



**GIS-Based Oil Spill Incidents and Hazard Mapping in Gokana  
Local Government Area, Rivers State, Nigeria**

by

Obot A. Ibanga  
Department of Geography and  
Regional Planning  
Faculty of Social Sciences  
University of Benin,  
Benin City, Nigeria

Joseph C. Udoh  
Department of Geography and Natural  
Resources Management  
Faculty of Social Sciences  
University of Uyo, Uyo, Nigeria.  
josehudoh@uniuyo.edu.ng

**Abstract**

*Spatial analysis of oil spill incident is essential in oil spill contingency management. This study focused on application of geographic information systems (GIS) in oil spill incidents and hazard mapping for sustainable remediation in Gokana Local Government Area (LGA), Rivers State, Nigeria. Datasets used include oil spill location and incidents, digital elevation model (DEM) and map showing oil installations. The oil spill location and incidents data was retrieved from National Oil Spill Detection & Response Agency archive; a 30 X 30 meters' resolution DEM was sourced from the United States Geological Surveys (USGS) while map showing oil installations in Gokana was extracted from the United Nations Environmental Programme (UNEP) report. Nearest Neighbor Analysis (NNA), vector flow mapping and proximity-based buffer analysis were the GIS functionalities used in data analyses and presentation. The result showed that oil spill incidents displayed a clustered pattern with a NNA value of 0.35 at 99% confidence level. Also, a minimum flow velocity which rose in the central, eastern and north-western parts of the study area was uncovered. Result also showed that a greater part of the area was categorized as "High" hazard zone, followed by "Moderate" hazard zone and "Low" hazard zone. The study recommended renewed commitment for human and settlement relocation from well mapped out hazard and high risk areas to safer locations. This also calls for the adoption of GIS in oil spill contingency planning and sustainable remediation of host communities by multinational oil producing companies.*

**Keywords:** GIS, Oil Spill, Incidents, Hazard, Mapping, Gokana LGA,

---

**1. Introduction**

The need to address the threats of copious natural and human-induced disasters including oil spills to the environment and developmental facets of many societies

globally, depend highly on availability of evident-based geographically-referenced information. This is because of the occurrence of these disasters in a specific location, in a particular time with the possibility of impacting negatively on socio-ecological, economic and political landscape of the place. The evident-based geographically-referenced information is able to isolate hazards and disaster locations, who and what is at risk or vulnerable and offer proactive decision support mechanisms for time-based mitigation measures. Oil spill, an environmental hazard, occur where people live and interact with nature and one of the emerging frameworks for incidence and hazard mapping for sustainable remediation is geographic information systems (GIS).

Fascinatingly, GIS has been conceptualized to reflect a conglomeration of information and communication technology devices, human capital, financial resources as well as governance frameworks necessary to facilitate geospatial and associated data sourcing and preservation in order (in present or future) to retrieve, analyze, synthesize and put on view to advance knowledge in addition to aiding policy formulation (Kennedy, 2009). Besides, GIS has also been viewed as a computerized arrangement where geographically-related phenomenon is captured, stored, queried, analyzed and displayed (Chang, 2010). The science aspect of GIS established the manner which the results add value to the interpretation of geographic phenomenon including the application, wisdom, knowledge, and theory underpinning the procedure taken (Longley *et al.*, 2011). The capability of spatial data acquisition, efficient storage, retrieval, analysis and visualization interface as well as the flexibility of integrating other data from various sources and formats has made GIS earn reputation oil spill debate in recent years (Mohamadi *et al.*, 2015).

GIS has wide application areas (United Nations Institute for Training and Research- UNITAR, 2019) and has recently been used in mapping local forest conservation area (Miardini and Susanti, 2019), public health mapping (Nuramalina, Ibrahim and Ludin, 2019) and in optimum site suitability assessment (Rahayu *et al.*, 2019). Oil spill are space-based incidents with several attributes like volume of oil spilled, time of occurrence, effects, causes and other inputs that can be built into the GIS database for form spatiotemporal and volumetric decision support tool (Oyehan and Al-Ramadan, 2014). GIS technologies can significantly improve identification or even classification of oil spills allowing making the final product – oil spill distribution maps (Ivanov and Zatyagalova, 2014). Oil spill and sensitive areas can easily be detected, analysed and mapped, monitor spread and clean-up exercises with the use of GIS/RS (Mohamadi *et al.*, 2015).

Udoh and Ekanem (2011) applied GIS in risk assessment of oil spill in the coastal areas of Akwa Ibom State, Nigeria. Well heads, flow stations, storage tank farms, pipelines, water bodies and oil wells which constituted oil spill hazard sources were combined with impedance which includes soil characteristics and slope constituted to derive oil spill hazard map. Arable crop sensitivity, settlement development, vegetation and land use, road network and socio-economy were used to model vulnerability. Oil spill risk was mapped as a function of oil spill hazard and vulnerability and categorized into very high, high moderate and marginal risk zones. Iko and the environs were found to be

in the very high risk zone and it was recommended that GIS be integrated into oil spill emergency planning (Udoh and Ekanem, 2011).

Similarly, Mohamadi *et al* (2015) built oil spill risk assessment model for vegetation (OSRAMV) in Bonny, Rivers State using GIS/RS. It was found that 72% of impacted areas pixels were in severe oil spill hazard areas. Whanda *et al* (2016) also deployed various geostatistical analytical frameworks in GIS to analyse oil spill spread and vulnerability in the Niger Delta Region of Nigeria. Findings showed that the frequency of oil spills from 1985-2008 was 443. Highly hazardous zones included settlements located between 0-500meters from oil installations and spill cites while low hazard zone were found 500meters away. Spatial distribution of oil spill was clustered as revealed in nearest neighbour index of 0.19 and Getis-Ord General G test on volume spilled (mean distance of 400 meters) all at 99% confidence level using Moran I index.

The use of multiple ring buffer-based proximity algorithms in Arc GIS software with a mean distance range of 500-1000 meters apart in mapping spatial extent of crude oil spill hazard zones has also documented. Nwankwoala and Nwaogu (2009) used  $\leq 500$  meters around oil pipeline and water bodies to map high oil spill hazard area, 501-1000 meters (moderate) and 1001-1500 meters (low). Guadalupo-Blanco River Authority (2011) used  $\leq 500$  meters to map high hazard zone and 2500 meters away from oil installations as low hazard zone. Shittu *et al* (2011) used 1000 meters for high hazard zone, 1500 meters for moderate hazard zone and 2000 meters for low hazard zone assessment.

Whanda (2014) used buffer distance of 500 meter interval (from 500-4000 meters) to generate eight hazard zones ranging from extremely high to extremely low hazard zones. Makinde and Tologbonse (2017) used  $\leq 500$  meters (very high hazard), 501-1000 meters (high hazard), 1001-1500 (moderate hazard) and 1501-2000 meters (marginal hazard). These also yielded varying results across different study areas. For instance, Nwankwoala and Nwaogu (2009) result showed that 134.73km<sup>2</sup> was the spatial extent covered by high oil spill hazard area while Shittu *et al* (2011) 114 communities as being found within the same hazard category. Also, Whanda (2014) reported 30-40 settlements as being found within the low oil spill hazard area while Makinde and Tologbonse (2017) reported 35.8 km<sup>2</sup> in the same hazard category.

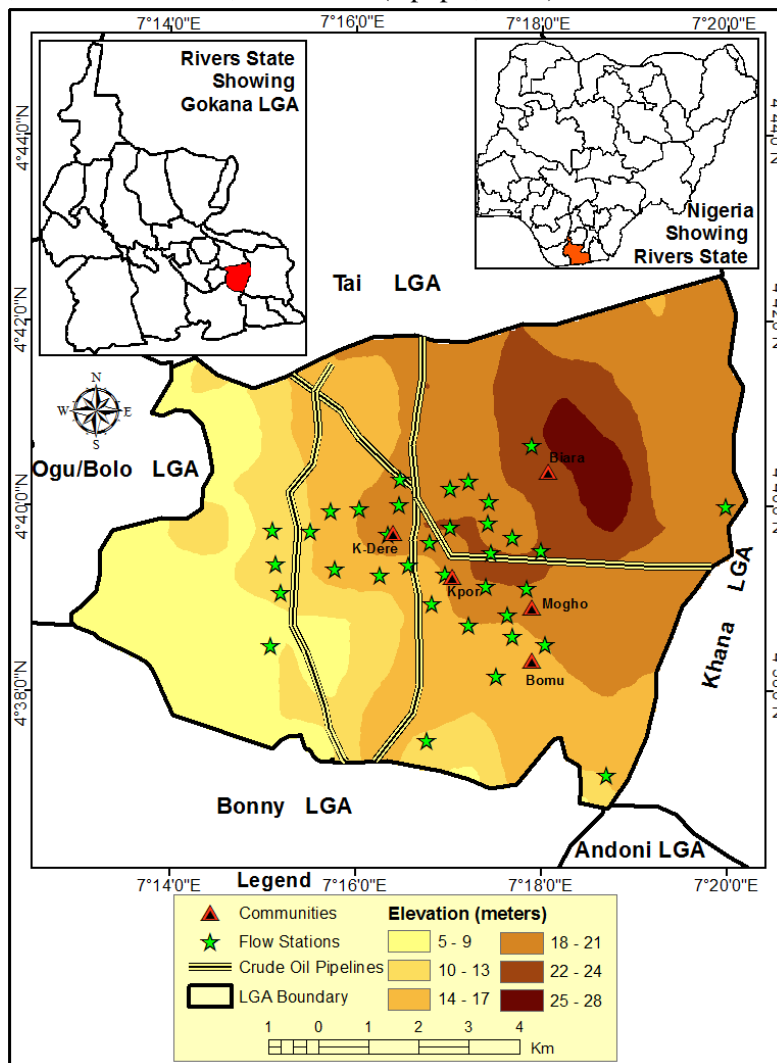
In oil spill hazard remediation, the extent of clean-up exercise is a function of the knowledge of the spill incident location, the distributional pattern, nature of terrain, hazard coverage, direction as well as the velocity of flow. The foregoing application of GIS framework therefore justifies its deployment in this study with view to providing a visual representation of a true world situation. This will aid policy makers and stakeholders in making purposeful decisions and deployment for sustainable oil spill remediation in Gokona Local Government Area (LGA), Rivers State, Nigeria.

The specific objectives were to apply GIS in:

- Determination of spatial distribution of oil spill incidents in Gokona LGA;
- Mapping the flow direction and magnitude of oil spill incidents in Gokona LGA; and
- Mapping the spatial extent of crude oil spill hazard zones in Gokona LGA.

## 2. The Study Area

This study was carried out in Gokana LGA which is one of the 23 LGAs in Rivers State, Nigeria with headquarters in Kpor Town found in the central part of the LGA. Gokana LGA is spatially situated between latitudes  $4^{\circ}36' 43.69''$  –  $4^{\circ}42' 29.758''$  North of Equator and longitudes  $7^{\circ}12' 55.16''$  –  $7^{\circ}20' 13.057''$  East of Greenwich. It is bounded in the north by Tai LGA, in the east by Khana LGA, in the south by Andoni and Bonny LGAs and in the west by Ogu/Bolo LGA as seen in Figure 1. The National Population Commission (NpopC) reported Gokana LGA covers a total land area of about  $126.758\text{km}^2$ . Based on the 2006 census, Gokana LGA had a total population of 233,813 people with 118,222males and 115,591females (NpopC, 2010).



**Figure 1: Gokana Local Government Area**

The climate of Gokana LGA falls within the tropical rainforest with frequent influence of tropical continental and maritime air masses. The high-resolution time-series

(TS) gridded climatic data of month-by-month variation in climate (version 4.03 - January 1901 - December 2018) released by the University of East Anglia-Climatic Research Unit, Harris and Jones (2019) indicate that temperature is as low as 21°C in January and as high as 33°C in September in Gokona LGA. Rainfall pattern is bi-modal with the first peak of 320.3mm in July with a short dry season in August and the second peak of 359.3mm in September and a total about 2435.8mm per annum. Annual potential evapotranspiration is about 50.3mm with highest value of 5.2mm observed in February and lowest value of 3.1mm noticed in July. Annual soil moisture (0 – 10cm) is about 337.9mm with highest value of 30.2mm observed in July and lowest value of 24.2mm noticed in January and February. Mean wind speed is about 4.2 meters per second and may sometime exceed 10 meters per second in peak rainy season.

With respect to the relief, Gokona LGA is generally a low-lying area which situate within the Niger – Delta plain. Digital elevation model (DEM) is a representation of the general relief of the area. DEM represent continuous elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEMs are typically used to represent terrain relief. Six distinct relief classes is found in the area which ranged from 5 meters to 28 meters above sea level. Vegetation is characteristic fresh water intermingled with mangrove swamp forest which constitute breeding habitat for fishes and other biodiversity although these have been significantly altered by oil pollution (United Nations Environmental Programme – UNEP, 2011). The dominant occupation in the area is predominantly fishing and farming as well as other informal artisanal socio-economic activities like agricultural processing, hunting, trading, etc (Wizor and Eludonyi, 2020).

### **3. Materials and Methods**

Principal datasets used for this study include oil spill location and incidents data, DEM and map showing oil installations in Gokona LGA. The oil spill location and incidents data was retrieved from NOSDRA archive (2019), a 30 X 30 meters' resolution DEM was sourced from the United States Geological Surveys (USGS) while map showing oil installations in Gokona was extracted from UNEP (2011) report. They were imported in ArcMap 10.1, georeferenced with latitude-longitude geographic coordinate system (GCS) and vectorized using on-screen digitization. All the layers were reprojected to Universal Transverse Mercator (UTM-zone 32) coordinate system.

In order to determine the spatial distribution of oil spill incidence in Gokona LGA, nearest neighbor analysis was used. Nearest Neighbor Analysis (NNA) examines the distances between each point and closest point to it. The nearest neighbor analysis is a method of exploring patterns in locational data by comparing graphically the observed distribution functions of event-to-event or random point-to-event nearest to neighbor distances. In this study, the oil spill incidents data were used as the operational unit. The nearest neighbor analysis was used to measure the distribution pattern of oil spill incidents (2006 to 2019) using ArcMap 10.1 software. The nearest neighbor analysis tends to measure the distributions according to whether they are clustered, random or

regular (uniform). The nearest neighbor formula produces a result between 0 and 2.15 and is computed using the formula in equation (1) as follows:

$$R_n = 2d\sqrt{n/a} \dots\dots\dots (1)$$

Where:  $R_n$ = nearest neighbor value;  $d$ = the mean distance between oil spill sites (meters);  $a$ = the local government area;  $n$ = total number of oil spill sites.

This study also sought to apply GIS in mapping the potential direction and magnitude of flow of oil spill with the aid of flow direction and vector flows. This was made possible by the creation of random spot heights used in extracting elevation values from the 30 X 30-meter resolution DEM. To facilitate smooth surface modelling, 10,000 random spot heights at a mean distance of 10 meters were automatically generated. The field geometry algorithm in ArcMap 10.1 in the layer properties also assisted in the computation of the x (longitude) and y (latitude) coordinates of all the generated elevation spot heights. Attribute database of this elevation spot heights was exported to Surfer 11 GIS Software where it was converted into grid using kriging interpolation framework. The resultant grid file was used in vector flow mapping.

With respect to the determination of the spatial extent crude oil spill hazard zones in Gokona LGA, the digitized layers of crude oil pipelines, manifolds, flow stations and well heads which formed major sources of oil spills hazard in the area were used in proximity/buffer analysis. However, in literature, settlements staying 500 meters from oil infrastructures have been reported to be of high risk in event of any oil spill (Nwankwoala and Nwaogu, 2009; Guadalupo-Blanco River Authority, 2011; Shittu et al, 2011; Whanda, 2014; Makinde and Tologbonse, 2017). Thus, 500m, 1000m and above 1500m buffers representing “High”, “Moderate” and “Low” hazard zones were created along the digitized oil spills hazard layers using ArcMap 10.1 Analysis Extension. The final the spatial extent crude oil spill hazard zones in Gokona LGA was computed using Field Calculator in the final oil spill hazard layer property.

#### **4. Result and Discussion**

##### **4.1 Spatial Distribution of Oil Spill Incidents in Gokona LGA**

Determining the spatial patterns of phenomena in space is one of the core issues addressed by geographers, planners, environment and development analysts. The cardinal motivation is to support decision. Several methods used in determining the spatial patterns of phenomena are also available in literature. It was found that about 145 oil spill incidents occurred from 2006 to 2019. Spatial analysis also showed that the Observed Mean Distance of oil spill incidence was 84.02 meters while the Expected Mean Distance was 239.57meters (see Figure 2). Two hypotheses (null and alternate) were formulated to assess oil spill incidents spatial pattern in Gokona LGA with the aid of NNI and z-score. The null hypothesis stated that oil spill incidents are not randomly located (distributed) while the alternate stated that oil spill incidents are randomly located (distributed) within Gokona LGA.

Thus, with the Nearest Neighbor Index of 0.35 indicate that the distribution is clustered. With a z-score of -14.96 and p-value of 0.0000, the null hypothesis is hereby accepted while the alternate hypothesis rejected at 99% confidence level. This finding

corroborates earlier study by Park et al (2016) who used alternative Getis-Ord General G test function to obtain similar clustered pattern of oil spill incidents in North Dakota, USA. It also agrees with Whanda et al (2016) who reported nearest neighbour index of 0.19 in other locations in Niger Delta Region of Nigeria. Clustered pattern is pointer to the recurrent nature and significant occurrence of this environmental incident which can facilitate informed decision of spill reduction and risk assessment (Park et al., 2016).

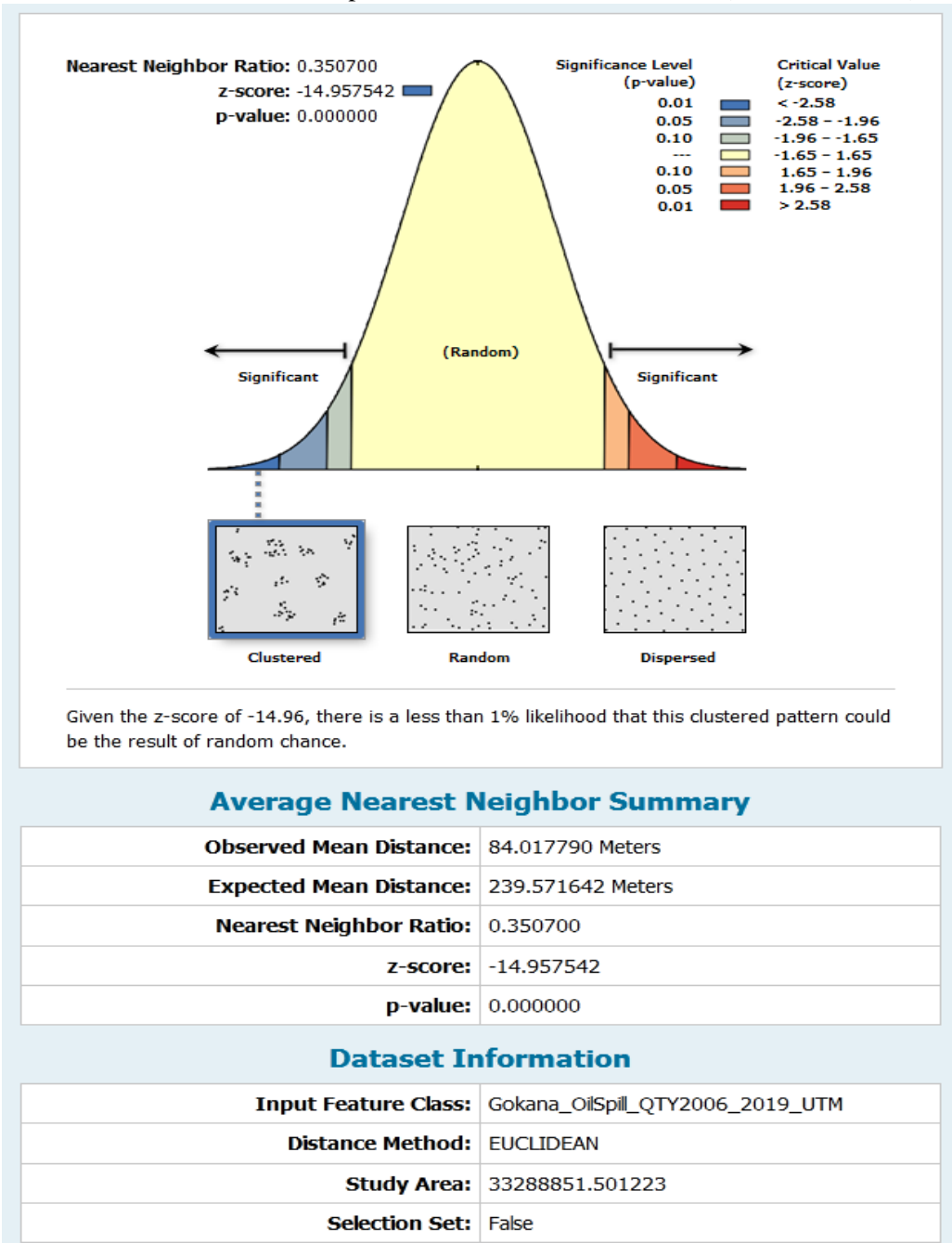
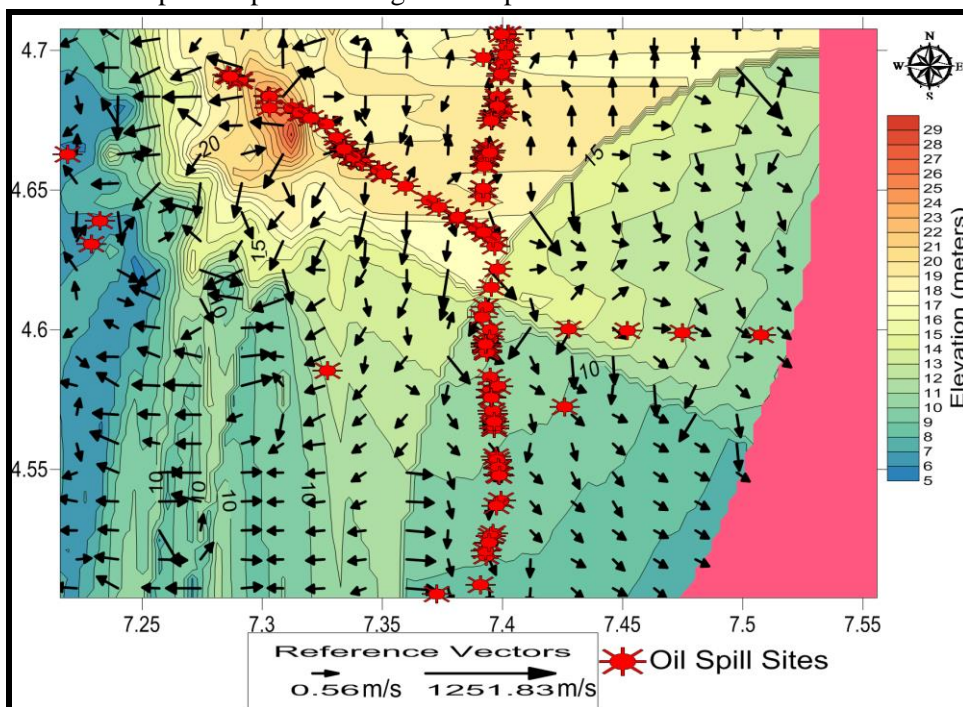


Figure 2: Nearest Neighbour Statistics of Oil Spill Incidents in Gokona LGA

#### 4.2 Flow Direction and Magnitude of Oil Spill Incidents in Gokona LGA

In any situation, it is quite obvious that movement of substances (in this case oil) would follow an upstream (source) – downstream (destination) pattern. The vector map in Figure 3 shows the direction and magnitude of oil spill incidence in Gokona LGA and was overlaid with a shaded contour (relief). Thus, as oil spills on the study area, the direction arrows indicate the probable direction of oil flows - from high elevation to low elevation. In other words, areas with relatively high elevation represent the potential source of hazard while the transition zone is the area characterized by moderate relief. Low – lying area thus becomes the potential destination. Similarly, magnitude is indicated by the length of the arrow. Areas with steeper slopes have longer arrows while relatively shorter arrows represent places with gentle slopes.



**Figure 3: Vector Flow Map of Oil Spill Incidents in Gokona LGA**

In this vector flow map, the elevation of the area play vital role in contaminants/materials migration as opposed to wind and current in water surfaces and aquatic environment as reported by Vethamony et al (2007). Besides, Gokona LGA have a minimum flow velocity of  $0.56\text{m/s}^2$  and rises to about  $1251.83\text{m/s}^2$  in central, eastern and north-western parts of the map. This finding revealed a characteristic relationship between the time it will take for the spilled contaminants to escape from the spill sites, nature of terrain (the slope track) and the possible route where the spilled contaminants will follow and finally settles. Similar significant link between oil spill trails and the direction of waves in maritime areas with the use of vector flow models has also been reported (Wang, 2013; Hardeo and Chakrabarti, 2016; Zanier et al., 2019).



### 4.3 Spatial Extent of Crude Oil Spill Hazard Zones in Gokona LGA

It is a well-established fact that crude oil exploitation has immediate and recurrent impacts on communities in Gokona LGA. The impacts include contamination of natural source of water including streams and river, problem of oil spill, forest destruction and bio-diversity loss, environmental effect of gas flaring as well as effluent discharge and disposal (UNEP, 2011; Wizer and Eludonyi, 2020). Thus, in an attempt to determine the spatial extent of crude oil spill hazard zones in Gokona LGA, GIS technique was deployed. With the modelling capability of GIS, complex analysis were carried out with available data. Oil spill incidents data and oil pipeline infrastructure of the study area served as the input data in investigation of the levels of vulnerability to crude oil exploitation in with particular reference to its spatial extent.

The result as presented in Figure 4 indicates that about 24.15km<sup>2</sup> (49.1%) of the area lying 500m away from the oil installations fell under “High” hazard zone. Also, area located about 1000m away near land from the oil installations and categorized as “Moderate” hazard zone span across 13.55 km<sup>2</sup> (27.5%) of the hazard coverage area while “Low” hazard zone covered about 11.53 km<sup>2</sup> (23.4%) which is situated about 1500m away from the oil installations. It has been reported that distance-based analysis (such as this) assumes that residing in either a location containing a hazard (spatial coincidence analysis) or within a specific distance from a hazard (distance-based analysis) leads to environmental exposure (Chakraborty and Maantay, 2011).

Consequently, it could be inferred that K-Dere and Kpor are the communities that are likely to be *highly* exposed to oil spill hazard in Gokona LGA. Mogho Town will probably be *moderately* exposed to oil spill hazard incidents while Biara Town will almost certainly be *lowly* exposed to oil spill hazard in Gokona LGA. This is to say that oil spill hazard decreases as distance increases and a town like Bomu, although not in any oil spill hazard zone may likely be affected based on the flow direction and speed as determined by the nature of the terrain. At a glance, one is able to visualize the extent of devastation of oil spill on the LGA.

In retrospect, oil spills (as seen in Plates 1 and 2) occur more often in the communities Gokona LGA due to transportation and marketing, damage to oil pipelines and accidents involving road trucks and tankers generate oil spills and hydrocarbon emissions have a lot of impact, because the toxicity of the oil adversely affect the soil, plant, animal and water resources (UNEP, 2011). The extent to which changes could harm the environment, or to which the community can be affected by the impact of a hazard or exposed to the possibility of being attacked or harmed is also shown in Plate 3. Area demarcated with red is crude oil that had seeped through the fence of the heavily polluted facility and contaminated several surrounding soils outside the complex. Recent findings by Wizer and Eludonyi (2020) also linked environmental impacts of oil spill on pollution of surface and ground water, loss of livelihood sources, poverty and famine.

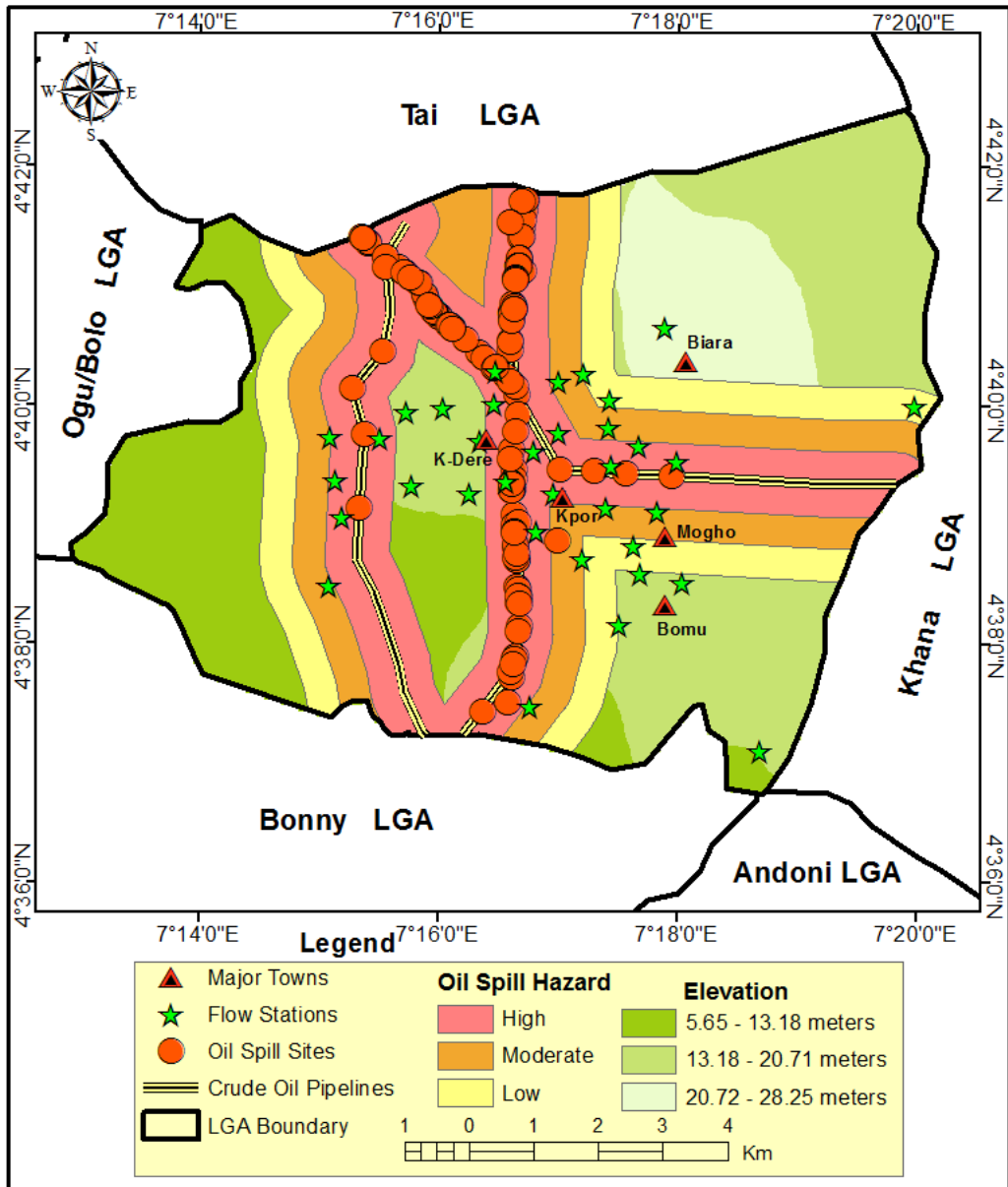


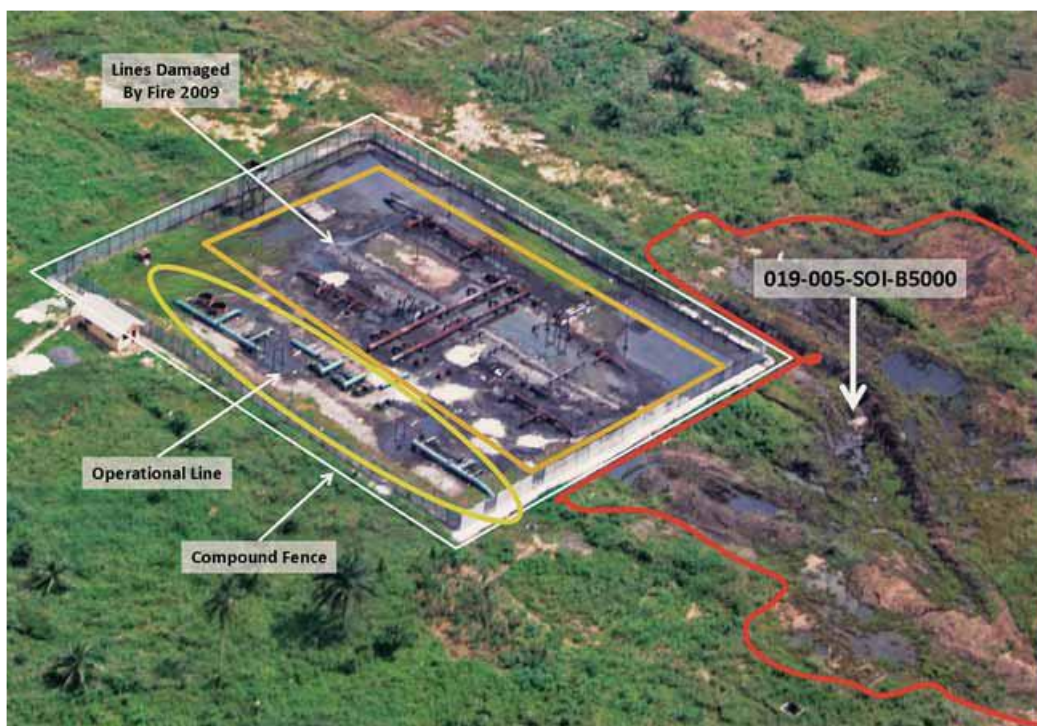
Figure 4: Oil Spill Incidents and Hazard Map of Gokana LGA



**Plate 1: Abandoned Wellhead with Spill in Bomu (Source: UNEP, 2011)**



**Plate 2: Oil Pipeline Spill in K-Dere (Source: UNEP, 2011).**



**Plate 3: Aerial View of Oil Facility in K-Dere (Source: UNEP, 2011)**

## **5. Conclusion**

The science, technology and information nexus have made easy the evaluation of global environmental and developmental challenges confronting the collective human existence on planet earth. This study have yet unravel the potentials of GIS functionalities in oil spill incidents and hazard mapping for sustainable remediation in Gokana Local Government Area, Rivers State, Nigeria. The clustered pattern uncovered in this study indicates the incessantness of oil spill in many areas where oil exploration, exploitation, transportation and other upstream and downstream activities take place. Effective and sustainable remediation of oil spill from the environment can be facilitated with the deployment of vector flow model with the knowledge of direction and velocity of oil spill diffusion. The spatial coverage of oil spill hazard can clearly direct policy makers on what is actually destroyed in event of oil spill as well as the extent to which remediation can be undertaken. In view of these, it is recommended that:

- i. This also calls for adoption of GIS in oil spill contingency planning and sustainable remediation of host communities by multinational oil producing companies.
- ii. Routine quality checks as well as periodic monitoring and evaluation of oil facilities and installations by experts should be carried out to forestall future occurrence.
- iii. Justifiable compensation to households and communities whose livelihoods like farmlands and fishing gears have been affected.

- iv. Immediate access to portable water and improved sanitation facilities should be provided to oil spill hazard communities.
- v. There should be renewed commitment for human and settlement relocation from well mapped out hazard and high risk areas to safer locations. This also calls for cooperation of the host communities and multinational oil producing companies.

## References

- Achebe, C.H., Nneke, U.C., Anisiji, O.E., 2012. Analysis of Oil Pipeline Failures in the Oil and Gas Industries in the Niger Delta Area of Nigeria. Proceedings of the International MultiConference of Engineers and Computer Scientists, Hong Kong, 14-16 March, 2012.
- Adesope, O. M., Ifeanyi-Obi, C. C., Ugwuja, V. C., Nwakwasi, R., 2012. Effects of Malaria on the Farm Income of Rural Households in Ekeremor Local Government Area, Bayelsa State. *International Journal of Agricultural Economics and Management*, 2 (1): 27-36.
- Alberta, O. N., Amaratungaa, D. Haigh, R. P., 2018. Evaluation of the Impacts of Oil Spill Disaster on Communities and its Influence on Restiveness in Niger Delta, Nigeria. *Procedia Engineering*, 212: 1054 – 1061.
- Ayanlade, A., 2012. Evaluating Environmental Change Impacts on Ecological Services in the Niger Delta of Nigeria. *Ife Research Publications in Geography*, 11 (1): 111 – 125.
- Azebri, P. B., Lawrence, A. L., Oweibo, S., 2015. Perception of Residents in Selected
- Baumann, P. R., 2001. Environmental Warfare: 1991 Persian Gulf War.
- Bruederle, A., Hodler, R., 2019. Effect of oil spills on infant mortality in Nigeria. <https://www.pnas.org/content/116/12/5467> (Accessed 23 March, 2020).
- Burgherr, P., 2007. In-depth analysis of accidental oil spills from tankers in the context of global spill trends from all sources. *Journal of Hazardous Materials*, 140 (1-2):245-56.
- Chakraborty, J., Maantay, J., 2011. Proximity Analysis for Exposure Assessment in Environmental Health Justice Research. In J.A. Maantay and S. McLafferty (eds.), *Geospatial Analysis of Environmental Health, Geotechnologies and the Environment* 4. New York, United States, Springer (pp.111-138). 10.1007/978-94-007-0329-2\_5.
- Chang, K., 2010. *Introduction to Geographic Information Systems* (5th edition). New York, McGraw-Hill.
- Chinedu, E., Chukwuemeka, C. K., 2018. Oil Spillage and Heavy Metals Toxicity Risk in the Niger Delta, Nigeria. *Journal of Health & Pollution*, 8 (19): 1-8.
- Chuks-Ezike, C., 2018. Deficient Legislation Sanctioning Oil Spill in Nigeria: A Need for a Review of the Regulatory Component of Petroleum Laws in Nigeria and the Petroleum Industries Bill. *International Journal of Environment and Sustainability*, 2018, 7(1): 30-44
- Compounds in Amassoma towards Early Marriage in Southern Ijaw Local Government Area, Bayelsa State. *International Journal of Science and Research*, 4 (5): 1399-1403. ENVIRONMENTAL\_WARFARE.htm (Accessed 23 March, 2020).
- Etkin, D. S., 2001. Analysis of Oil Spill Trends in the United States and Worldwide. <https://www.researchgate.net/publication/237554256> (Accessed 23 March, 2020).

- Geography Revision, 2020. The concept of hazard in a geographical context. Retrieved on 23<sup>rd</sup> <https://geography-revision.co.uk/a-level/physical/the-concept-of-hazard-in-a-geographical-context/> (Accessed 23 March, 2020).
- Guadalupo-Blanco River Authority, 2011. Oil and Gas Pipeline Failure. <http://www.gbra.org/documents/hazardmitigation/update/Section15-PipelineFailure.pdf> (Accessed 27 March, 2020).
- Hardeo, A., Chakrabarti, D. P., 2016. Vector-Based Oil Spill Model, *Chemical Engineering Communications*, 203:12, 1656-1665, DOI: 10.1080/00986445.2016.1230103 [http://employees.oneonta.edu/baumanpr/geosat2/Environmental\\_Warfare/](http://employees.oneonta.edu/baumanpr/geosat2/Environmental_Warfare/)
- Iden, M., 2020. Oil Pipeline Vandals in Nigeria Strike Again. <https://www.pipeline-journal.net/news/oil-pipeline-vandals-nigeria-strike-again> (Accessed 23 March, 2020).
- Ivanov, A. Y., Zatyagalova, V. V., 2014. A GIS Approach to Mapping Oil Spills in the Marine Environment. <https://www.researchgate.net/publication/241531967> (Accessed 23 March, 2020).
- Kadafa, A. A., 2012. Oil Exploration and Spillage in the Niger Delta of Nigeria. *Civil and Environmental Research*, 2 (3): 38-51.
- Kennedy, M., 2009. *The Global Positioning System and GIS*. London: CRC Press.
- Ladan, M., 2017. 2,418 Oil spills reported in seven years by Agip. <https://www.atmosi.com/us/news-events/news/2-418-oil-spills-reported-in-seven-years-by-agip/> (Accessed 23 March, 2020).
- Longley, P. A., Goodchild, M., Maguire, D. J., Rhind, D. W., 2011. *Geographic information systems and science*. Hoboken, New Jersey: Wiley.
- Makinde, E. O., Tologbonse, A. S., 2017. Oil Spill Assessment in Ijeododo Area of Lagos State, Nigeria Using Geospatial Techniques. *Ethiopian Journal of Environmental Studies and Management*, 10 (4): 427 – 442.
- Miardini, A., Susanti, P.D., 2019. Spatial Distribution of Potential Area for Community Forest Development in Grindulu Watershed. *Geoplanning: Journal of Geomatics and Planning*, 6(1), 73-80. doi:10.14710/geoplanning.6.1.73-80.
- Michel, J., Fingas, M., 2016. Oil Spills: Causes, Consequences, Prevention, and Countermeasures. *Fossil Fuels*. [tps://www.researchgate.net/publication/301932090\\_Oil\\_Spills\\_Causes\\_Consequences\\_Prevention\\_and\\_Countermeasures](https://www.researchgate.net/publication/301932090_Oil_Spills_Causes_Consequences_Prevention_and_Countermeasures) (Accessed 8 April, 2020).
- Mohamadi, B., Xie, Z., Liu, F., 2015. GIS Based Oil Spill Risk Assessment Model for the Niger Delta's Vegetation. *Nature Environment and Pollution Technology*, 14 (2):545 – 552.
- Morales, M., 2018. How do we calculate anomalies? Is there an acceptable, standard way of calculating rainfall anomalies? [https://www.researchgate.net/post/How\\_do\\_we\\_calculate\\_anomalies\\_Is\\_there\\_an\\_acceptable\\_standard\\_way\\_of\\_calculating\\_rainfall\\_anomalies](https://www.researchgate.net/post/How_do_we_calculate_anomalies_Is_there_an_acceptable_standard_way_of_calculating_rainfall_anomalies) (Accessed 8 April, 2020).
- National Oil Spill Detection & Response Agency, NOSDRA, 2019. Nigerian Oil Spill Monitor. <https://oilspillmonitor.ng/> (Accessed 23 March, 2020).
- National Population Commission, NPopC., 2010. *2006 Population and Housing Census: Population Distribution by Sex, State, LGA and Senatorial District. Priority Table, 3*. Abuja, NPopC.

- Nuramalina, M., Ibrahim, W.Y.W., Ludin, A. N. M., 2019. Assessing Landscape Pattern Relationship with Dengue Incidence in Peninsular Malaysia. *Geoplanning: Journal of Geomatics and Planning*, 6(1), 31-42. doi:10.14710/geoplanning.6.1.31-42.
- Nwankwoala, H. O., Nwaogu, C., 2009. Utilizing the Tool of GIS in Oil Spill Management – A Case Study of Etche LGA, Rivers State, Nigeria. *Global Journal of Environmental Sciences*, 8 (1): 19 – 29.
- Olaifa, E., Osuagwu, E. S., 2017. Effects of Oil Spills on Fish Production in the Niger Delta of Nigeria. Paper Presented at e-Governance Conference, Covenant University, Ota, Nigeria, pp595 – 608.
- Ordinioha, B., Brisibe, S., 2013. The human health implications of crude oil spills in the Niger delta, Nigeria: An interpretation of published studies. *Nigerian Medical Journal: Journal of the Nigeria Medical Association*, 54(1), 10–16. <https://doi.org/10.4103/0300-1652.108887>
- Osahon, J., 2020. ERA/FoEN demands remediation of oil spill site in Bayelsa community. <https://guardian.ng/news/era-foen-demands-remediation-of-oil-spill-site-in-bayelsa-community/> (Accessed 15 April, 2020).
- Osuagwu, E. S., Olaifa, E., 2018. Effects of oil spills on fish production in the Niger Delta. *PLoS ONE*, 13(10): e0205114. <https://doi.org/10.1371/journal.pone.0205114>
- Oyehan, T. A., Al-Ramadan, B. M., 2014. A GIS Approach to the Management of Oil Spill in Nigeria. A Paper Presented at the 9th National GIS Symposium, Dammam, Saudi Arabia. April 28 – 30, 2014: 1 – 14.
- Paraskova, T., 2019. Oil Pipeline Vandalism In Nigeria Soars 77%. <https://oilprice.com/Energy/Energy-General/Oil-Pipeline-Vandalism-In-Nigeria-Soars-77.html> (Accessed 20 April, 2020).
- Park, Y. S., Al-Qublan, H., Lee, E., Egilmez, G., 2016. Interactive Spatiotemporal Analysis of Oil Spills Using Comap in North Dakota. *Informatics*, 3(4): 1 - 14. doi:10.3390/informatics3020004.
- Rahayu, M. J., Widjajanti, R., Buchori, I., Putri, R. A., 2019. Mapping the Alternative Locations of Street Vendor Stabilization in Surakarta, Indonesia. *Geoplanning: Journal of Geomatics and Planning*, 6(1), 43-54. doi: 10.14710/geoplanning.6.1.43-54
- Rintoul, W., Hodgson, S. F., 1990. Drilling Through Time: 75 Years with California's Division of Oil and Gas in Nigeria. Sacramento: Department of Conservation, Division of Oil and Gas, 13–15. ISBN 0-9627124-0-X.
- Roser, M., 2020. Oil Spills. Published online at OurWorldInData.org. <https://ourworldindata.org/oil-spills> [Online Resource] (Accessed 23 March, 2020).
- Shittu, W. J., Nathanail, C. P. and Abrahart, R. J., 2011. Generic Mapping of Human Activity-Based Exposure Scenarios to Petroleum hydrocarbon Contaminants in an Oil Producing Area of the Niger Delta Region of Nigeria. In: C. A. Brebbia (Ed.), *Environmental Health and Biomedicine: Volume 15 of WIT transactions on biomedicine and health* (pp. 79-90). Southampton, United Kingdom: WIT Press.

- Shosanya, M., 2019. Implications of Oil Theft and Illegal Bunkering in Niger Delta: The Ojumole Case Study. <https://www.independent.ng/implications-of-oil-theft-and-illegal-bunkering-in-niger-delta-the-ojumole-case-study/> (Accessed 23 March, 2020).
- Tiefenbacher, J. P. 2013. Natural Hazards and Risk. <https://www.oxfordbibliographies.com/view/document/obo-9780199874002/obo-9780199874002-0082.xml> (Accessed 20 April, 2020).
- Tuodolo, F. 1998. Shell FIRE: Unrepentant Shell Sets Another Forest Ablaze (Era Field Report # 15). <https://www.essentialaction.org/shell/era/eraField15.html> (Accessed 23 March, 2020).
- Udoh, J. C., Ekanem, E. M., 2011. GIS based risk assessment of oil spill in the coastal areas of Akwa Ibom State, Nigeria. *African Journal of Environmental Science and Technology*, 5(3): 205-211.
- UEA-CRU (University of East Anglia-Climatic Research Unit), Harris, I. C., Jones, P. D., 2019. CRU TS4.03: Climatic Research Unit (CRU) Time-Series (TS) version 4.03 of high-resolution gridded data of month-by-month variation in climate (January 1901 December 2018). Centre for Environmental Data Analysis, 15 May, 2019. doi:10.5285/58a8802721c94c66ae45c3baa4d814d0. (Accessed 23 March, 2020).
- Umana, K., 2018. Causes and Sources of Oil Spillage in Nigeria. <https://researchcyber.com/causes-sources-oil-spillage-nigeria/>(Accessed 23 March, 2020)
- UNEP, 2011. Environmental Assessment of Ogoniland. Nairobi, United Nations Environment Programme. [www.unep.org/nigeria](http://www.unep.org/nigeria). (Accessed 20 April, 2020).
- United Nations Institute for Training and Research, UNITAR, 2019. Introduction to Geospatial Information Technology for Disaster Risk Management. Retrieved on 20th April, 2020 from <https://www.unitar.org/event/full-catalog/introduction-geospatial-information-technology-disaster-risk-management>
- United Nations, 1997. Glossary of Environment Statistics, Studies in Methods, Series F, No. 67, United Nations, New York, 1997. <https://stats.oecd.org/glossary/detail.asp?ID=1902> (Accessed 23 March, 2020).
- Vethamony, P., Kotteppad, S., Babu, M. T., SEELAM, J. K., Murali, M., Saran, A. K., Sharma, L. H., Rajan, B., Srivastava, M., 2007. Trajectory of an oil spill off Goa, eastern Arabian Sea: Field observations and simulations. *Environmental Pollution*, 148: 438-444.
- Wang, Y., 2013. Study of oil-spill diffusions on marine environments. Edited by Wen-Pei Sung, Jimmy C. M. Kao and Ran Chen. *Environment, Energy and Sustainable Development* (CRC Press), 2013: 865-868.
- Whanda, S. J., 2014. Mapping oil spill human health risk in rivers state, Niger Delta, Nigeria PhD Thesis, University of Nottingham, Nottingham, UK. [http://eprints.nottingham.ac.uk/14115/1/Shittu\\_PhD\\_Thesis\\_%282014%29.pdf](http://eprints.nottingham.ac.uk/14115/1/Shittu_PhD_Thesis_%282014%29.pdf) (Accessed 23 March, 2020).
- Whanda, S., Adekola, O., Adamu, B., Yahaya, S., Pandey, P., 2016. Geo-Spatial Analysis of Oil Spill Distribution and Susceptibility in the Niger Delta Region of Nigeria. *Journal of Geographic Information System*, 8, 438-456. doi: 10.4236/jgis.2016.84037.



- Wizor, C. H., Eludonyi, S. O., 2020. Analysis of the Socio-Economic Impact of Oil Spills in Gokana Local Government Area of Rivers State, Nigeria. *International Journal of Research and Scientific Innovation*, 7 (2): 79 – 86.
- Zanier, G., Palma, M., Petronio, A., Roman, F., Armenio, V., 2019. Oil Spill Scenarios in the Kotor Bay: Results from High Resolution Numerical Simulations. *Journal of marine science and engineering*, 7 (54): 256 – 278.