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DEVELOPMENT OF INUNDATION MAP FOR HYPOTHETICAL ASA DAM BREAK USING HEC-RAS AND ARC GIS

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Abstract
Asa Dam in Ilorin, Nigeria was constructed in the1980s. The dam made of earth material has a length of 507 meters and height of 27 meters. The maximum capacity of the impoundment during the raining season is approximately 43 x 10^6 m^3. Years after construction, tremendous physical development is taking place along the river channel starting from the dam axis towards downstream for a distance of approximately 12 km. It is estimated that several thousands of people are currently living and performing various activities within the vicinity of the river channel. It is therefore necessary to evaluate the risk involved in case of a possible dam break disaster. In view of this, a hypothetical dam break scenario was studied and analyzed using Hydrologic Engineering Center's River Analysis System computer model. Unsteady flow simulation was performed using geometric data obtained from Digital Terrain Model with 100-year, 24 hr flow event. The HEC-RAS was used in concert with HEC-GeoRAS to assess the flood hazard along the approximately 12 km river channel. The simulated water surface elevations were exported to Arc GIS to produce an inundation map that graphically indicates the extent of the flood hazard. The results show that some important locations such as industrial, residential, motor parks, recreational and places of worship along the river length are prone to significant flood impact. This map serves as an input for emergency preparation programme in the event of the dam break.

Keywords: Dam Break, Computer Model, Flood Hazard, Inundation Map, River Channel

1.0 Introduction

Dam provides many benefits for the society, but floods resulting from the failure of constructed dams have also produced some of the most devastating disasters of the last two centuries (Xiong, 2011). Dam failure is of particular concern because it rarely occurs but its occurrence may be very catastrophic which cause more deaths and destruction than the failure of any other man-made structure. This is because of the inherent destructive power of the flood wave that would be released due to the sudden collapse (Wrachian and Mambretti, 2009). A dam may be susceptible to failure from multiple causes depending on the type of dam and site-specific locations. Some of the causes: are overtopping, piping or seepage, structural overstressing of dam components, surface erosion from high velocity and wave action, internal erosion, earthquake and seismic failures (FEMA, 2013). The above causes lead to problems as a result of dam break occurrence. Thus, some of the prominent problems are loss of humans and animals, property damages and economic losses, and environmental damages when the reservoir contains materials that are deleterious to human or aquatic life habitat.

The history of dam failure events span over several decades. These could be found in almost every part of the world. Some of the recent and well known occurrences of dam failure are Germano mine tailings dam located in Minas Gerais, Brazil, November, 2015 due to an unknown cause, on leashing a massive flood of mud, water and debris on the downstream community (The Wall Street Journal, 2015). Ka Loko dam located in the northeast section of the Island of Kauai in Hawaii (USA) failed in 2006 as a result of overtopping (Godbey, 2007), Igabi dam in Kaduna State failure as a result of overflow of its banks, which submerged several streets and housing estates (Etiosa, 2006) and Ojirami dam located at Akoko Edo in Edo State, failed due to technical breakdown in 1980 which inundated Akuku and Enwan communities (Hope, 2003 and Etiosa, 2006).

Several researchers have compared one and two-dimensional hydraulic models developed by various institutions and research centres which include HEC-RAS, SOBEK, MIKE 2 and FLO-2D for dam break analysis (Fosu *et al.*, 2012). HEC-RAS was chosen for this study based among other reasons on the fact that it is an open source application and its geometric data input and simulation can be performed in arc GIS environment. Some of the past HEC-RAS applications are analysis and modeling of hypothetical dam breach inundation of Pinaus Lake Dam and Cold Spring Creek Dam in Canada by (Ahmad *et al.*, 2014). The analysis estimated the inundation levels resulting to damages of downstream communities and potential loss of life, (Changzhi *et al.*, 2014) determined the flood inundation extents and the break velocities of a hypothetical failure of the Muya reservoir dam in Shandong Province, China. The result indicated that most of the urban area would be flooded and a plan for integrated dam break flood management was presented to mitigate the food risk.

As the world population is increasing, it is certain that a large number of home structures may be built in flood prone areas due to lack of proper guidance (Walker and Maidment, 2006). Since the construction of the Asa dam in 1984, it has been observed that a lot of physical developments are taking place within the flood plain along the downstream section. There are many private residential, commercial as well as religious houses, farms, industries, bridges and roads which have the potential of being completely inundated or at least in some way adversely affected by the catastrophic flooding that may result from the failure of Asa Dam. This study provides a realistic view of using arc GIS analysis and its display capabilities combined with hydraulic modeling tools to develop flood inundation map. HEC-GeoRAS was used to extract geometric information from a digital terrain model and provide the tools to develop and modify HEC-RAS model simulation as well as to perform flood extent mapping analysis. The hydraulic modeling results were displayed in map using Geometric Information System which is currently the most widely used tools in the management of floods.

1.1 The Study Area

Asa River has its source in Oyo State, South-West Nigeria and it flows through Ilorin, capital of Kwara State, Nigeria in a South-North direction forming a dividing boundary between the eastern and western parts of Ilorin metropolis. Asa River major tributary is River Awon, which continues to form one of the tributaries of River Niger at approximately 12.2 km North of Ilorin. River Asa is joined by River Oyun to the East and to the West by River Imoru. Afidikodi, Ekoro, Obe are among the earliest tributaries of Asa River while its tributaries in Ilorin include River Agba, Aluko, Atikeke, Mitile, Odota, Okun and Osere (Ojo, 1998 and Ibrahim *et al.*, 2013). The Asa Dam is located between latitudes 8°36′N and 8°24′N and longitudes 4°36′E and 4°10′E in Ilorin. The River is approximately 56 km long with a maximum width of approximately 100 m within the dam site. Its total catchment area is approximately 1037 km^2 lying within Kwara State and Oyo State of Nigeria with about one third of the basin area located in Oyo State (Okekunle, 2000).

The Asa River channelization corridor is characterized by many significant features, among which include the downstream of the Asa Dam. Generally, the Asa river channelization can be divided into six (6) main consistent sections with about four significant features of water reservoir, bridges and culverts and the extent of urbanization (Balogun and Ganiyu, 2017). The various segments are (i) From Asa Dam axis to Asa Dam Road/Dangote Factory Crossing, (ii) River Course from the Dam Crossing to the Bridge at Geri Alimi/Offa Garage Bye Pass, (iii) The Stretch between Geri Alimi Bye pass and Unity Road Bridge (Coca Cola Axis) (iv) Stretch between Unity Road Bridge and Emir's

Road (Behind the Railway station) (v) Emir's Road/Amilegbe Stretch* and (vi) The stretch from Amilegbe and beyond to Duma. Asa River is a very significant source of water in terms of economic, agricultural and environmental purposes in the city as it is used in homes and industries (Ahaneku and Animashaun, 2013). There are farmlands, residential and industrial buildings along the banks of the river upstream and downstream of the dam. Figure 1 is the map of Kwara State showing the Study Area (Inset: Map of Nigeria)

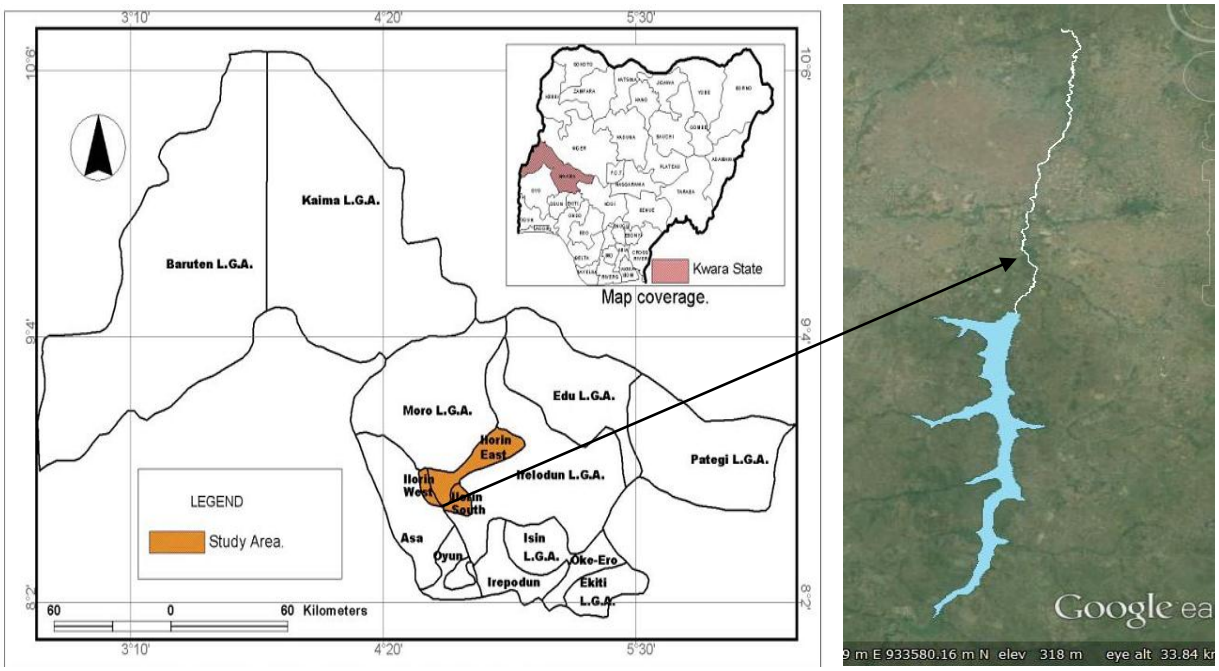


Figure 1: Map of Kwara State Showing the Study Area (Source: Olorunfemi and Raheem, 2013)

2.0 Model Development

The methodology used in this study consists of three steps: (i) Pre-processing of geometric data for the HEC-RAS computer program using HEC-GeoRAS (ii) Hydraulic analysis in HEC-RAS and (iii) Post-processing of the HEC-RAS results and floodplain (inundation) mapping using HEC-GeoRAS. Figure 2 shows the flow diagram for using HEC-GeoRAS which describes how the three processes listed above are being carried out:

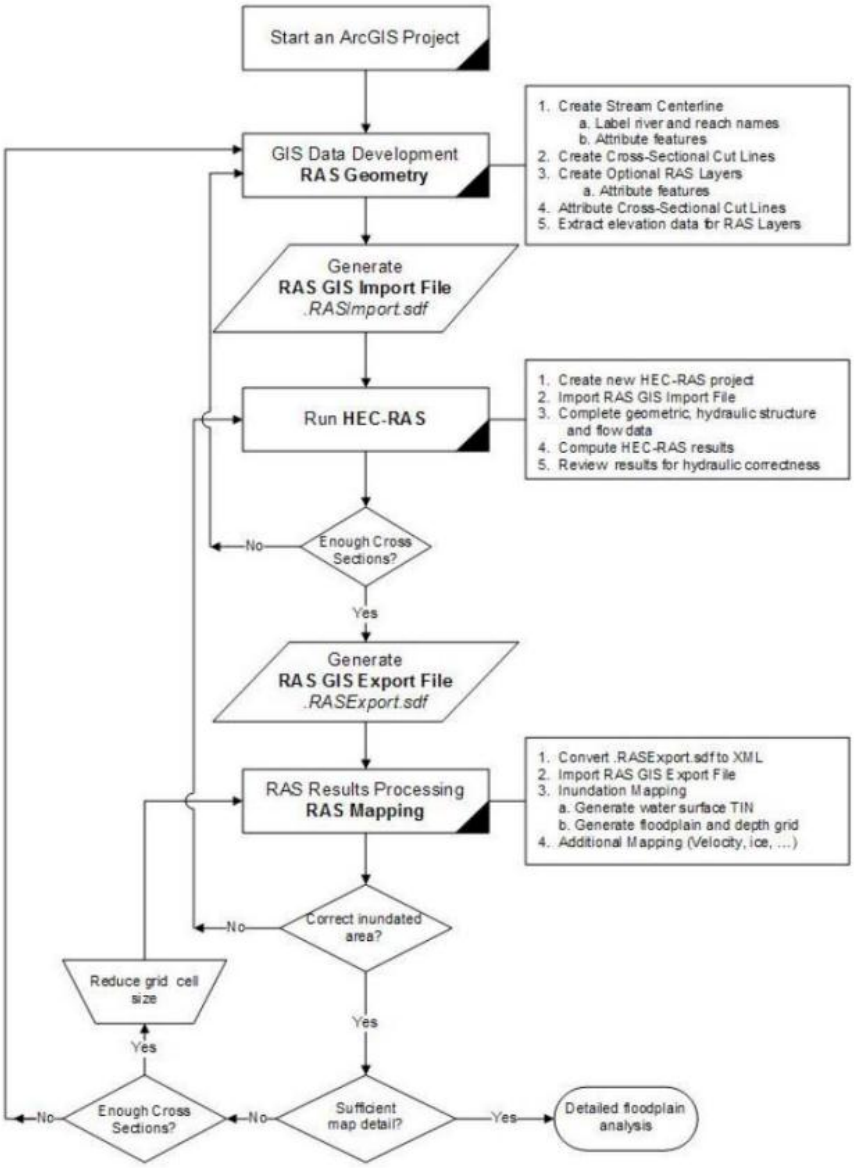


Figure 2: Flow Diagram Showing the Methodology Used (Source: Gary (2010))

3.0 Results and Discussion

In Table 1, column 2 lists the river stations, column 3 describes the locations, column 4 lists the computed water surface elevations in meters and column 5 lists the ground level elevations in meters. The water surface elevations (WSE) at the selected locations were extracted from the complete HEC-RAS results output and ground elevations were obtained from the lowest floodplain elevations at each of the listed river stations.

The simulation was modelled with 100 year 24 hr flow event data which was selected to illustrate severe event scenario. For the flow scenario investigated, the results show that at the industrial area where Coca-Cola and Pepsi factories are located, the computed water surface elevation (WSE) is 265.95 m with corresponding ground elevation of 262.62 m and WSE of 265.97 m with corresponding ground elevation of 262.11 m respectively, recreational centre, Circular Hotel has computed WSE of 265.94 m with corresponding ground elevation of 261.91 m, worship house, Church of Christ along Adura Lere Road has a computed WSE of 258.63 m with corresponding ground elevation of 257.54 m. In all these cases, the computed water surface elevations are higher

than the ground elevations which clearly indicate that the areas will be inundated during the dam break phenomenon.

Table 1: HEC-RAS Simulated Results at Some Selected Cross Sections Along Asa River Channel

S/No	River Station	Description of Cross Section Locations Along Asa River	W.S. Elev (m)	Ground Elev (m)
1	11+372	160 m away from the Dam	271.8	270.15
2	8+987	1.19 km away from Asa Dam Bridge	265.94	264.69
3	8+188	Along Coca Cola Factory	265.97	262.11
4	7+829	Along Pepsi Factory	265.95	262.62
5	7+430	Along Ash Asset Nigeria Limited	265.95	263.99
6	7+385	Residential Areas along Coca Cola Road	265.95	265.67
7	6+696	Along Circular Hotel	265.94	261.91
8	6+504	Residential Areas (250 m before Unity Bridge)	265.94	262.12
9	6+291	38 m close to Unity Road Bridge	265.93	264.58
10	6+238	15 m downstream of Unity Road Bridge	265.65	264.73
11	5+913	Residential Areas (530 m close to Emirs' Road Bridge)	265.64	264.65
12	5+635	Residential Areas (250 m close to Emirs' Road Bridge)	262.9	261.08
13	5+423	40 m close to Emirs' Road Bridge	263.02	261.89
14	5173	Confluence of Aluko Stream and Asa River (Along Iyana Opomolu Bus Stop)	262.81	261.04
15	4+680	280 m close to Amilegbe Bridge	262.43	261.67
16	4+486	85 m close to Amilegbe Bridge	258.84	257.34
17	4+243	160 m away from Amilegbe Bridge	258.79	257.28
18	3+977	Church of Christ along Adura Lere Road	258.63	257.54
19	3+517	885 m away from Amilegbe Bridge	258.03	257.00
20	2+968	1.43 km away from Amilegbe Bridge	257.96	256.17
21	2+037	1.64 km close to Royal Valley Estate Bridge	257.90	254.60
22	0+293	Royal Valley Estate	251.12	251.00

In addition to the table, Figure 3 shows the plot of water surface and ground elevations versus river station. It is clearly shown in the plot that the water surface elevation is greater than the natural ground elevation for some selected locations within the river length, which indicates that most of the areas will be inundated.

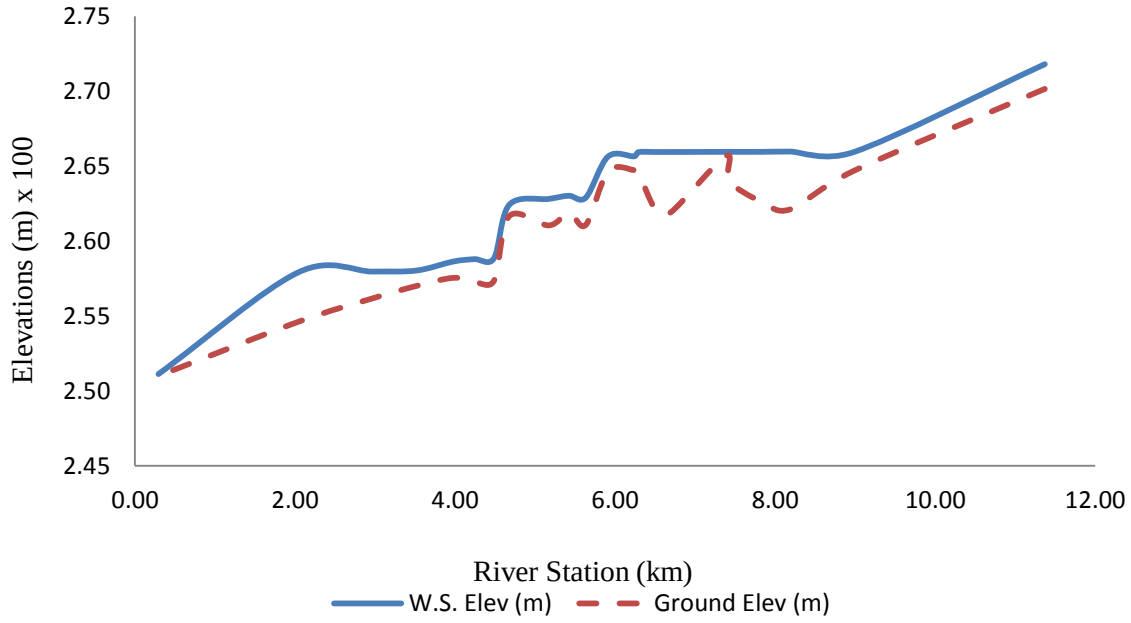


Figure 3: Plot of Water Surface Elevation and Ground Elevation versus River Station

3.1 Developing the Flood Inundation Map

Dam break flood inundation map is a graphic display that can be used to indicate areas that may be flooded as a result of dam failure. The map may be used by a wide range of end-users for planning and as a response tool to determine the effects of dam failure in downstream areas. For this study, flood inundation map was generated using HEC-GeoRAS and ArcGIS.

The floodplain result from the HEC-GeoRAS model of Asa River is shown in Figure 4. The floodplain boundary (b max.WS) is represented by the yellow line. The inundation depth grid is represented with different hues of blue. The largest and smallest values of water depth are represented with dark and light blue respectively.

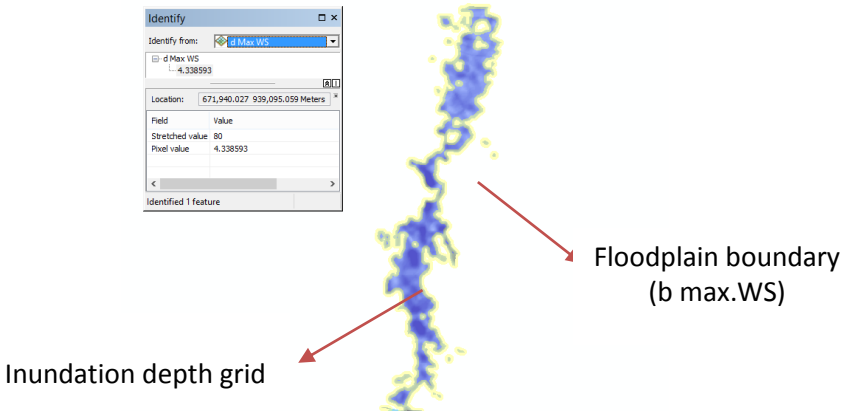


Figure 4: The Floodplain Delineation

Figure 5 shows the floodplain result of the study area in Google earth (inundation map) from the upstream to downstream of the channel indicating several areas that will be inundated. The inundation map indicates that extensive length of major roads such as Asa dam road, Unity road, Emirs' road and Amilegbe road would be inundated with the spread of water ranging between 120 m and 1.2 km in width under the dam break scenario considered. Some of these areas with their approximate values of extent of spread include: Coca Cola factory (800 m), Pepsi factory (720 m),

Honey Moon Hotel (720 m), Kasmag Bus Park (710 m), Young Legacy (460 m), Ilorin Railway Station (240 m), Iyana Opomalu Bus Stop (480 m) and Church of Christ along Adura Lere (610 m). Severe environmental damage would also be expected throughout the length of the downstream river channel and floodplain areas due to the size of the flood wave and expected inundation areas.

When the simulated results were studied critically, it was noticed that the flood polygon shows some flow discontinuities in some areas. This is because these areas have steep river beds which cause water to move quickly downstream preventing inundation. Also, some of the areas have high banks which serve as impedance to overflow.

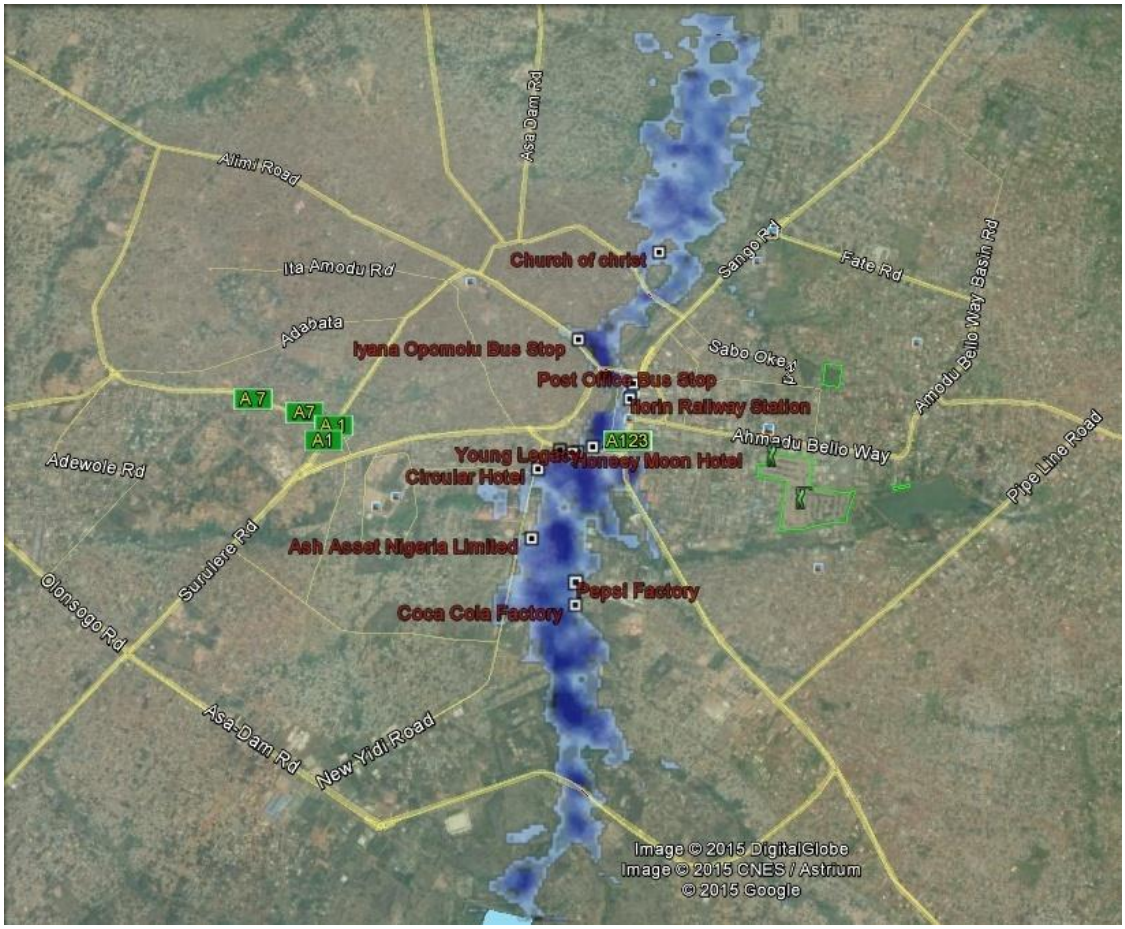


Figure 5: Inundation Map between the Dam Axis and along Adura Lere (Upstream to Downstream of the River Channel)

4.0 Conclusion

In this study, the flood inundation map was generated by HEC-GeoRAS (a tool box for ArcGIS™) and imported into Google Earth to delineate the areas flooded under the assumed dam break scenario. The outcome of the modelling showed that in the event of failure of Asa dam, some areas which include industrial and residential areas were identified to have very high risk of being inundated due to the significant difference in the value of water surface elevation and ground elevation. For example, at station 8+188 (Coca Cola Factory), the computed water surface elevation is 265.97 m while the corresponding ground elevation is 262.11 m or approximately 3.90 m elevation difference and at station 6+504 which is a predominantly residential area along unity road, the computed water surface elevation is 265.94 m while the corresponding ground elevation is 262.12 m or approximately 3.80 m elevation difference.

Due to the scenario described above, it was established that displacement of people from residential homes and commercial establishments located along the study area, such as business centers, recreational areas, industrial areas and worship places will occur. The inundation map was developed based on the extent of the water spread along the channel. The map is very useful as a tool to formulate an emergency rescue plan of the affected areas.

Recommendations

The following recommendations are proposed for future consideration.

1. Conduct additional study to investigate flood events that are of lower magnitude compared to the extreme event studied in this report.
2. In view of the on-going channel improvement project along the Asa River channel, it is important to perform these studies using the most current bathymetry data of the newly constructed channel.
3. Carry out investigation of practical implementation of the results of this study in assisting to prepare an emergency evacuation plan.

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