Geomatics Support View in Flood Control and Watershed Management Within the Niger Delta Region of Nigeria

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Key words: Flood management, Digital Elevation Model, Watersheds, IFSAR, GNSS RTK

SUMMARY

The Niger Delta region is a low-lying area consisting of several tributaries of the Niger River and ending at the edge of the Atlantic Ocean. It consists of several creeks and estuaries as well as stagnant mangrove swamps. The region has an area of approximately 20,000 km^2 and a 450m coastline. Nigeria's economy depends predominantly on oil and gas from the region as the main source of foreign revenue. Rise in sea level is a major problem for the Niger Delta as sea level rise creates inundation due to coastal flooding by incoming rivers.

The Niger Delta region has been experiencing recurrent flooding especially in the low lying areas along the Niger River and its tributaries as well as far east to the Calabar river. The Federal Government attempted some mitigation measures after the 2012 flooding but these were only palliatives. Knowing these problems, it is necessary to embark on flood forecasting and develop watershed management programs.

The aim of the study is to improve on the mechanism for the protection of people and properties from flood events and create a sustainable environment for the utilization of land and water resources. The study focuses on DEM generation using IFSAR Sentinel 1A/B TOPS satellite mission for watershed delineation and flood zoning of the study area. The Digital Elevation model (DEM) generation was derived through radar interferometry, utilizing the phase difference between the representations of the interferometric pairs of Sentinel 1 single look complex (SLC) scenes. The Interferometric Wide (IW) swath mode acquires data with a 250km swath at 5m X 20m spatial resolution (single look). It captures three sub-swaths using the Terrain Observation with progressive scans SAR (TOPSAR) acquisition principle. Thirty-seven (37) interferometric pairs of the Sentinel 1A/B acquired from January 2016 to September 2019 (4years) obtained from the European Space Agency (ESA) were used in this study. The Digital Elevation Models generate were validated from GNSS RTK results. Based on the generated DEM, watershed and sub-watersheds were delineated. Slopes and aspects were determined for flood mitigation planning and management.

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1. INTRODUCTION

Flood is among the most devastating natural hazards in the world claiming lives and properties more than any other natural phenomena (Alcira and Martha, 1991; Ologunorisa, 2006; Ehiorobo, 2012; Izinyon and Ehiorobo, 2014.) Within the Niger Delta region, human population increase, landscaping in paved areas, stream and channel obstruction due to bad waste disposal habit and other human activities at flood plains were considered to be the major causes of floods. Flood vulnerability mapping can offer appropriate security against floods. Rapid population growth create extra presure on land in urban areas, agriculture lands give way to housing development and roads without adequate drainage facilities give rise to flooding and erosion problems (Ehiorobo et al 2010). The intensity and amount of rainfall in recent times has resultedd is some of the most significant fooding and erosion experienced within the Niger Delta region in the last years. With climate change, heavy and damaging storms will continue to increase in frequency. Temperature also has an effect on vegetative materials which are used as mulching to control erosion (Ehiorobo and Izinyon, 2011). A watershed is simply the land that flows across or through on its way to a common stream, river, or lake. A watershed can be very large (e.g draining thousand of square kilometers to a major river or lake or the ocean), or very small. A small watershed that nest inside of a large watershed is sometimes reffered to as a sub watershed. As rainwater or melted snow runs downhill in the watershed, it collects and transport sediment and other materials and deposit them into the receiving water body. Watershed management is a term used to describe the process of implementing land use practices and water management practices to protect and improve the quality of the water and other natural resources within a watershed by managing the use of those land and water resources in a comprehensive manner. Watershed management planning is a process that results in a plan or a blueprint of how to best protect and improve the water quality and other natural resources in a watershed. Very often, watershed boundaries extend over political boundaries into adjacent municipalities and/or states. That is why a comprehensive planning process that involves all affected municipalities located in the watershed is essential to successful watershed management.

Runoff from rainwater can contribute significant amounts of pollution into the lake or river. Watershed managernent helps to control pollution of the water and other natural resources in the watershed by identifying the different kinds of pollution present in the watershed and how those pollutants are transported, and recommending ways to reduce or climinate those pollution sources. All activities that occur within a watershed will somehow affect that watershed's natural resources and water quality. New land development, runoff from already-developed arcas, agricultural activities, and houschold activities such as gardening/lawn care, septic system usc/maintenance, water diversion and car maintenance all can affect the quality of the resources within a watershed. Watershed management planning comprehensively identifies those activities that affect the health of the watershed and makes recommendations to properly address them so that adverse impacts from pollution are reduced. Watershed management is also important because the planning process results in a partnership among all affected parties in the watershed. That partnership is essential to the use of the land and water resources in the watershed since all partners have a stake in the health of the watershed. It is also an efficient way to prepare the location of watershed management plans in times when resources may be limited. Because watershed boundaries do not coincide with political boundaries, the locations of adjacent municipalities upstream can have as much of an impact on the downstream municipality and water resources as these actions carried out locally Impacts from stream sources can sometimes undermine the efforts of downstream municipality to control pollution Comprehensive planning for the resources within the entire watershed with participation and commitment from all municipalities in the watershed, is critical to protecting the health of the watershed resources. Comprehensive watershed plans should first identify the characteristics of the watershed and inventory the watershed's natural resource it is important to establish a scene of the overall nature and quality of the watershed in order to plan properly for the improvement of the resources in the watershed and to actually measure those improvements.

The first steps in watershed management planning are to:

- Delineate and map the watershed's boundaries and the smaller drainage basins within the watershed;
- Inventory and map the resources in the watershed
- Inventory and map the natural and manmade drainage systems in the watershed
- Inventory and map land use and land cover,
- Inventory and map soils;
- Identify areas of erosion, including stream banks and construction sites;
- Identify the quality of water resources in the watershed as a bascline, and
- Inventory and map pollution sources, both point sources (such as industrial discharge pipes) and nonpoint sources (such as municipal storm water systems, failing septic systems, illicit discharges).

Watershed planning should also identify and include the partners, or ”stakeholders” in the watershed. Development of local partnerships can also lead to greater awareness and support from the general public. Once individuals become aware of and interested in their watershed, they often become more involved in decision-making as well as hands-on protection and restoration efforts. Through such involvement, watershed management builds a sense of community, helps reduce conflicts, increases commitment to the actions necessary to mcct environmental goals, and ultimately, improves the likelihood of success for the watershed management plan.

1.1 DESCRIPTION OF THE STUDY AREA

The Niger Delta region is about 500km fron the mouth of Benin River to Imo river in the East. This mangrove swamp is essentially vegetated tidal flat and best vegetation along the Nigeria Coast (Ibe 1995). The area spans over 20,000km^2 and it has the largest wetland in Africa and among the three largest in the world. It is the second largest delta in the world. About 2,370km^2 of the Niger Delta area consist of rivers, creeks and estuaries with stagnant swamps covering over 8,600km^2 (Uyigue et al 2007). The region is divided into four ecological zones: Coastal inland zone, Mangrove Swamp zone, Fresh water zone and lowland rainforest Zone. The region is one of the ecological sensitive regions in Nigeria. Non-renewable resources such as sharp sand, gravel, oil and gas from the region are the main sources of revenue and environmental problems in Nigeria. The Niger Delta region is a low-lying area consisting of several tributaries of the Niger River and ending at the edge of the Atlantic Ocean (Fig 1). Nigeria's economy depends predominantly on oil and gas from the region as the main source of foreign revenue.

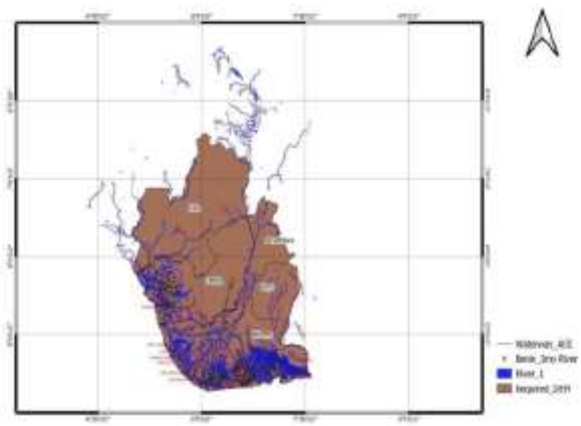

Figure 1.: Study Area

Rise in sea level is a major problem for the Niger Delta as sea level rise creates inundation due to coastal flooding by incoming rivers. Relative sea level rise values are usually higher in subsiding coasts like river deltas than the ones in stable coastal rivers (Musa et al, 2014) Although subsidence occurs relatively in deltas, in the case of Niger Delta, it is increased even more by oil extraction from underground sources (Erickson et al, 2006).

The extraction of oil and gas has increased land subsidence in the Delta, with values estimated to range from 25 - 125mm per year (Syvilski, 2008). Land subsidence lowers the topography of delta area with respect to the sea level and makes the area highly vulnerable to river floods. Other environmental problems include sediment reduction to the Niger Delta region as a result of the construction of Dams upstream of the Niger River. Since deltas are replenished by upstream sediments supply, this condition makes the Niger Delta vulnerable to flooding and coastal crosion with the attendant land loss (IPCC, 2007)

The Niger Delta zone experiences a tropical climate consisting of raining season (April - October) and dry season (November - March) with diumal temperature as high as about 35 and relative humidity not lower than 60% in the main. Mangrove swamps are predominant and flourishing in the region. Wetlands are major habitats in the Niger Delta which support vegetation that is adapted to continuous water logging Mmom and Chikun-Okah (2011).
The estimated total area of wetlands in the Niger Delta is about (1,794,000 Hectares of fresh water swamps (ONEST, 1991).
The Niger Delta region has been experiencing recurrent flooding especially in the low lying areas along the Niger River and its tributaries as well as Far East to the Calabar River. The Federal Government attempted some mitigation measures after the 2012 flooding but these were only palliatives.(Ehiorobo 2012)

2.0 FLOOD CONTROL AND WATERSHED MANAGEMENT USING GEOINFORMATION TECHNOLOGY

Flood is among the most devastating natural hazards in the world claiming lives and properties more than any other natural phenomena (Alcira and Martha, 1991; Ologunorisa, 2006; Ehiorobo, 2012; Izinyon and Ehiorobo, 2014). Within the Niger Delta region, human population increase, landscaping in paved areas, stream and channel obstruction due to bad waste disposal habit and other human activities at flood plains were considered to be the major causes of floods. Flood vulnerability mapping can offer appropriate security against floods. Rapid population growth create extra presure on land in urban areas, agriculture lands give way housing development and roads without adequate drainage facilities give rise to flooding and erosion problems (Ehiorobo et al 2010). The intensity and amount of rainfall in recent times has resultedd is some of the most significant fooding and erosion experienced within the Niger Delta region in the last years. With climate change, heavy and damaging storms will continue to increase in frequency. Temperature also has an effect on vegetative materials which are used as mulching to control erosion (Ehiorobo and Izinyon, 2011)

2.1 FLOOD CONTROL AND MANAGEMENT

Flood disaster management just as other disasters management can be grouped into (i) the preparedness phase where activities such as prediction and risk zone identification or valnerable mapping are undertaken up long before the event occurs; (ii) the prevention phase where activities such as forecasting, early warning, monitoring and preparation of contigency plans are done just before or during the event and (iii) the response and mitigation phase where activities are undertaken just after the disaster and it includes image assessment and relief management (Van Western et al., 1993; Ehiorobo, 2012)

To acquire information for flood management and control and identify areas that are vulnerable to flooding, reliable techniques of collecting and analyzing geospatial information are required. In this regard, an integrated approach of Remote Sensing (RS) and Geopgraphics Information System (GIS) has proved to be the most effective and perhaps the only option to flood hazard preparedness and to reduce potential risk. This will be part of a larger, long term effort to gain a better understanding of community vulnerable on the floodplains and low elevated areas to flood hazard. (Ehiorobo and Akpejiori 2016, Akpejiori and Ehiorobo 2017)

Geo-informatics technology plays a major role in Humanitarian Emergency Response Management as well as Disaster Mnanagement. Map; positions and other atribute about region can be captured, stored, update and easily retrieved through the medium of the computer. The Global Positioning System (GPS), Remote Sensing and Geo-spatial information System (GIS) can be integrated for quich results and improved decision- making vis-å-vis disaster management. (Ehiorobo and Audu, 2006)

GIS technology is a valuable tool in developing environmental models and they include space and time as a common denominator and also possess advanced features for data storage, management analysis and display. Geoinformation technologies aside from being used to integrate various models also enable us to acquire information about the environment. Remote sensing technology provide land use and land cover images which when combined with ground survey data by GPS and Total station instrument enable us to model flood event and other environmental hazards. The integration of these various Geoinformation technologies does not only enable us to estimate soil loss but they provide the spatial distribution of the flood and erosion sites. Accurate erosion risks and sensitivity index maps can be generated by the system (Yuksel et al 2008, Ehiorobo et al 2010)

2.2 WATERSHED MANAGEMENT

Watershed management are increasingly reliant on informmation Technology. Recent advances in dara acquisition through remote sensing,Global Navigation Satelite System (GNSS), data utilization through GIS and data sharing and communication through the internet and the use of models woud provide managers with the needed tools for informed decision.

New technologies such as interferometre Synthetic- Aperture Radar (IFSAR) are proviling data with greater spatial resolution now increase our capacty to aralyze and predict water resources phenomena.

Effective watershed decision making requires the integration of Data, expert judgnent, knowledge and simulation model to solve practical problems. A decision support system that integrate Database Maragemers System (DIMS). GIS, Simulation model, Decision models and Computer interface are needed. Digital Elevation model (DEM) are used as input for the spatial decision support system.

Field survey data by GNSS and Total Station Instrument can be used to evaluate error in the DEM. For different DEMs, watershed and stream networks are delineated and derived parameters from these delineation are compared using different watershed complexities and sizes. The values to be used for comparison should be based on hydrologic model parameters and this will usually include total watershed area, number of channel segments, mean channel lenght, mean channel slope, number of upland plane elements, mean upland plane area and mean upland plane slope. Within the Niger Delta Basin for instance along the Nun and Forcados River, erosion control upland to reduce sediment delivery to channels will affect downstream water supply

The watershed management plan should be such as will minimize costs and have a low erosion and sediment yield from a defned watershed. All these activities are based mainly on Geomatics measurements and analysis.

In general, the main input data will be topography, soil and land cover. However the general spatial data will also include hydrography Digital Elevation Models, Land cover Data and Population data. A typical case study is the on going research project on Flood Frequency Analysis and Watershed Management within the Niger Delta region by Ehiorobo and his Team.

A major advance in data generation, preparation and management is in the use of Geospatial technologies such as Geographic in Information System (GIS), Global Navigation Satelite System (GNSS), and Remote Sensing.

In term of watershed modelling, a typical model preparation would include the use of Remotely Sensed data for the extraction of Terrain Canopy data or the use of Digital Terrain Model (DTM) or Digital Elevation Model (DEM) data for extraction of hydrologic catchment properties such as Elevation Matrix and Flow direction Matrix, ranked elevation matrix, flow accumulation matrix.

Work done by Prodamovic et al 2009, Maidment 2002 utilized DEM-based GIS algorithms to improve DEM data accuracy and usability.

When Digital data are used for hydrologic modelling, they offer the following data evaluation procedures to improve accuracy and usability (Edsel et al 2011)

a) They help check what percentage of the area that has slope of 0%
b) Use of the surface flow routing to check whether water will flow across the watershed area if arbitrary point source is selected
c) Check of the orientation and interconnection of the stream network
d) Use of stream as ”cut out” across DATUM and check whether the slope of a longitudinal section towards the lowest exit node is continous.

In many instances in places such as the Niger Delta region, there is limited or no data available for the watershed. GIS automated tools based on geostatistical interpolation techniques for instance using inverse distance weighting or Kriging after improved options for generating new DEMs, data sets from points and contour data sets. Example of previous related studies using Kriging includes those by Filopo et al 2007, Frei et al 2009, Tague and Polil-Costello (2008)

As a first step in the study, the Digital Elevation Model (DEM) for the study area was obtained from the Shuttle Rader Topography Mission database (SRTM) at a spatial resolution of 30m with the use of Google Earth Engine interface. This was then used to delineate the sub-watershed of the lower Niger Delta River Basin and extract major streams within the area (using ArcHyro extension in ArcGIS). The DEM with the defined streams and the delineated sub watersheds is shown in Figure 2.

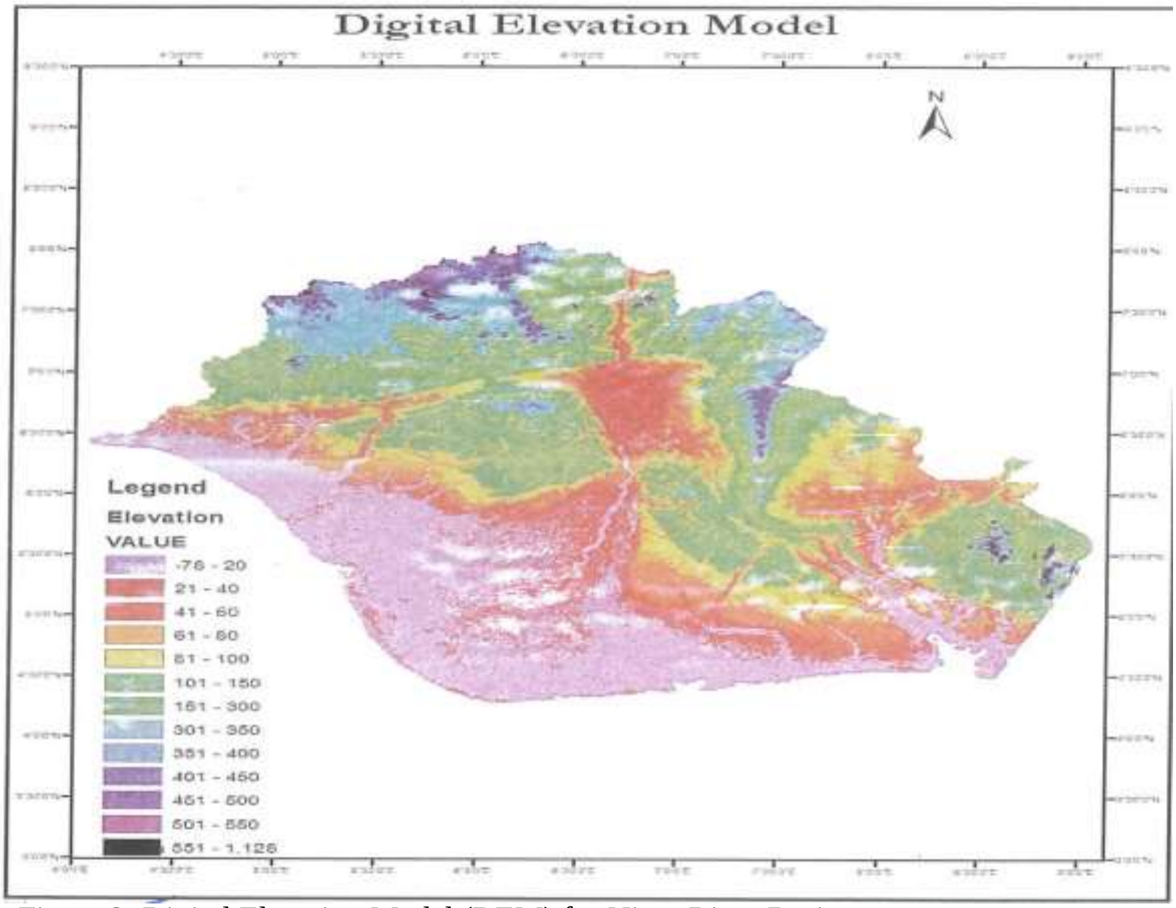

Figure 2: Digital Elevation Model (DEM) for Niger River Basin

3.0 ACQUISITION, PROCESSING AND GROUND THRUTHING/ VALIDATION OF IFSAR IMAGERIES FOR WATERSHED DELINEATION AND FLOOD MANAGEMENT.

3.1 IFSAR derived Digital Elevation Model (DEM) from Sentinel 1A/B for Flood FrequencyAnalysis and Watershed Management.

This section focuses on DEM generation using IFSAR Sentinel 1A/B TOPS satellite mission for watershed delineation and flood zoning of the study area. The Digital Elevation Model (DEM) generation was derived through radar interferometry, utilizing the phase difference between the representations of the interferometric pairs of Sentinel-1 Single Look Complex (SLC) scenes. The Interferometric Wide (IW) swath mode acquires data with a 250km swath at 5m x 20m spatial resolution (single look). It captures three sub-swaths using the Terrain Observation with Progressive Scans SAR (TOPSAR) acquisition principle.

3.1.1 The Sentinel 1A/B data

Thirty-seven (37) interferometric pairs of the Sentinel 1A/B acquired from January 2016 to September 2019 (4years) obtained from the European Space Agency (ESA) were used in this study. Table 1 describes the characteristics of the SAR dataset used in the processing and generation of DEM image.

Table 1 SAR characteristics

Satellite	Periods of Data Acquisition	Freq. Band	Polarization	Cycle and Days	Altitude (km)	Look angle, deg	Swath width IW (km)	Resolution (m)
Sentinel-1A and 1B	2016 to 2019	C	Dual	12	693	20-45	400	2

Figure 3: Sample of Interferometric Wide (IW) swath of the study area

The design procedure is guided by the aim of the project, study area and data coverage/type. The months of January and September were chosen as periods with low and high-water levels across the study area and used in the processing.

The number of RTK GNSS control points for DEM Ground Truthing/validation established per States is presented in Table 2

Table 2 RTK GNSS control points for DEM Ground Thruthing / validation per state

State	No. of points
Edo	16
Delta	20
Bayelsa	25
Rivers	20

3.1.2 Data Processing

The Multi-date data processing technique was adopted because of coverage of the Interferometric Wide swath (Khosravi et al., 2019). This is because of the temporal analysis or change detection over the area of interest.

The processing workflows are provided in Figure 4

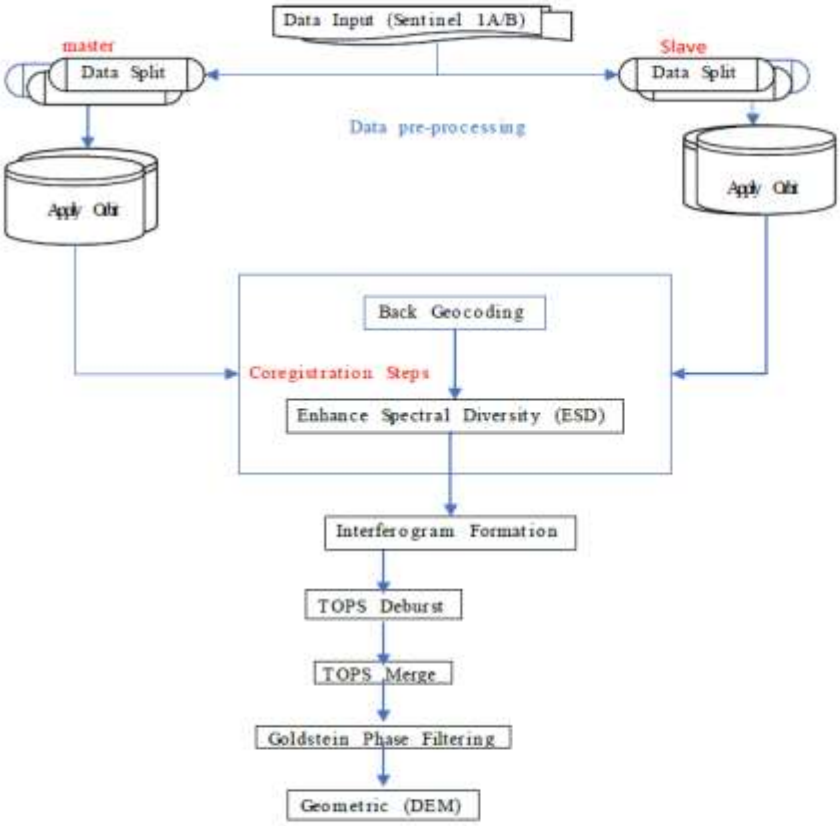

Figure 4: Data Processing Workflow

The First Step in The Data Processing Process of the Data Input

It involves reading the data set in software processing environment. The data were imported in step as a master or a slave image. Figure 5 shows a screen shot of the imported data into the processing environment.

The detailed work flow process are presented in Fig. 4

The final out put which is the DEM of the study area, the Niger Delta Region of Nigeria in the software environment are presented in fig 6 and 7

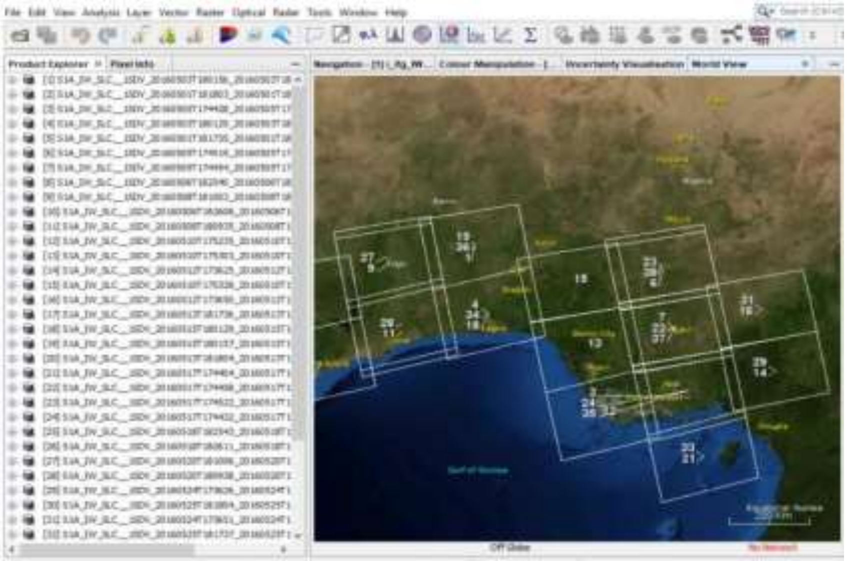

Figure 5: Data input

The DEM produced in the software environment is presented in Figure 6 while the DEM derived from 2019 images imported into the Google Earth engine is shown in Fig 7

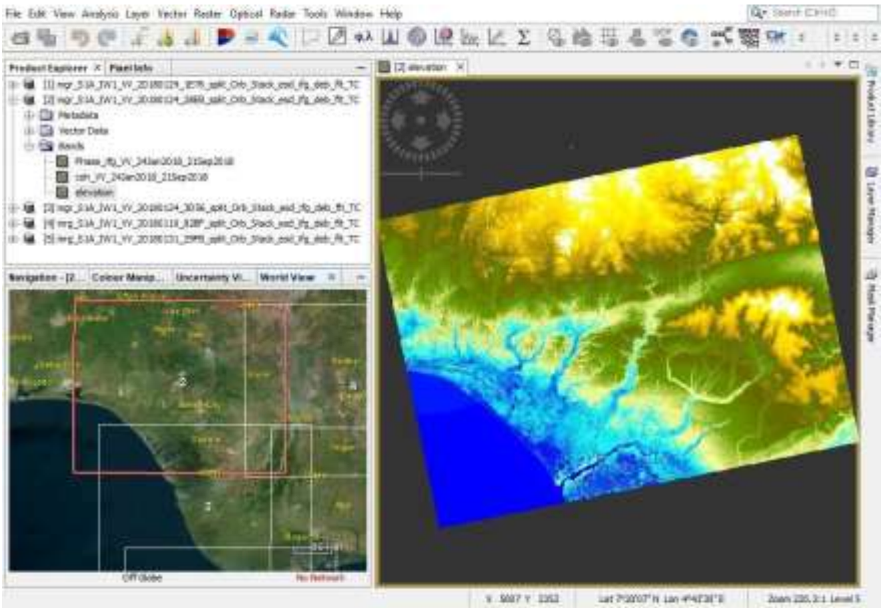

Figure 6: The DEM of the study area in the software environment.

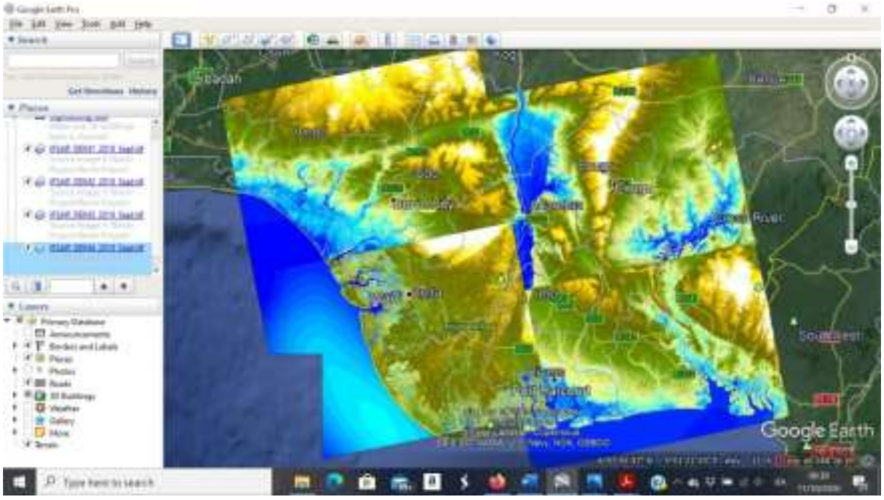

Figure 7: September 2019 DEM of the Study area imported into Google Earth

4.0 CONCLUSIONS

The Niger Delta region is a low lying area crisscrossed **by series of** Creeks and Rivers. As a result of sea level rise, there is inundation of the coastal area and this give rise to coastal flooding. This has resulted in environmental disaster within the study area resulting in loss of lives and properties. It has become therefore expedient to carryout continuous studies of the area and develops measures for flood control and watershed management. Geoinformation Technology (Geomatics) consisting of a combination of Satellite Remote Sensing, GIS and Ground Survey methods using GNSS are important tools for such studies. Flood Zone Mapping and Watershed Delineation using DEM generated from SRTM obtained from Google Search engine were used for preliminary watershed delineation. Further work is ongoing in the continuous IFSAR imagers to generate more accurate DEM for the study area. The DEM and Flood Zone maps will help in carrying out flood control, Flood preparedness and management as well as appropriate watershed delineation for effective planning and management. As part of the watershed management process, water sampling need to be carried out and the sample point need to be Geo-referenced. Land use and land cover maps need to be produced for watershed development planning. It is anticipated that this study will help significantly in improving the socio-economic wellbeing of the people living within the study area. Geomatics support is an essential and veritable tool necessary for flood control and watershed management within the study area.

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