**Geoelectrical assessment of the impact of indiscriminate in-stream sand/gravel mining on hydrogeological system of selected river mining sites in Akwa Ibom State, Nigeria**

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**Abstract**

The geoelectrical measurement using Schlumberger electrode array was conducted with the aim of assessing the impact of indiscriminate in-stream sand/gravels mining on hydrogeological system of selected mining sites in Akwa Ibom State. A total of 15 VES was carried out and results were interpreted using manual curve plotting and computer software. A comparative analysis between the VES for mining and non-mining sites was conducted. The variation of in situ resistivity of geounit shows that mining sites produced mostly AK and K curve types with comparatively higher values (1042-12827Ωm). This was contrary to the HQ and H curves with relatively lower resistivity values (162-4736Ωm) obtained for geolayer of non-mining sites. The HQ and the H curve types with the associated low resistivity values, complemented with productive wells at 5m depth indicated superficial location of the groundwater table. The AK and K curves as well as the associated high resistivity values of earth layer pointed to unsaturated geolayer, and suggested deeply buried groundwater table (contact point between the phreatic zone and the vadose zone). This was supported by non-productive 10m deep hand dug well at the mining site. It means that groundwater could only be abstracted from deeper aquifers in locations with intensive sand/gravels mining. To maintain a balance in hydrogeological system of mining sites, a well-planned sand/gravels mining programme should be employed. These include volume of materials to be removed at a given period of time and where to dump the mine materials.

**Keywords:** Geoelectrical, In-stream, Sands, Gravel, Mining, Hydrogeology.

**1.0 Introduction**

Sand and gravel are naturally endowed unconsolidated rock fragments with a general particulate size. For granular gravel, the size ranges from 2-4mm; for pebble gravel, the size ranged between 4 and 64mm; while particulate size for sand ranges from 0.0520 – 0.0002005 mm. These rock fragments are useful in the construction of roads, dams, buildings and bridges, as well as in the manufacturing of glass wares. Today, the demand for sand and gravel has continued to be on the increase nationwide (Lawal 2011). Sands and gravel mine in the Niger Delta is seen as lucrative business by the populace and major source of employment for local dwellers. Mining operation can be done either mechanically using dredgers or manually using steel pails. Besides in-stream mining, red earth mining is also going on ashore (Aromolaran 2012).

In-channel or near-channel sand/gravel mining can change the sediment budget of a site, and may result in substantial modifications of the channel hydraulics. These may have variable effects on aquatic habitat, depending on the magnitude and frequency of the modification, mining methods, particle-size characteristics of the sediment, the characteristics of riparian vegetation, and the magnitude and frequency of hydrologic events following the modification. The effect of in-stream mining is further compounded by the effect of sea level rise (Kondolf et al. 2001; Stearns 2009). Any volume of sand exported from streambeds and 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 uses that local people make of them. Alexander and Hansen (1983); Aigbedon (2005) noted that, sand/gravel mining has the tendency of causing undercutting and collapse of river banks, loss of adjacent land and/or structures, upstream erosion as a result of increase in channel slope/changes in flow velocity and downstream erosion due to increased carrying capacity of the stream, downstream changes in patterns of deposition, and changes in channel bed and habitat type.

The temporal and spatial responses of alluvial river systems are functions of geomorphic thresholds, feedbacks, lags, upstream or downstream transmission of disturbances, and geologic/physiographic controls as well as alluvial system of an area. These can be determined by the site-specific topographic, hydrologic, hydraulic and geologic information. From the above, the amount of sand that can be removed from the area without causing undue erosion or degradation, either at the site or at adjoining location, upstream or downstream can be determined. Geoelectrical studies employing vertical electrical soundings have proved to be very successful in subsurface mapping to delineate lithology and hydrogeologic conditions of various sites (Batayneh 2007; Evans et al. 2010).

At present, the level of understanding of alluvial systems in the study area is generally not sufficient to enable the prediction of channel responses quantitatively and with confidence; therefore, reference states are difficult to determine. Thus, it becomes difficult to make decisions on where to mine, how much and how often a particular stream should be mined. This paper therefore, examined the impact of sand/gravel mine from streams on the hydrogeological systems of some communities in Akwa Ibom State Nigeria in order to infer possible measures to safeguard the ecosystem.

**2.0 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 (Evans et al. 2012; Evans et al. 2014; Evans et al. 2015). 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 (Evans et al. 2015). 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 (Evans et al. 2015). 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 (Osakuni and Abam, 2004). The flood plains adjoins 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 1.5m to 1.8m 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 (Abam 1999). The undulating lowland is characterized by extensive, irregular distribution of near shore coarse – fine grains permeable sands, which are subject to enormous seepage pressures, and are mined for construction work (Evans et al. 2014).

**3.0 Geology of the study area**

The study area falls within the coastal plain sands (otherwise called Benin Formation) of the deltaic depositional environment of the Nigerian Niger Delta. 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 (Hosper 1971; Onyeagocha 1980; Kogbe and Buriollet 1990). The Benin Formation is the uppermost unit of the Niger Deltaic lithofacies and has clastic sedimentary rocks formed either as terrestrial or marine deposits (Reyment 1965; Fetters 1980). The sediments are predominantly sandy with minor shale intercalations. Onyeagocha (1980) 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 (Short and Stauble 1967; Parkinson 1997; Petters 1991).

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 and underlain by impervious shale layer, which is also characterized by lateral and vertical variations in lithology (Ekine and Osobenye 1996). This composition provides favorable condition for fresh-water bearing. The thickness of the Benin Formation is variable and may be more than 6,000ft in some locations (Kogbe and Buriollet 1990). The coastal sediments of the Benin Formation develop frequent anticlinoid fault structure at depth of importance in the search for oil traps (Reyment 1964; Mbonu et al. 1991; Okwueze et al. 1995).

The geologic map of the study area shows that the area is of intense coastal sands/gravels and alluvial deposits (Fig. 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 (Evans et al. 2012).

**4.0 Impact of in-stream mining on riparian habitat, flora and fauna**

In the Niger Delta environment, petroleum exploration has been identified as having the greatest pollutant effect. However, most hazards on the environment brought about by sand and gravel mining activities are also of severe consequences (Adekoya 1995; UNESCO 1995; Aigbedon 2005). Abam (1999) and Whitehead (2007) reported that the possible ecological impact of the indiscriminate sand mining and threats to the livelihoods of local communities include the pollution of surface water; lesser availability of water for industrial, agricultural and drinking purposes; destruction of agricultural land; loss of employment to farm workers, and damage to farm roads and bridges. Many hectares of fertile streamside land are lost annually, as well as valuable timber resources and wildlife habitats in the riparian areas. It has been observed that degraded stream results in loss of fisheries productivity, biodiversity, recreational potential and aesthetic values (Adepelumi et al. 2006).

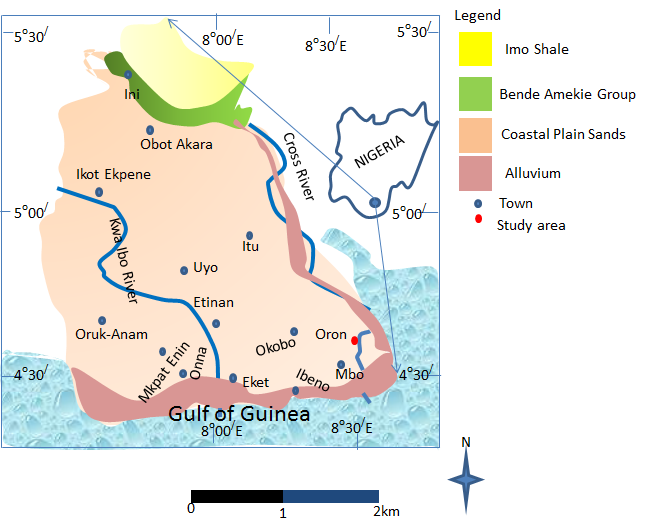


Fig. 1: Map of Akwa Ibom State showing the study area, geology, towns and rivers

All species require specific habitat conditions to ensure long-term survival. Native species in streams are uniquely adapted to the habitat conditions that existed before humans began large-scale alterations. Kondolf (2001) and Jacobson (2004) asserted that the major habitat disruptions that favoured some species over others and caused overall declines in biological diversity and productivity are caused by in-stream sand mining. In most streams and rivers, habitat quality is strongly linked to the stability of channel bed and banks. Bayley et al. (2000) and Martin (2001) noted that unstable stream channels are inhospitable to most aquatic species. The stability of sand-bed and gravel-bed streams depends on a delicate balance between stream flow, sediment supplied from the watershed, and channel form. In addition, channel widening causes swallowing of the streambed, producing braided flow or subsurface intergravel flow in riffle areas, hindering movement of fishes between pools as well as the movement of unstable substrates downstream, which may lead to sedimentation of habitats. Channel reaches become more uniformly shallow as deep pools filled with gravel and other sediments, this may reduce habitat complexity, riffle-pool structure, and numbers of large predatory fishes (Martin 2001; UNESCO 1995).

Adekoya (1995); Aigbedon and Iyayi (2007); Whitehead (2007); Aromolaran (2012) reported that, the complete removal of vegetation and destruction of the soil profile destroys habitat above and below the ground as well as within the aquatic ecosystem, resulting in the reduction in faunal populations. Jacobson (2004); Mbamali (2007) observed excessive in-stream sand/gravel mining the causes the degradation of rivers. In-stream mining lowers the stream bottom, which may lead to bank erosion (Kondolf 2001; Edet and Okereke 2002). 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.

**5.0 Methodology**

The vertical electrical sounding (VES) using the Schlumberger array was employed to probe the subsurface adjacent to selected sites (rivers) in Oron Local Government Area of Akwa Ibom State where in-stream sand/gravels mining activities are practiced. These sites include: Etim Inyang beach, Benson beach and Uya-Oron creek. Three VESs were carried out in each mining site along traverse close and parallel to the river channels using ABEM Terrameter (SAS 4000) and its accessories. In addition, two VESs were conducted at non-mining sites. These were necessary to have a control and complementary data. In all, a total of 15 VESs were taken to generate data for the study. Also, three hand-dug wells and the lithology log of a motorized borehole were used for purpose of ground truthing.

At every sounding point, current was injected into the subsurface by means of two current electrodes, while 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 were situated near the centre of the array. The current electrodes separation was step-wise increased to a maximum of 600m to allow injected current probe deep into the subsurface. The measured earth resistance was combined with the geometrical factor for Schlumberger electrode array to compute the subsurface electrical apparent resistivity used for the study.

The plots of earth apparent resistivity values against half current electrodes spacing on double logarithmic paper yielded geo-resistivity graph for the area. The achieved field curves were manually smoothened to remove extraneous signatures from the field data. 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 (Fig. 2). The combination of data interpreted from VES and hydrogeologic information from ground truthing, aided geo-interpretation of the hydrogeological system of the subsurface area studied.

**6.0 Results and Discussion**

The results of interpreted data for the study area are contained in table 1. A maximum of 4 geounits have been delineated with 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 (1042-12827Ωm). This was contrary to the

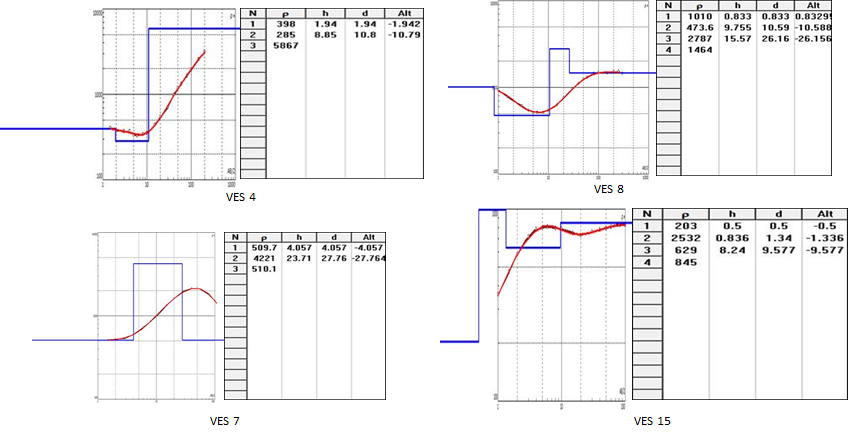


Fig. 2: Typical electrical resistivity sounding data and best-fit layer model interpretations for the study area

Table 1: Geoelectrical layer parameters for the studied area

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| VES | N | Location |  |  |  |  |  |  |  |  |  |  | %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 | 10 | AK | Yes | 4.802 | 8.261 |

Mining: “Yes” for site where sand/gravel is being mined; “No” indicates site where on mining activity is going on.

relatively lower resistivity values (162-4736Ωm) which generates HQ and H curve types for geolayer at non-mining sites. These resistivity values determine the curve types which define the shapes, forms and patterns of vertical variation of resistivity in the study area. Geoelectrical curve types are characteristic curves used to examine and identify the shapes, forms and pattern of resistivity variation with depth in an area (Orellana and Mooney 1966; Edet and Okereke 2002; Batayneh 2007; George et al. 2008; Evans et al. 2012). The resistivity values obtained, complemented with borehole lithology log (Fig. 3) near VES 11 was used to construct the geoelectrical sections (Fig. 4 and 5) for non-mining and mining sites of the study area respectively.

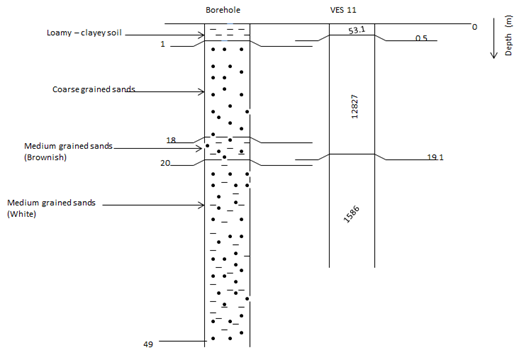


Fig 3. Ground truthing using the lithology log of a borehole drilled 20m away from VES 11

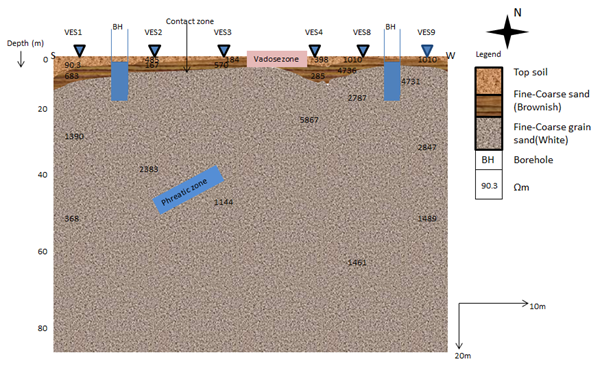


Fig. 4: Geoelectrical section showing the subsurface unit for the non-mine sites studied

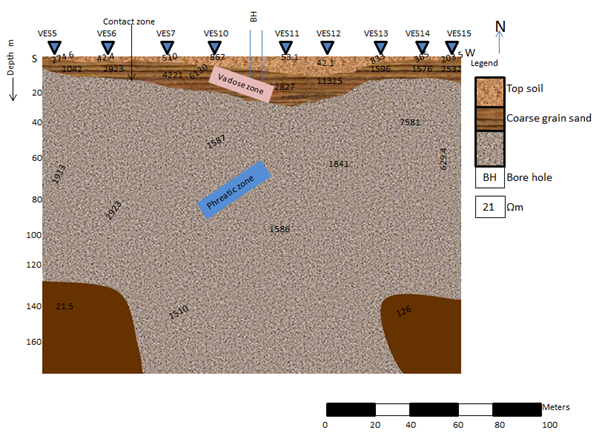


Fig. 5: Geoelectrical section showing geolayers and their resistivity values for mining sites within the study area

The AK and K curves as well as the associated high resistivity values of earth layer pointed to unsaturated geolayer, and further suggest the absence of phreatic zone. While The HQ and the H curve types with the associated low resistivity values at shallow depth, suggest that the contact point between the phreatic zone and the vadose zone was close to the surface. Wells drilled at the mining and non-mining sites of the study area show that at 5m depth, the wells at non-mining sites were productive. While at 10m depth the bore hole at mining sites was not producing. The borehole lithology log (Fig.3) and physical inspections of hand dug wells in the study area reveal that, the near surface geology comprises sand of different grains with little or no clay intercalation. This implies that, the relatively low resistivity values of the middle layer in Fig. 4 (non-mining site), indicates the contact zone between the phreatic zone and the overlying vadose zone. It was interpreted to mean, shallow buried aquifer. Fig 5 (mining site) shows that the contact zone between the phreatic zone and the overlying vadose zone is deeply situated. Therefore, wells shallower than 10m depth will not be productive. The results show that sand/gravel mining activities had depleted the groundwater level and increase the thickness of the vadose zone. This result is in support of (Bayley and Baker 2000; Kondolf et al. 2001; Bashir and Adebayo 2002; Adekoya 2003). They posited that stream mining has the capacity to transform riverbeds into large and deep pits with attendant effect of depleting groundwater table. This can leave drinking water wells on the embankments of the river dry, lowers stream flow elevation and floodplains water table as well as elimination of water table dependents 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 extinct.

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. 1989 and Amadi and Amadi (1990) noted that, the Southern Nigeria was prone to salt water ingress. This can result to serious groundwater pollution. Besides, Aigbedon (2005) and Aromolaran (2012) 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 at mining sites. This often informs short term turbidity, which impact 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 (Adekoya 1995; Mbamali 2007; Stearns 2009; Lawal 2011).

The contour plot (Fig. 6) has been used to differentiate the study area into active mining, passive mining and non-sand/gravel 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. Fig. 7 is the spatial distributions of subsurface resistivity observed at various locations in the study 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/gravels. But should be given time for natural recovery. The study encouraged mining for in-steam sands and gravels at estuarine located at the fringes of the map.

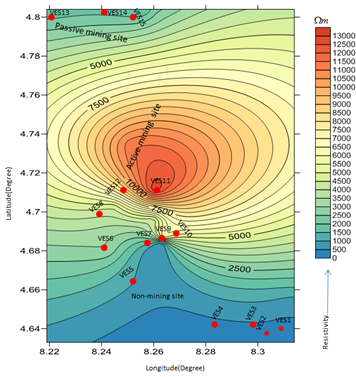


Fig.6: Geo-resistivity contour map showing spatial resistivity variation with survey stations.

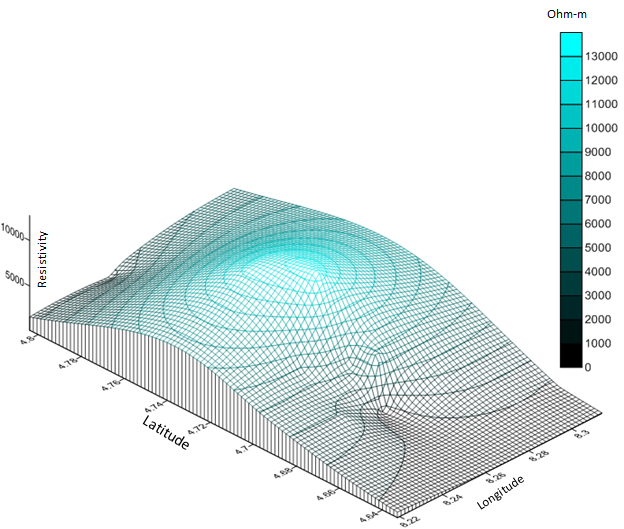


Fig. 7: 3-D spatial distributions of geo-resistivity for the study area

**7.0 Conclusion**

The quantification and interpretation of spatial variability of the contact zone between the phreatic zone and the overlying vadose zone have been used to assess the impact of wild-cat in-stream sands/gravel mining on hydrogeological system of Akwa Ibom State employing VES. Results indicate that, in-stream sand mining activities had impacted negatively on the hydrogeological system of the study area. The results specifically show that, sand/gravel mining activities had depleted the groundwater level and increase the thickness of the vadose zone in the study area. This has attendant effects on drinking water wells and rivers embankment. It could lower stream flow elevation and floodplains water table as well as elimination of water table dependents vegetation in the riparian area.

Other impacts of wild-cat in-stream sands/gravel 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, increases suspension of solids in the water at the excavation site and downstream (these suspended solids could adversely affect water users and aquatic ecosystems). Indiscriminate in-stream sands/gravel mining is characterized by poorly planned stockpiling and uncontrolled dumping of overburden and chemical/fuel spills which has the potential to reduce water quality for downstream users, increased cost for downstream water treatment and poisoning of aquatic life. The impact could be particularly devastating if water users downstream of the site are abstracting water for drinking and other domestic uses. The work hereby recommends that Government should plan sand/gravel mining activities to include where to mine, volume of materials to be removed at a given period of time as well as where to dumping the mine materials. With this, a balance in hydrogeological system of mining sites as well as a sustainable ecosystem can be achieved.

To maintain a balance in hydrogeological system of mining sites, a well-planned sand/gravels mining programme should be employed. These should include volume of materials to be removed at a given period of time as well as where to dump the mine materials should be put in place.

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