

Coastal land subsidence and Morphological changes within Nigerian coastal areas

Oluseyi O. Fabiyi & Glory O. Enaruvbe
*Department of Geographic Information Science,
Regional Centre for Training in Aerospace Surveys (RECTAS), Obafemi
Awolowo University Campus, Ile-Ife Nigeria.*

Abstract

Nigerian coastline is increasingly subjected to a number of geomorphic, structural and morphological changes due to a combination of several processes and change factors. Land subsidence is one of the major event causing geomorphic and morphological changes in the coastal areas. This study utilized GIS techniques, multi-date remote sensing data, auxiliary data and field work to examine, identify and estimate varying degrees of subsidence in Nigerian coastal region. A total of 503 study stations were randomly generated along 853 kilometres stretch and 15 kilometres inland trajectory. The subsidence or elevation differentials at each station was computed as arithmetic difference of the two digital terrain data sets (Aster 2001 and SRTM 2008). Correlation analyses were performed on the subsidence and distance of study stations to oil wells and corresponding land use types around the study stations. Subsidence was found to be positively correlated with distance to oil wells (0.557) while it has weak negative correlation with land use types(-0.0610). The study concluded that subsidence taking place in Nigerian coastal area is compensated by river discharge in the delta region, sand filling in the Lagos end and construction of shoreline protection, jetty and sand filling in the eastern end.

Keywords: Coastal subsidence, sea level rise, river recharge, landuse

Résumé

Littoral nigérian est de plus en plus soumis à un certain nombre de changements géomorphologiques, structurales et morphologiques en

raison d'une combinaison de plusieurs processus et facteurs de changement tels que l'élévation du niveau de la mer, l'affaissement du sol, de l'huile, le gaz et l'exploration de l'eau et d'autres activités anthropiques. Sur l'ensemble de ces changements qui se produisent dans la région côtière, l'affaissement de terrain est l'un des événement majeur entraînant des changements géomorphologiques et morphologiques dans les zones côtières. Cette étude utilisé SIG, multi-date de données de télédétection, des données auxiliaires et travail sur le terrain pour examiner, identifier et évaluer des degrés divers de la subsidence dans la région côtière du Nigeria. Un total de 503 stations d'étude ont été générés de façon aléatoire le long de 853 km extensibles et 15 kilomètres à l'intérieur trajectoire. L'affaissement ou l'élévation des écarts à chaque station a été calculé comme la différence arithmétique des deux ensembles de données numérique de terrain (Aster 2001 et SRTM, 2008). Les analyses de corrélation ont été effectués sur la subsidence et de la distance des stations d'étude de puits de pétrole et les types d'utilisation des terres correspondantes autour des stations d'étude. L'affaissement a été constaté une corrélation positive avec la distance aux puits de pétrole (0,557) alors qu'il a une faible corrélation négative avec les types d'utilisation des terres (-0,0610). L'étude a conclu que la subsidence qui a lieu dans la zone côtière du Nigeria est compensé par le débit des rivières dans la région du delta, le remplissage de sable en fin de Lagos et de la construction de la protection du littoral, jetée et le remplissage de sable dans l'extrémité orientale.

Mots clés : Subsidence côtière, l'élévation du niveau de la mer, la recharge de la rivière, l'utilisation des terres

Introduction

Nigerian coastal terrain is constantly modified and realigned by a number of geomorphic, structural and morphological changes occurring in long and medium term intervals. A combination of several processes and change actors such as sea level rise, land subsidence, oil, gas and water exploration, erosion, coastal flooding and other anthropogenic activities are causing changes to the terrain and coastal ecosystem. A graphic understanding of these changes is imperative for the survival of the Nigerian coastal population and the fragile ecosystems. Nigerian coastline of about 853 kilo metres together with the inland trajectory of about 15 kilometre inhabit up to 25 % of Nigerian teaming population of over 160 million. Notable changes in the morphological and geomorphological landscape of the coastal regions include sea level rise and subsidence. Coastal land subsidence has particularly attracted

research interests especially due to the linkages with climatic change and the survival of the coastal inhabitants. (Xue et al 2005; Larson et al 2001, Liu et al 2004, Holzer and Johnson 1985)

Land subsidence is the sinking or settling of the land. The major cause of land subsidence is the depletion of ground water level especially in unstable and clay substructure layer. When underground water is pumped to the surface for provision of domestic water or as associated process of oil exploration, the piezometric head layer drops and the effective stress on the aquifer increases and thus causing the compression of the soil and land subsidence. (Larson *et al* 2001).

Land subsidence is caused by the lowering of the land-surface elevation through changes taking place underground. The major cause of land subsidence is coastal marine processes through attrition and erosion; however a number of anthropogenic activities can also result in coastal land subsidence. Such activities include pumping water, oil, and gas exploration from underground reservoirs; dissolution of limestone aquifers (sinkholes); collapse of underground mines; drainage of organic soils; and initial wetting of dry soils (hydrocompaction).

In Nigeria there are evidences of coastal subsidence which manifested in many reported building collapses in Lagos, Port Harcourt and other coastal settlements (Ibe 1996). Unequal settlement of buildings (see fig 1) and large cracks on buildings which are common in many coastal cities in Nigeria are also signs of land subsidence and substructure deformation. Some of these evidences have been documented in anecdotal reports and scanty academic publications. For instance Udoh and Udofia (2014) estimated the potential subsidence in Akwa Ibom through the ground water levels indexing using GIS techniques. A number of committee report on inquiry into building collapse have fingered land subsidence as major cause of building failure coupled with the use of substandard materials not commensurate with the bearing capacity of the soil. (Environmental Statistics: Situation Report of Federal Republic of Nigeria)

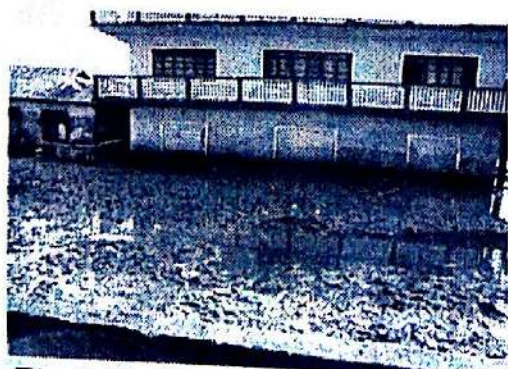


Fig.1 Evidences of Subsidence in Ayetoro Ondo State and Ogulaha in Delta state Nigeria

The monitoring of subsidence requires detecting changes in the earth's surface across a region over a period of time (Koulali et al., 2013). Several methods have been adopted by researchers especially to measure and monitor subsidence at small and large scales. These approaches could be broadly classified into three; which are ground based observation and measurement, Airborne observation and measurements and space based observation and measurement.

Ground based observation and measurements method has been widely used for experimental research over a limited land area and specific period. The approaches used by researchers under the ground based observation and measurements are many but the popular one is the (RGS) Repeated Ground Surveys. The method, though has been widely used in the past, is prone to gross error of estimation. Permanent compaction recorders and vertical extensometers were developed as improvements over the use of GPS but were also fraught with limitation of accuracy. Tilt meters technique was also developed to improve on accuracy of ground based measurement. Tilt meter has improved accuracy over extensometers but it is rather expensive and has only been limited to experimental use over small area (Holzer and Johnson, 1985).

The ground based observation and measurement method has limited application and can only be used for experimental purposes in area around 20 kilo metre. It is also difficult to set up in rural areas where protection of equipment cannot be guaranteed aside from the high cost of setting up and maintaining experimental stations.

Airborne Observation and Measurement method; the method requires scheduled repeated aerial surveys of Interferometry Synthetic Aperture radar (InSAR) over the study area to measure and monitor land subsidence (Galloway et al 1998). The method has theoretical high accuracy in the order of 0.1mm but the accuracy is limited by atmospheric disturbances (Cigna et al 2013). The approach also has application potential over large area up to 100 kilometres. The airborne method also require the installation on the ground targets, sensor or reflector which can also be dislodged or removed by human interference especially if they are installed in farmlands or other active areas.

Space Based Observation and Measurement method; the space based method is the most cost effective approach over large area with uniform accuracy of estimation. Space based radar data have been used to measure and monitor subsidence over large area with minimum cost per

unit area and with satisfactory accuracy level (5- 100mm). The Space based method is often preferred in the developing countries where resources to setup ground based experimental stations is fraught with a number of challenges ranging from prohibitive cost and insecurity of equipment's and field staff.

The aim of the study is to evaluate differential subsidence along the Nigerian coastal area and examine the possible causes. The specific objectives include the extraction of elevation values from sampled stations from to date data and identifying the elevation differentials over the period. The causes of the elevation difference were also explored. The next section of the paper described the study area while section three presented the methodology, section four presented the results while section five showed the policy implication and conclusion.

Study Area

The study area is the entire stretch of Nigeria coastline which is a total of 853 kilometre stretch and include a trajectory of 15 kilometre inland (Figure 2).

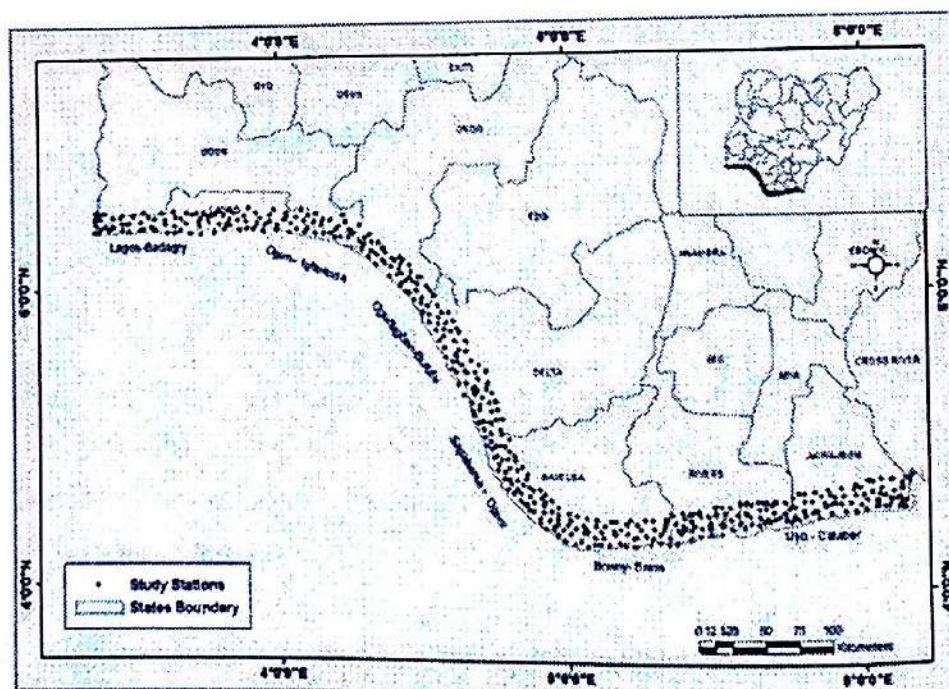


Fig.2: The study area

The study area shows the prevalence of onshore south western winds which is even very strong during the dry season (November – March). When the north east wind reaches the coastal areas as a consequence of the downward migration of the inter-tropical convergence zone (ITCZ) the wind velocities are usually between 2.5 and 5m/sec (French et al., 1995). The waves in the coastal area include regular wind waves and sea waves around (pariv 3-8 sec). The intense wave in the coastline with

great physical energy on the beaches generates destructive littoral currents which result in coastal flooding, uprooting of settlements, destroying of agricultural and recreational groups.

Nigerian coastline subsidence has been evaluated by researchers and authors specially Ajakaiye and Burke (1973) estimated coastal subsidence of 80m in about 15,000 years and was due to the eustatic sea level rise and the isostatic adjustment to water load. Allen and Wells, (1962) also noted sequential subsidence and attributed the sinking to dewatering and compaction of rapidly deposited sediments.

The rate of subsidence in the Nigerian coastline is still inconclusive. It has been estimated that Nigerian coastal land around Akwalbom is sinking at an average rate of 2.5 cm/year (Udoh and Udofia, 2014). An accurate and uniform measurement of Nigerian coastal subsidence is necessary for effective sustainable development of coastal resources.

Methodology

Data sourcing: The study utilized three types of data sets which include Advanced Space borne Thermal Emission and Reflection (ASTER) captured in 2001 and obtained from NASA website <http://asterweb.jpl.nasa.gov/>. The Shuttle Radar Topography Mission (SRTM) data captured in 2008 and accessed through USGS website at <http://srtm.usgs.gov>. The study also utilized Landsat ETM data obtained in 2005 and accessed from GLCF website glcf.umd.edu/data/landsat/. Other data used include location of oil wells obtained from Department of petroleum Resources (DPR) Nigeria and other anecdotal data obtained from reports of environmental studies.

Data Processing and Analyses: The land surface elevation values were extracted from the digital terrain models developed from ASTER and SRTM data. The two data sets have different spatial resolution (ASTER 30 meters and SRTM 90 meters) therefore SRTM data was resampled through pixel disaggregation to conform to the Aster data spatial resolution.

The entire study area was divided into a grid of 5,000 cells, from which a random sample of 560 cells were selected for study stations. Upon closer observations of these study stations, some stations were discarded when they were found to be at the border of highland and lowland such as river banks, or the base of a ridge which could increase the error levels of the estimate. Consequently, in the final analysis a total of 503 study stations were used for the study.

The values extracted from the two datasets were stored in a relational database for spatial analysis. Arithmetic difference between the surface elevation values recorded for each station were used to measure subsidence or otherwise in all the stations.

Correlation analyses of land subsidence: Data on location of oil wells was overlaid on the study stations layer and the distances of the study stations to the nearest oil well was computed and stored in the database. Land use /land cover was also extracted from the Landsat ETM data obtained in 2005. The land use classes were ranked based on the weight or pressure exerted on the soil and the substrate characteristics associated with particular land use. The classification ranks are shown in table 1.

Pearson moment correlation analysis of elevation difference (subsidence) and the distance of station to oil well and the land use classes were computed.

Table 1: Subjective Ranks of land use types,

SN	Rank	Land use
1	1	Water
2	2	Secondary Vegetation, Cultivated farmlands, Bush Fallow
3	3	Open Space
4	4	Settlements
5	5	Rainfed Deltaic
6	6	Nypa Palm
7	7	Swamp
8	8	Fine Sand
9	9	Mangrove ,Mud Flat
10	10	Oil Facility

Results and Discussion

The result of the analysis showed that though Nigerian coastline is relatively low-lying, there are pockets of upland area within the 15 kilometre inland trajectory. Figure 3 shows the elevation models of the study area in 2008. A large portion of the study area lies below 6 meters above mean sea level. The upland area can be found in Ondo state around Igbokoda, Okitipupa sections and the Uyo- Calabar ends of the coastal zone. Some of these areas have elevation in the range of 25- 38 meters above mean sea level.

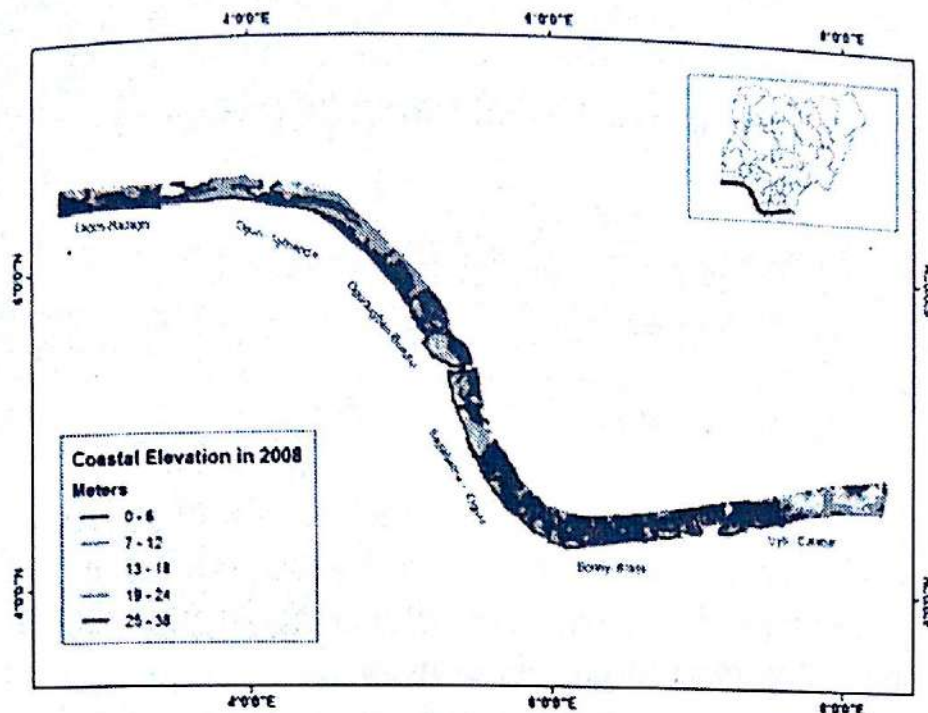


Fig.3: Coastal terrain in 2008

This eastern part of the coast is close to Cameroun highland and the Adamawa ridge which account for the high elevation at the Bakassi region. A number of sand filling exercises are also taking place in Lagos end for developmental purposes and coastal protection purposes which account for relatively high elevation between 2-12 metres above mean sea level in some parts of Lagos around 10 kilometres away from the coastline.

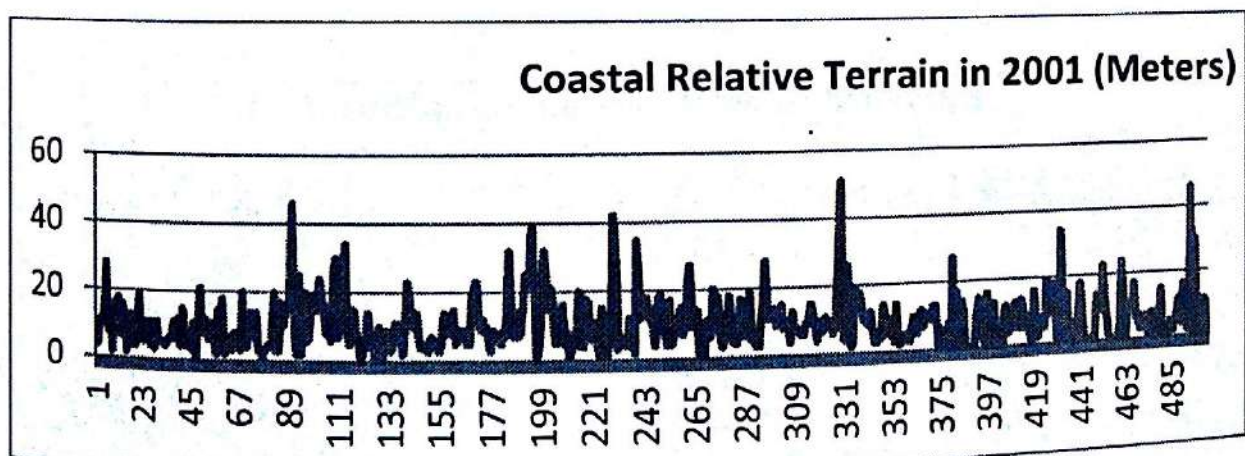


Fig 4: Estimated Coastal relative Terrain 2001

An analysis of the terrain in 2001 shows an average elevation between 0 meter to above 38 meters. The highest points are isolated around Ondo state, Delta, River and Cross River states. This further

strengthens the earlier position that Nigerian coast is not uniform plain terrain.

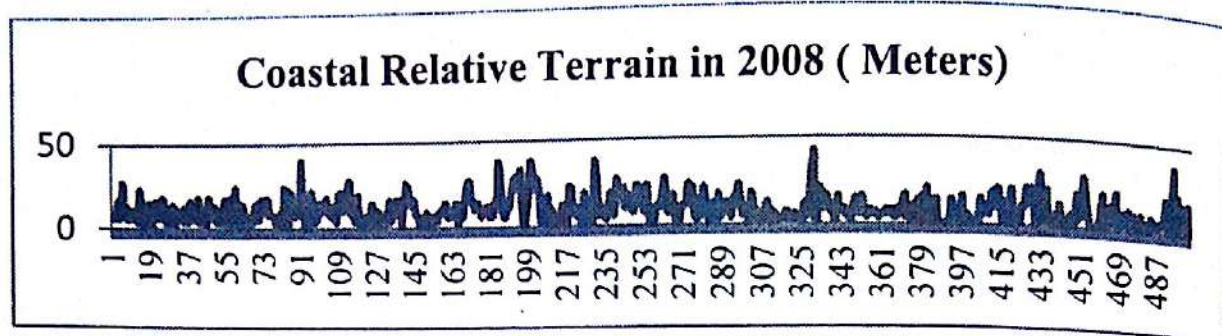


Fig 5: Estimated coastal relative Terrain in 2008

The 2008 elevation data extractions show similar terrain characteristics with very minor changes in 7 years. The changes are both negative and positive but negative elevation difference are more pronounced than the gain area. The negative elevation area can be attributed to subsidence while the positive area could be attributed to the sand filling and development programme taking place in the coastal area. It could however be due to error level introduced from the different spatial resolution of the images. The establishment of this error terms is not within the scope of this research. The dominant highest points are retained but with little modifications in some parts. Major positive change could be identified, Delta and River states where a number of manmade structures such as riprap, boulders, and concrete infrastructures were erected to protect shoreline from coastal erosion.

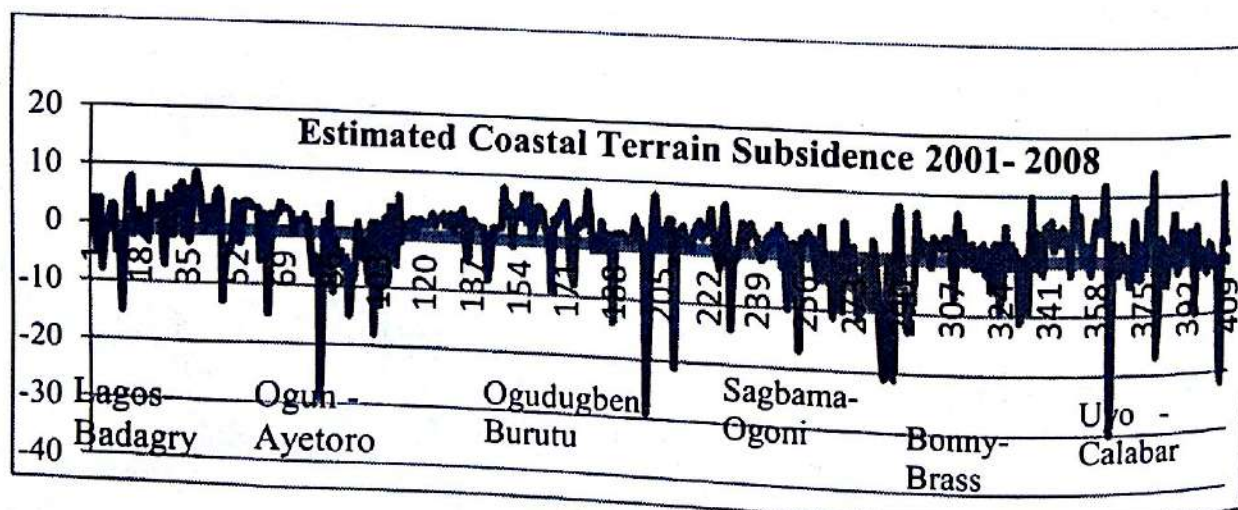


Fig.6: Estimated coastal subsidence along Nigerian coast

The subsidence as shown in figure 6 indicates that the coastal subsidence within the period of study is on the average of 5km in most cases less than 2 meters. Increase in elevation were also noted in some area which could be attributed deposition of sediments especially in the

Delta region and sand filling in the Lagos end shoreline protection infrastructure in the eastern end of the coastline.

Generally land Subsidence was noted in all the coastal areas but notable ones could be found around Igbokoda, Burutu Sagbama and part of Uyo. The most extensive subsidence could be noted at Ayetoro and Sagabama. Where most of the stations recorded subsidence. The annual rate of subsidence is in the range of 0.1 metre or 10 centimetre 2 centimetres in most parts of the Coastal region in Nigeria.

General terrain analysis showed that the Lagos Badagry end of the coastline had relatively stable condition as fluctuation in elevation is noted to be very marginal around 2 to 3 meters variation, In the Igbokoda and Ogun water side part of the coastline there are variation in the elevation as shown in figure 6. Major subsidence or negative terrain differentials were noted around the transgressive mud coast of Ogun waterside, Ayetoro, Igbokoda axis, and Mud flat and mangrove region of Ogudugbe, Burutu, Forcados axis. Marginal or no terrain loss was noted in Lagos Badagry Axis and Bonny- Brass axis.

Results of Pearson Correlation Analysis of land subsidence and selected anthropogenic factors

Statistical analysis of the relationship between subsidence and land use types around the study stations was conducted. The landuse types were ranked according to the soil substrate that the landuse types thrive, the root structure and the effects on the soil bearing capacity and the weight of the super structure of the canopy on the soil. The ranks for the landuse types are shown in table 1. The correlation analysis, showed a negative correlation value of -0.0610 significant at two tailed test. This shows a very weak negative correlation value which indicates there is a very weak negative relationship between the land use types and the nature, types and levels of subsidence in the study area. The relationship between the presence and distances of oil wells to the subsidence levels in the study stations showed positive correlation values of 0.557 significant at two tailed test.

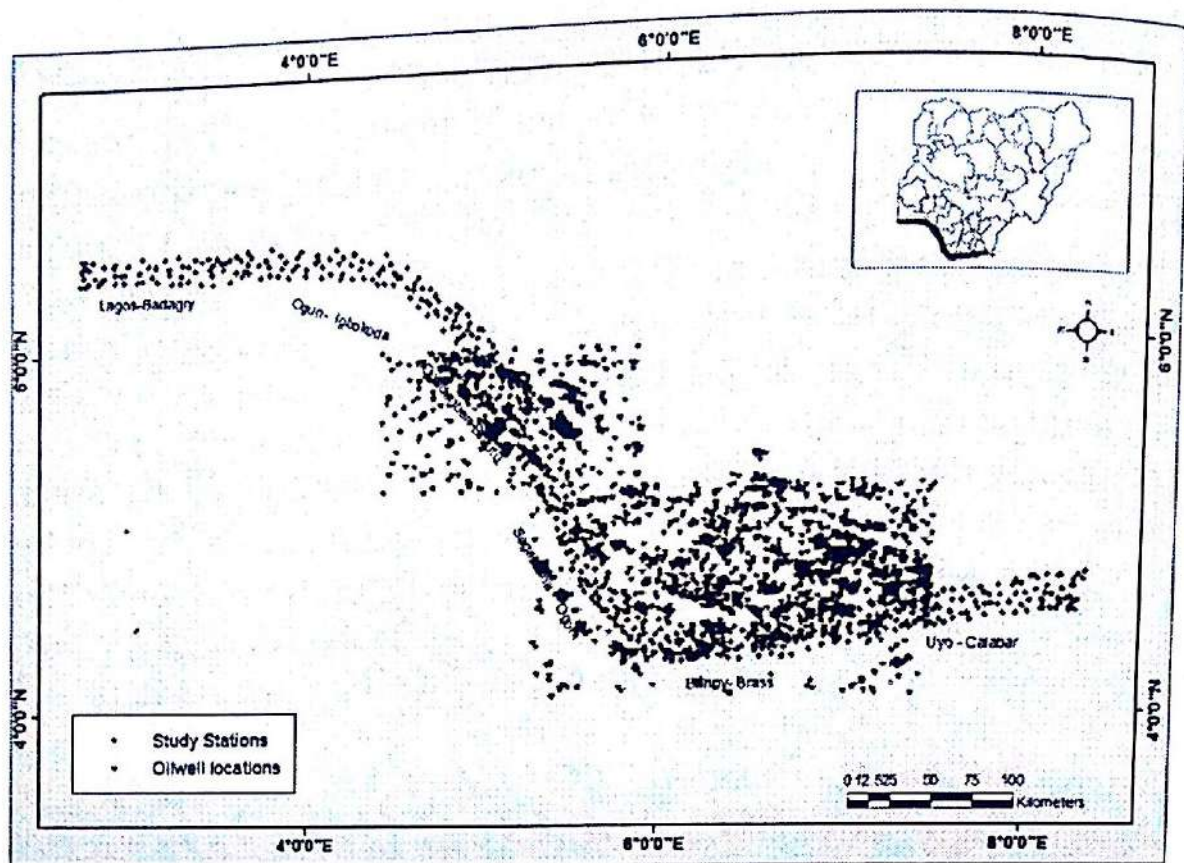


Fig. 7: Location of oilwells and study stations

The result shows that the nature of subsidence observed in the study area is influenced by the oil exploration especially on point by point basis though it cannot be ascertained on the general terrain differentials in the entire coastal region. The general elevation differential could be attributed to other forms of anthropogenic activities and natural processes. It was also observed that in the Niger Delta region of the study area where the oil wells are concentrated a number of activities are also taking place which can raise the ground level and thus the elevation. Such activities or projects include including shoreline protection, sand filling of previously vegetal area to create settlements and fishing camps, construction of manmade structures such as riprap, stone embankment, jetty and concrete beaches and other structures. Sediment discharge is also prominent in the delta region of the study area and results in raising elevation area of the study stations. From the analysis of the land use characterisation of the study area it could be deduced that the Niger delta is very active in terms of deposition of sediments from brackish water of the distributaries of River Niger and the tidal deposition of sands and sediments from the Atlantic. The deformation and the subsidence being caused by the oil drilling and compaction of the mud flat and marshy land are being replenished by the sediments transport and deposition along the coast. Manmade structure from Niger Delta Development

Corporation (NDDC) aggressive drive to improve the living condition of the Delta include sand filling and compaction of sediments to create space for developmental projects and to protect the shoreline from further erosion.

In the Lagos end of the coast the elevation is fairly stable though there are a number of boreholes involving pumping underground water to the surface which theoretically should have resulted in large scale subsidence, however it could not be noticed from the methods used because there are aggressive sand filling of the creeks to create islands and development pads. The lagoon has been heavily dredged to provide sand for the filling of the upland. It is plausible that the rate of sand filling is commensurate to the rate of subsidence. However some stations in this segment of the coastline record subsidence as shown in Fig 6. Especially around station 11 and station 51. These include areas around Badagry, Ibeju and Epe-Lekki of Lagos.

Conclusion and Policy Implications

Effects of Land subsidence in the coastal sedimentary region typically include changes in elevation and slope of streams, canals, and drains, which can increase coastal flooding, damage to bridges, roads, railroads, storm drains, sanitary sewers and canals. It also includes unequal settlements of buildings or collapse of buildings and public infrastructure. There is noted increase in tides moving into previously upland areas used for fresh water agriculture. When salt water from the ocean move into farmlands the crops gets destroyed and food security in the rural areas is constrained. When the coastland gets submerged it accelerates sea level rise in the region and this further reduces the amount of land available for other anthropogenic activities in the coastal region.

The subsidence is not uniform in the study area even in a relatively small area some places experience high subsidence than others. It could be inferred that the subsidence are rather localised and are related to anthropogenic activities rather than climate change. The geology of the subsurface of the coastline is also relevant in the subsidence recorded in the study area.

It is expected that as population pressure increases in the coastal region land subsidence will be aggravated. There are evidences of an average annual subsidence rate of 10 centimetres in some areas and between 2 and 5 centimetres in most areas of Nigerian coastal region. It is expected that the rate will increase as the increase in population results in increase demands for ground-water supplies and increased oil

exploration in the Niger Delta. As coastal settlements increase in terms of number of buildings and population and sophistication, more ground water will be exploited for domestic and industrial use. Intense oil exploration and a host of other activities in the coastal area will further exacerbate the subsidence of the Nigerian coastal region.

Possible measures to reduce subsidence in the coastal region is to explore offshore drilling rather than the onshore drilling which has greater potential for causing land subsidence. Efforts should be directed towards reducing ground water usage in the coastal cities through provision of pipe borne water and from other surface water sources and rain harvesting. Environmental impact assessments of projects in the coastal areas should include the implication of these projects on land subsidence.

References

- Ajakaiye, D. E., & Burke, K. (1973). A Bouguer gravity map of Nigeria. *Tectonophysics*, 16(1), 103-115.
- Allen, J. R. L., & Wells, J. W. (1962). Holocene coral banks and subsidence in the Niger Delta. *The Journal of Geology*, 70(4) 381-397.
- Balogun, W. O. B., M. A. Anifowose, M. A. Shogo, F. A. Salaudeen (2011). Trends and mechanisms of land subsidence of a coastal plain in the delta of Yangtze River-China, *Researcher*, 3(3), pp. 76-81
- Barends, F., F. Brouwer and Schroder F. 1995. Land Subsidence. Balkema, Rotterdam, The Netherlands (ISBN 90 5410 589 5), pp. XI-XIV.
- Cigna, F., Bianchini, S., & Casagli, N. (2013). How to assess landslide activity and intensity with Persistent Scattered Interferometry (PSI): the PSI-based matrix approach. *Landslides*, 10(3), 267-283.
- Devin, G. Jones, D and Ingebritsen, S. E., (1999). Land Subsidence in the United States, U.S. Geological Survey Circular 1182, 1999.
- Dottridge, J., and Jaber, N.A., 1999. Groundwater resources and quality in northeastern Jordan: safe yield and sustainability. *Applied Geography*, 19, 313-323.
- French, G. T., Awosika, L. F., & Ibe, C. E. (1995). Sea-level rise and Nigeria: potential impacts and consequences. *Journal of Coastal Research*, 14, 224-242.
- Galloway, D. L., K. W. Hudnut, S. E. Ingebritsen, S. P. Phillips, G. Peltzer, F. Rogez and P. A. Rosen (1998). Detection of Aquifer System Compaction and Land Subsidence Using Interferometric Synthetic Aperture Radar, Antelope Valley, Mojave Desert,

- California, *Water Resources Research* 34(10)1998, pp 2573–2585.
<http://dx.doi.org/10.1029/98WR01285>
- Holzer T.L. and Johnson A.I.(1985). Land Subsidence caused by Ground Water Withdrawal in Urban Areas. US Geological Survey, MS 977, 345 Middlefield Road, Menlo Park, CA 94025, USA. *GeoJournal* 11(3) 245-255.
- Hu R.L., Yue, Z.Q., Wang. L. C, and. Wang, S.J. (2004). Review on current status and challenging issues of land subsidence in China. *Eng Geol Environ* (76):65–77
- Ibe. C. A. (1996) The Niger Delta & Sea-Level Rise in J.D milliman & B.U Haq (eds) *Sea – Level Rise and coastal subsidence*, 249-269. Kluwer Academic Publishers. Netherlands.
- Kaveh K. Arash Z., Arash K. (2008). Land Subsidence Modeling due to groundwater Drainage Using “WTAQ” Software. *WSEAS Transaction on Environment and Development*. 4 (6) 1790-5079.
- Larson J.K., Basagaoglu, H., and Marino M.A. (2001). Prediction of optimal safe groundwater yield and land subsidence in the Los Banos-Kettleman City area California, using a calibrated numerical simulation model. *Journal of Hydrology*, 242:79–102
- Liu C.H., Pan Y.W., Liao J.J., Huang C.T., and Shoung O.Y. (2004)., Characterization of land subsidence in the Choshui River Alluvial Fan, Taiwan. *Environ Geol* 45(8):1154–1166.
- Koulali Idrissi, A., McClusky, S., & Tregoning, P. (2013). Present-day Kinematics of Papua New Guinea from GPS campaign measurements. In AGU Fall Meeting Abstracts Vol. 1, p. 929.
- Poland J.F. and Davis G.H. (1969). Land subsidence due to withdrawal of fluids. In: Reviews in engineering geology, Vol 2. *Geological Society of America*, p 187.
- Putra, D. P. E.. Setianto, A Keokhampui K. and Fukuoka, H.,(2011). Land Subsidence Risk Assessment case study: Rongkop, Gunung Kidul, Yogyakarta–Indonesia, The 4th AUN/SEED-Net Regional Conference on Geo-Disaster Mitigation in ASEAN, The Royal Paradise Hotel & Spa, Phuket, Thailand, October 25-26, (2011).
- Udoh, J. C. and Udofia, E. P. (2014). Land Subsidence Monitoring Using Geographic Information System (GIS) Techniques in Akwa Ibom State, Nigeria. *Current World Environment*. 9(1): 1-6.
<http://dx.doi.org/10.12944/CWE.9.1.01>.
- Xue Y.Q, Zhang Y, and Ye S.J.,(2005). Land subsidence in China. *Enviorn Geol* 48:713–720

- Yun, Z. Yu-Qun, X. Ji-Chun, W. Shu-Jun, Y. Zi- Xin, W. Qin-Fen, L. and Jun, Y.(2007). Characteristics of aquifer system deformation in the Southern Yangtse Delta, China. *Eng Geol Environ* (90) 160-173.