity at the mining site due to re-suspension of sediment, sedimentation due to stockpiling and dumping of excess mining materials and organic particulate matter, and oil spills or leakage from excavation machinery and transportation vehicles. It could cause riverbed and bank erosion. It could also increase suspension of solids in the water at the excavation site and downstream (these solids suspended, could adversely affect water users and aquatic ecosystems). Indiscriminate in-stream sand mining is characterized by poorly planned stockpiling, uncontrolled dumping of overburden and chemical/fuel spills. This has not only the potential to reduce water quality for downstream users, but also increase the cost for downstream water treatment and poisoning of aquatic life.

To maintain a balance in hydrological system, this study encouraged mining for in-stream sand at estuaries located at the fringes of the map. Also, a well-planned sand mining programme should be adopted in the study area. These should include volume of materials to be removed at a given period of time and the sites to mining for sand.

Acknowledgement

Due acknowledgement is made to Maritime Academy of Nigeria, the local authorities of Oron community and all the field staff used during data collection.

References

1. George NJ, Akpan AE, Evans UF (2016) Prediction of geohydraulic pore pressure gradient differentials for hydrodynamic assessment of hydrogeological units using geophysical and laboratory techniques: a case study of the coastal sector of Akwa Ibom State, Southern Nigeria. Arabian J Geosciences 9: 305.
2. Evans UF, Abdulsalam NN, Mallam A (2017) Natural vulnerability estimate of groundwater resources in the Coastal Area of Ibaka Community, using Dar Zarrouk geoelectrical parameters. J Geology and Geophysics 6: 295-303.
3. Jarray H, Zammouri M, Ouessar M, Hamzaoui-Azaza F, Barbieri M et al. (2017) Groundwater vulnerability based on GIS approach: Case study of Zeuss-Koutine aquifer, South-Eastern Tunisia. Geofísica Internacional 56: 157-172.
4. Martin K (2015) How to estimate mean residence times of groundwater. Procedia Earth and Planetary Science 13: 301-306.
5. Koestel J, Moeys J, Jarvus NJ (2012) Meta-analysis of the effects of soil properties, site factors and experimental conditions on solute transport. Hydrol Earth Syst Sci 16: 1647-1665.
6. Groh J, Vanderborght J, Pütz T, Gerke HH, Wollschläger U, et al. (2015) Which Key Properties Control the Preferential Transport in the Vadose Zone Under Transient Hydrological Conditions?
7. Lawal PO (2011) Effects of sand/gravel mining in Minna, Emirate Area of Nigeria on stakeholders. J Sus Dev 4: 193-199.
8. Aromolaran AK (2012) Effects of sand mining activities on land in Agraian communities of Ogun state, Nigeria. Cont J Agri Sci 6: 41-49.
9. Ojos Negros Research Group (ONRG) (2016) Sustainable management of water in Ojos Negros valley, Baja, California.
10. Jacobson RB Watershed sustainability: Downstream effects of timber harvest in the Ozarks of Missouri. pp: 106-128.
11. Aigbedon IN, Iyayi SE (2007) Environmental effect of mineral exploration in Nigeria. Int J Physi Sci 2: 33-38.
12. Whitehead GJ Land and environment: sand mining. (2007)
13. Bruce PE (2009) In-stream gravel mining impacts and environmental degradation feedback associated with gravel mining on the Rio Tigre of the OSA Peninsula, Costa Rica, and the proposed ADI Jimenez Gravel Mining Concession.
14. Kondolf GM, Smeltzer M, Kimball L (2001) Freshwater Gravel Mining and Dredging Issues.
15. Stearns S (2009) Illegal mining threatens Liberian rainforest.
16. Alexander GR, Hansen EA (1983) Sand sediment in a Michigan trout stream. Part 2. Effects of reducing bedload on a trout population. North Ame J of Fisheries Manag 3: 365-372.
17. Aigbedon IN (2005) Environmental pollution in Niger Delta Nigeria. Int-Discip J 3: 205- 210.
18. Batayneh AT (2007) Mapping subsurface formations on the Eastern Red Sea coast in Jordan using geoelectrical and techniques: geological and hydrogeological implications. Earth Sci Res J 11(2): 97-107.
19. Pitchaiah S, Sultana N (2016) Impact of sand mining on Asian countries-A review. Int J Geo inform Geolo Sci 3: 1-5.
20. Abam TKS (1999) Dynamics and quality of water resources in the Niger Delta. Proceedings of the symposium of the International Union of Geodesy and Geophysics held at Birmingham 259: 429-437.
21. Osakuni MU, Abam TK (2004) Shallow resistivity measurement for cathodic protection of pipelines in the Niger Delta. J Env Geol 45: 747-752.
22. Evans UF, Asamudo NU, Wanasah J (2012) A study of corrosion potential of the Nigerian Coastal Plain Sands using numerical corrosivity scale. International Review of Physics 6: 417-423.
23. Evans UF (2011) Geoelectrical resistivity and pipe-to-soil potential surveys: implications for mitigating external pipeline corrosion in the Niger Delta, Nigeria.
24. Hosper J (1971) Gravity field and the structure of the Niger Delta, Nigeria. Geol Soc Ame Bull 76: 407-422.
25. Onyeagocha AC (1980) Petrography and depositional environment of the Benin Formation. J Min and Geol 17: 147-151.
26. Kogbe CA, Buriollet PF (1990) A review of continental sediments in Africa. J Afri Earth Sci 10: 1-25.
27. Reyment RA (1965) Aspects of the Geology of Nigeria.
28. Fetters CW (1980) Applied Hydrology.
29. Parkinson J (1997) The post-Cretaceous stratigraphy of Southern Nigeria. J Geol Soc 63: 311-320.
30. Petters SW (1991) Regional Geology of Africa.
31. Ekine AS, Osobenye GT (1996) Surface geoelectric sounding for the determination of aquifer characteristics in parts of Bonny Local Government Area, River State, Nigeria. Nig J Phy 85: 93-99.
32. Reyment RA (1964) Review of Nigerian Cretaceous-Cenezoic stratigraphy. J Nig MinGeol and Met Soc 1: 61-80.
33. Mbonu PD, Ebeniro JO, Ofoegbu CO (1991) Geoelectric soundings for the determination of aquifer characteristics in parts of the Umuahia Area of Nigeria. J Geophy 6: 284-291.
34. Okwueze EE, Selemo A, Ezeanyim VI (1995) Preliminary lithologic deductions from a regional electrical resistivity survey of Ogoja, Nigeria. Nig J Phys 7: 15-17.
35. Adekoya JA (1995) Negative environmental impact of mineral exploration in Nigeria. Int J of Physi Sci: 613–619.
36. Nabegu AB (2013) Effect of sand mining on groundwater in Kano River Catchment. J Envi & Earth Sci 3: 81-87.
37. Bayley PB, Baker CF (2000) Floodplain restoration in off-channel habitats used for gravel mining in the Williamette River basin.

38. Martin Y (2001) Evaluation of bed load transport formula using field evidence from the Vedder River, British, Columbia. Geomorphology 53; 75-95.
39. Adepelumi AA, Solanke AA, Sanusi OB (2006) Model tank electrical resistivity characterization of LNAPL migration in a clayey-sand formation. Env Geology 50: 1221-1233.
40. Orellana E, Mooney H (1966) Master Tables and Curves for Vertical Electrical Soundings (VES) over Layered Structures. Interciencia Madrid. pp: 34
41. Edet AE, Okereke CS (2002) Delineation of shallow groundwater aquifers in the coastal plain sands of Calabar area (southern Nigeria) using surface resistivity and hydrogeological data. J Afri Earth Sci 35: 433-443.
42. George NJ, Akpabio GT, Evans UF (2008) Study of failed tarred roads using earth's resistivity values of local communities in Ukanafun Local Government Area, Akwa Ibom State, Southern Nigeria, Nigeria. Int J Phy Sci 3: 1-6.
43. Bashir BA, Adebayo AA (2002) Seasonal variations in water quality and occurrence of water borne diseases in Yola Area. Nig J Env Sci 6: 26- 32.
44. Adekoya JA (2003) Environmental effects of solid minerals mining. J Physi Sci Kenya. pp: 625-640.
45. Koestel J, Moeys J, Jarvis J (2011) Evaluation of nonparametric shape measures for solute breakthrough curves. Vadose Zone J 10: 1261-1275.
46. Mbipom EW, Archibong JE (1989) Vertical electrical sounding of coastal aquifers near Qua Iboe estuary, Nigeria. J Min and Geol 25: 151-154.
47. Amadi UM, Amadi PA (1990) Salt water migration in coastal aquifers of Southern Nigeria, Nigeria. J Min and Geol 26: 35-44.
48. Mbamali I (2007) Stone quarrying in Nigeria: an overview of necessary initiations towards a sustainable built environment. Constant Focus 1: 29-35.

Author Affiliations

Top

[1]*Department of Research & Statistics, Maritime Academy of Nigeria, Oron, Nigeria*

[2]*Geophysics Unit, Department of Physics, University of Calabar, Calabar, Nigeria*

[3]*Department of Zoology, University of Uyo, Uyo, Nigeria*