GEOGRAPHIC INFORMATION SYSTEM APPROACH IN EVALUATING SECURITY CHALLENGES TO CRITICAL INFRASTRUCTURES

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Abstract

In the past, criminality was a taboo and almost everybody franked at it and thus security challenges were so minimal or non-existent. Unfortunately it has now become a means of livelihood or a means to address disagreements where lives as well as critical infrastructures are destroyed mindlessly. While there are recognized occasional natural security challenges such as volcanic eruptions, Hurricane Katrina among others, most frequent security challenges are man-made organized and executed with cut edge professionalism and sophistication. Conventional methods and hence measures of monitoring and addressing various man-made security challenges have in the past been adopted by security operatives but criminals have always responded with sophisticated countermeasures and overwhelming successes maiming and massively in most cases destroying badly needed critical infrastructures. The intention of this research is to adopt Geographic Information System (GIS) approach, a real-time and speedy as well as reliable approach to address real-time security challenges to lives and critical infrastructures. In this method the study area was subdivided into geographic cells and an evaluation on each cell from some chosen observation posts were analyzed in a GIS environment to establish intervisibility to identified target location(s) which includes human habitations, critical infrastructures among others. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Digital Elevation Model (DEM) was used as the platform for Line-Of-Sight (LOS) and Viewshed Analysis (VA).Observation points were selected on both high and lowlands. Optimal observation posts including the target points together with their attribute details such as the X, Y, Z coordinates were obtained for rapid response to any security challenge. The results of the research showed that observations made on highlands produced more viewable areas than lowlands thus large critical infrastructures in the study area could be monitored from the identified optimal observation posts in a control room from where stationed strike force could be directed to confront any observed security challenge at the identified target location(s).

Keywords. Critical Infrastructure, Digital Elevation Model, Geographic Information System, Line-Of-Sight, Security challenge, Viewshed Analysis.

1. INTRODUCTION

Infrastructure is defined as the basic facilities, services, and installations needed for the functioning of a community or society, such as transportation and communications systems, water and power lines, and public institutions including schools, post offices, and prisons (American Heritage Dictionary [AHD], 2015). Critical Infrastructures are the necessary systems essential for effective functioning of an organization, a society or a nation. According to Executive Order (EO) 13010, Critical infrastructures includes the following: Telecommunication; electricity generation, transmission and distribution; security services – Police, Military, rescue and other security arms; Public health - hospital and others; water supply system; financial services – banking and finance, clearing; agricultural production lines – food production, processing and distribution; transportation systems – airports, seaports, railway network; energy, continuity of government ; among others (John and Paul, 2004). While these assets are the reason for the survival of a nation or an organization, they are what terrorists have their eyes on to destroy thus posing a continuous security challenge no nation or organization can ignore. Terrorism is a serious global security challenge affecting even the well prepared Nations.

In Nigeria, serious security challenges have been and are being experienced in almost all the thirty six states, including Abuja, Nigeria's capital. The first case of bomb blast in Nigeria was in 1986 when the Editor-In-Chief, Dele Giwa of Newswatch Magazine was killed by a parcel bomb. Apart from other several occasional bomb blast incidences, between March and December, 2012, there were a total of 151 successful explosions out of 535 Improvised Explosive Device (IED) threats; 384 were prevented by security operatives from exploding and causing harm (Usman, 2013). Nigeria is ranked 3rd out of 162 countries by the Institute for Economics & Peace (Global Terrorism Index [GTI], 2015). Yola, Adamawa state capital, Nigeria witnessed a number of preventable attacks where tremendous damages were recorded on infrastructures and human lives alike. For example there were explosions in Yola on October 23, 2015 (Pulse, 2015) and on November 28, 2015 (British Broadcasting Corporation [BBC]), 2015). Security challenges are faced both day and night and while traditional approaches employing military, police and other paramilitary agencies for occasional patrol of potential criminal locations or areas or employing watchtowers, yielded some expected results in the past, these approaches cannot longer cope effectively with modern technologies employed by hoodlums in executing criminal activities. This is so because while security operatives depend to some extent on informant in respect of location of criminal(s) or crime, criminals also have informant giving out information about the location of security operatives on patrol at a given time.

Watchtower an observation tower on which a guard or lookout is stationed to keep watch, as for enemies, for forest fires, or over prisoners (AHD, 2015) and security patrol are well known past approaches. Closed-circuit television (CCTV), relying on strategically installed cameras for surveillance and security purposes has been known to address infrastructural security challenges mainly within the facility thus remote security challenges become difficult to capture. This is one of the reasons most attacks on critical infrastructures have most times taken security guards unaware. Reliable and effective surveillance meant to timely confront security challenges must not only be limited within the infrastructure or at security check-points but should cover far beyond the facility by establishing direct remote visual correlation between control and command post and the facility; this way security operatives can view approaching security challenge or threat to an infrastructure and thus have enough time to plan and confront it before it gets close. In the study area there are no known watch towers

except ground level security check-points. An effective use of a watchtower where available, is to move away from the conventional approach where human observation with unaided eyes or use of binoculars or installed optical cameras or through CCTV were used to observe perceived potential criminal areas from unscientifically defined location and adopt modern technologies where the locations for both command and control post and the infrastructures are scientifically defined such as in Geographic Information System's environment to provide large areas surveillance both day and night for rapid response to security challenge on critical infrastructures.

Geographic Information Systems is a system for capturing, storing, retrieving integrating, analyzing geographically referenced data (Musa, 2007). GIS utilizes Digital Elevation Model and viewshed analysis approach where every cell in the study area is analyzed to establish intervisibility between the command and control post and the target area. DEM can be generated by any of the following techniques; ground survey techniques, airborne photogrammetric techniques, airborne laser scanning, radar altimetry techniques, interferometric synthetic aperture radar (InSAR) techniques, point interpolation techniques, interpolation of contour lines techniques (Hirt et al., 2013; Musa, 2011).Photogrammetry is an art, science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena with the following application techniques: orthorectification, stereo pair creation, feature collection, highly accurate point determination, control point extension, and automatic elevation extraction (Erdas, 2001).

Automatic elevation extraction can be achieved through photogrammetry approach using commercially available software such as ERDAS Imagine OrthoBASE, produced by ERDAS, Inc., Atlanta, Georgia; Desktop Mapping System (DSM), RE-WEL; PCI Geomatica OrthoEngine produced by PCI Geomatics, Canada (Hirano et al., 2003) using digital satellite stereo imageries from sensors such as ASAR, IRS, IKONOS, SPOT, QUICKBIRD, RADARSAT, ASTER (Geomatica OrthoEngine 9.1 user guide, 2003). ASTER captures high resolution images and is an advanced multispectral imager launched on board National Aeronautics and Space Administration (NASA)'s Terra spacecraft in December, 1999 and is jointly built by Japan's Ministry of Economy, Trade and Industry (METI) and NASA; it covers a wide spectral region in 14 bands from the visible to the thermal infrared with high spatial, spectral and radiometric resolution (ASTER User Handbook v2 and Drey et al., 2004). It's comprised of three subsystems: Visible Near Infrared (VNIR), Shortwave Infrared (SWIR), and Thermal Infrared (TIR). The VNIR subsystem consists of two independent telescope assemblies to provide stereo capabilities and minimize image distortion in the Nadir-looking (N) and Backward-looking (B) telescope and stereo images captured using digital scanners such as ASTER along-track sensor was and is the most common method used by mapping, geomatics and geoscientific organizations to generate digital elevation models (Toutin, 2008). The along-track ASTER stereo images are also well suited for generating DEM by automated stereocorrelation techniques, a computational and statistical procedure utilized to derive DEM automatically (Hirano et al., 2003).

Digital Elevation Model stores continuously varying variables such as elevation, groundwater depth or soil thickness and can be used in the following areas: creation of slope steepness maps, slope direction maps (slope aspect maps), slope convexity/concavity maps, hill shading maps (or shadow maps), three dimensional view maps, Cross-sections, Volume maps (cut-and-fill maps), creation of Ortho-images; visual and mathematical analysis of topography, landscapes and landforms, modeling of surface processes, landslides modeling, flight planning, rectification of

remote sensing imagery, urban planning, delineation of catchment areas, calculation of run off, generation of ortho maps, contour mapping, determination of area due to landslide, monitory land subsidence phenomenon, flood and tsunami disaster, gravity field modeling, military uses (Bambang and Ita, 2011; Chang et al., 2010; Drey et al., 2004; Hirt et al., 2013; Integrated Land and Water Information System [ILWIS] 3.0 User's Guide, 2001; Kamp et al., 2003). Military uses of DEM includes but not limited to visual and mathematical analysis of the terrain for maneuvers, flight planning, establishment of an unobstructed visual correlative between observation post and potential criminal areas.

GIS tool, Viewshed analysis is capable of efficiently determining an unobstructed view between an observer and a target using the terrain model. This is accomplished by regarding every cell of the DEM as target during analysis to establish intervisibility between the observer and the target (Stace, 2005). The application areas includes: study of tsunami, design of efficient wireless communication system, location of radio and television masts, locating wind turbines, evaluating urban environmental planning and optimal path planning, scenic routes design, facility location in visually sensitive areas such as national parks, wildlife refuge areas, reconnaissance facility site selection (fire watchtowers etc.), least-cost path analysis to determine routes with minimal exposure in military transportation application, positioning of watchtowers (Davin, 2006; Gary and Guerin, 1996; Li, 2005; Stace, 2005; and Young-Hoon et al., 2004).

Viewshed analysis has the capacity to identify position and area coverage around a infrastructure from an observation point, a supposed command and control center or watchtower through cell by cell comparison and analysis to establish whether or not there exists intervisibility. "A viewshed identifies the cells in an input raster that can be seen from one or more observation locations. Each cell in the output raster receives a value that indicates how many observer points can be seen from each location. If you have only one observer point, each cell that can see that observer point is given a value of 1. All cells that cannot see the observer point are given the value of 0" (ArcGIS, 2010).Where a cell obstructs the Line-of-sight, then there is no intervisibility and where there is no obstruction, intervisibility exists. This creates a binary map showing visible as well as non-visible areas of the study area coded in different colors. This research adopts Geographic Information System's tool, Viewshed Analysis approach to simultaneously correlate, identify and locate correctly, surveillance and security command and control post and potential areas under security challenge thereby providing surveillance and security in remote control room for rapid response to any security challenge real-time.

## 2.   METHOD AND MATERIALS

2.1   Overview

ASTER Global DEM covering the study area was downloaded and clipped to the study area. It was first edited to remove anomalies responsible for noisy elevation points and latter refined to create a DEM void of nodata and representing a continuous surface where each cell contains value and free of sink or depression or pit, and peak or spike. Four acquired analogue topographic maps were scanned, edge-matched to create the digital base map of the study area for locational identification of selected observation points and targets. This study is based on the concept of intervisibility or uninterrupted Line-of-Sight between two locations where one location known as the observation point (watchtower) is expected to have an uninterrupted view of a wide area of a location of a critical infrastructure. This was achieved through GIS tool, viewshed analysis and the use of DEM. Each observation point was tested at 100 high to

compare area coverage in each case and to obtain optimal positions that command wide area coverage of the infrastructures under study. Viewshed identifies every cell within a DEM and execute a correlative evaluation on cell by cell basis. Where a neighboring or remote cell location has an elevation that obstruct the Line-of-Sight, it is given 0 and given a prescribed color coding and where it does not constitute an obstruction, 1 is assigned with a prescribed distinguishing color coding. The final result is a binary map or viewshed map showing areas that are visible from the Watch tower and those that are not.
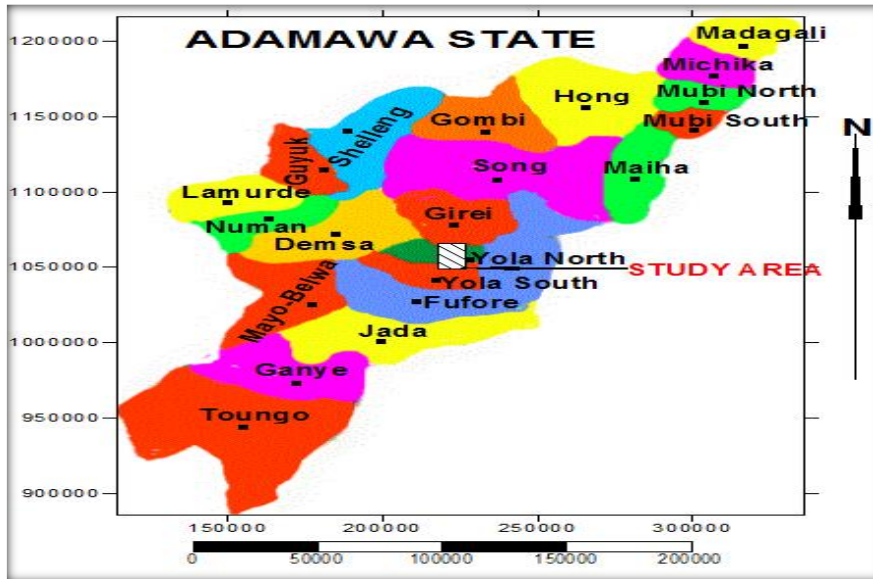
2.2   Study Area

The study area Yola, is located in Adamawa state, Nigeria within the semi-arid belt of Northern Nigeria (Figure 1) and is herein comprised of Vinikilang and environs in Girei LGA, Jimeta and environs in Yola North LGA, Yola town and environs in Yola south LGA. It covers an area of 150.6Km2 and is traversed by River Benue with peak discharge usually in September.

**Figure 1. Map of Nigeria showing Adamawa State**
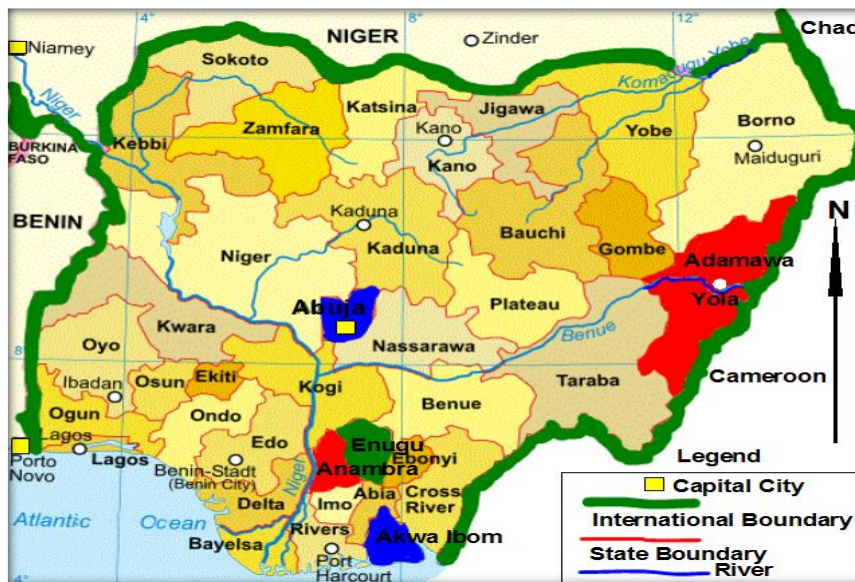
The State (Figure 2) which is located at approximate latitude and longitude range of 8˚00' 00"N - 11˚00' 00"N and 11˚ 30' 00"E - 14˚30' 00"E respectively has a land area of 42,158Km2 (Idowu, 2006) with a population of 3,168,101 (Federal Government of Nigeria [FGN], 2007). It has basically two vegetation zones, the sub-Sudan and the Guinea savanna located at the Northern and Southern axes respectively. The vegetation consists predominantly of short savannah trees and grasses.

Figure 2. Map of Adamawa State showing the Study Area.

The study area covers basically thirty one localities (Figure 3), namely Damare, Lainde, Bajabure, Vinikilang, Njobbore, Didango, Jimeta (Jambutu, Doubeli, Zango ward, Nassarawo, Damilu, Yola Airport, Demsawo, Yola International Hotel, Gov"t Girls College, Police RA, Bekaji Estate, Specialist Hospital, Baccure Kofa, Mallamre), Nyibango, Karewa Bakare, Ngesa Lamido, Yola Town, Bolobolere, Rumnde Mallum, Yolde Pate, Gireji, Madumari, Lelewalje. It lies within the geographic bounds of: West longitude 12° 24'49.5038"E, North latitude 9° 18' 44.5444"N, East longitude12° 30' 37.2945"E, and South latitude 9° 10' 56.2400"N, in zone 33, Mina, Nigeria Datum.

Figure 3. Location Map of Study Area
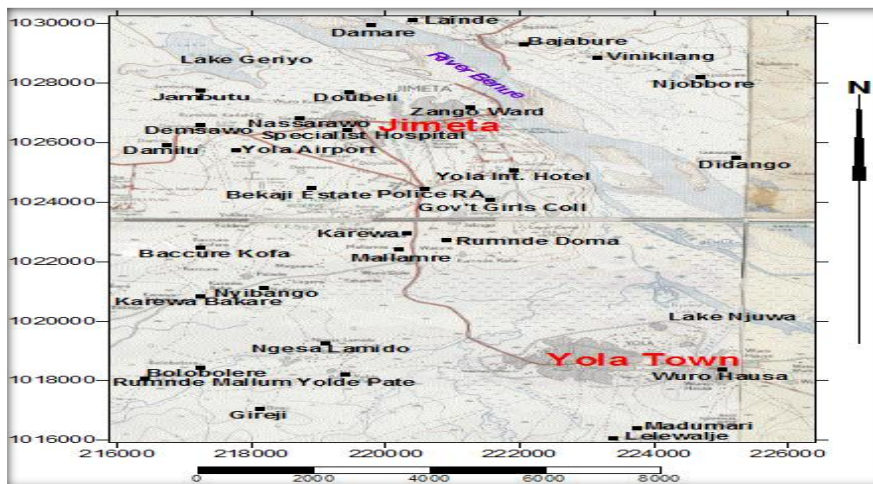
The relief is characterized by gentle slopes with an extension of Bagale hills at the Northeast portion of the study area with some small hills around Didango and Southwest of Gireji at elevation of 229m and 206m respectively (Figure 4). The elevations of the study area ranged from 152m to 235m above mean sea level. Bagale
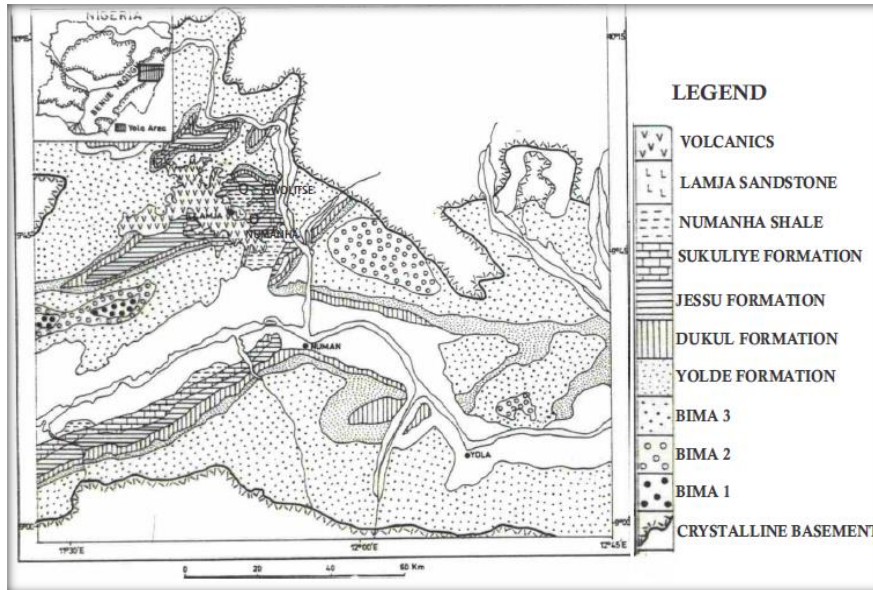
hills have average elevation of about 578m above mean sea level and the average annual rainfall of Yola is 950mm. Yola is characterized by monsoonal climate, a climatic condition where the year is divided into two; the dry and rainy seasons. While the dry season commonly referred to as the harmattan period laden with the dusty winds from the Sahara desert generally starts in November and ends in March, the rainy season normally commences in April and ends in October with peak rainfall usually in September. The surface air at about the latter part of March and in April is usually very hot with an average temperature range of 19ºC - 39.7ºC.

Figure 4. Advanced Spaceborne Thermal Emission and Reflection Radiometer Image of Study Area
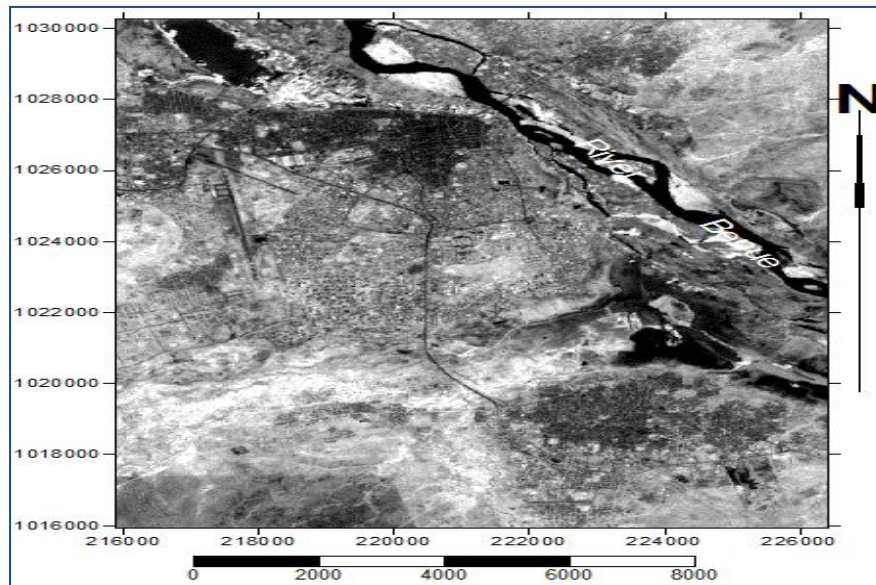
The geology of the study area is linked to the Benue Trough, Yola arm which is an east west Benue rift structure that connects the Nigerian basins to other rift in Africa to form the West Africa rift network system. Yola arm developed from wrench-fault tectonics with pre-santonian sedimentary infilling and Bima sandstone was the earliest sedimentary deposit (Ehinola et al., 2005). As in Figure 5, the Bima Formation which is predominant in the rifted basin, overlies the basement directly while the Yolde Formation succeeds the Bima sandstone. Bima sandstone consists of coarse grain sandstone (Umegu and Ojo, 2010). The post Yolde deposition is said to be of marine setting, the earliest of which is the Dakul Formation. Jessu Formation succeeds it (Dakul Formation) while a set of limestone and shale identified as Sukuliye and Numanha Formations succeed Jessu. The succession of the rifted basin ends with Lamja sandstone. Other constituents of the following formations are as follows: Yolde - fine to medium grained clean particle, Dukul - ammonite fossils (vascoceratids), Jessu - Ferruginous class, Sukuliye - thin to medium bedded limestone and grey fissile shale, Numanha - black shale beds, Lamja - fine grained parallel laminated sandstone with interbeds of limestone, coal seams and fossiliferous shale (Ehinola et al., 2005). While the study area is covered by light reddish to brownish sandy soil underlain by the Bima sandstone and Yola sandstone known as the Bima-Yola sandstone, aquifer and intra-formational clay prevalent in the study area are formed by the loose sand and friable sandstones (Onugba and Aboh, 2009).

Figure 5. Geological Map of Yola Arm of Upper Benue Trough (Saka, 2012)

LEGEND

VOLCANICS
LAMJA SANDSTONE
NUMANHA SHALE
SUKULIYE FORMATION
JESSU FORMATION
DUKUL FORMATION
YOLDE FORMATION
BIMA 3
BIMA 2
BIMA 1
CRYSTALLINE BASEMENT

2.3 Materials and Instruments Requirements

The data required were basically ASTER Global DEM and four 1:50000 topographic sheets, Numan N/E and S/E, Girei N/W and S/W, and X,Y coordinates of tiepoints. The hardware required included Handheld Gamin GPS receiver to capture coordinates of Ground Control Points (GCPs), HP Scanner for scanning into the computer the topographic sheets in the Area of Interest, Corel Draw version 12 for edge-matching, alignment of the four scanned portion of the topographic sheets to form a single jpeg object (Background map), HP Laptop for general processing of data using the following software: PCI OrthoEngine v9.1.0, ArcGIS 9.3 basically for editing and refining the ASTER GDEM, ILWIS 3.4 for creation of the Base map and Global Mapper v10 for Line-of-Sight and viewshed analysis.

2.4 Editing the Digital Elevation Model

The GDEM covering1° x 1° tile area was clipped to the size of the study area and resampled to 10m (Figure 6). Usually, Digital Elevation Model automatically extracted from satellite or aerial photo stereo pairs surfers from cloud cover anomalies, water bodies' anomalies and other anomalies responsible for noisy elevation points. Such DEMs need to be edited to remove such inherent anomalies. This was achieved through filtering and interpolation noise removal and Gaussian smoothing functions of Geomatica Focus "manually edit DEM" menu. Other detected errors such as wrong elevation of an area on the clipped DEM were corrected by masking the anomalous area and inputting the correct elevation extracted from the existing topographic sheets of the study area. Further enhancement of the DEM was achieved while interpolating elevation values for a raster (DEM) by imposing constraints that guarantee a connected drainage structure and correct representation of ridges and streams from input contour vector based on the ANUDEM program developed by Michael Hutchinson, 1988, 1989 (ArcGIS, 2010). This task is accomplished through ArcGIS 3D Analyst tool, "Topo to Raster" thus creating a DEM void of nodata that represents a continuous surface where each cell contains value. The downsized DEM was further refined (Figure 7) using ArcGIS Spatial Analyst tools, "Sink" to remove sink also

referred to as depression or pit an area/cell surrounded by higher elevation value or peak or spike an area/cell surrounded by cells of lower value.

Figure 6. Clipped Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model of Study Area Overlaid on 1° x 1° tile area Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model
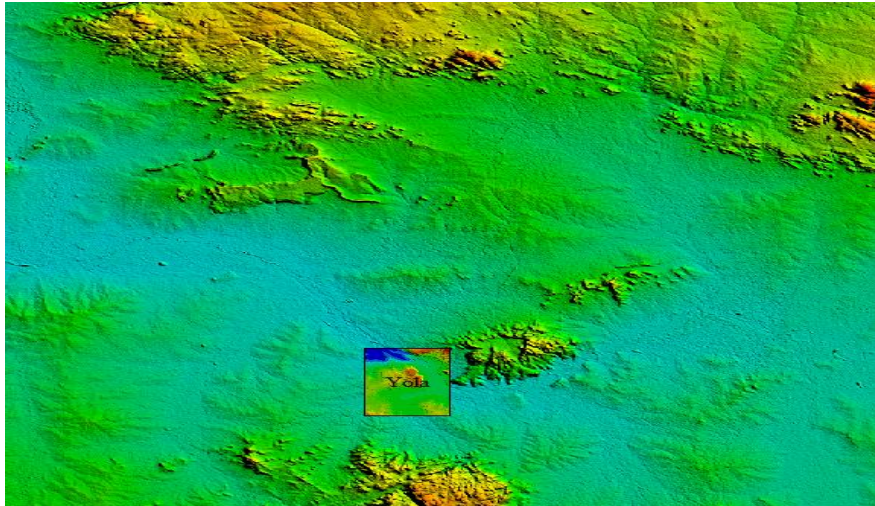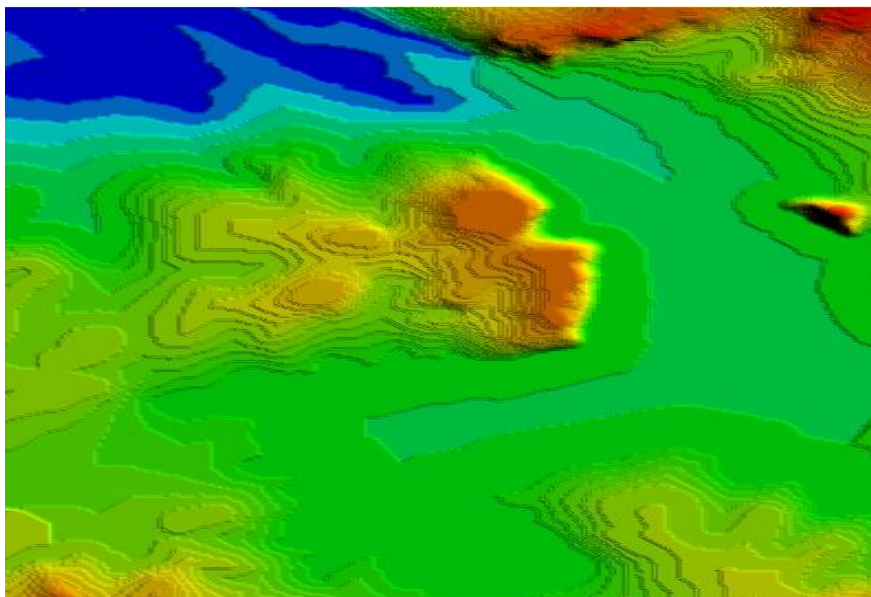

Figure 7. Refined Digital Elevation Model of Study Area

## 2.4   Creation of BaseMmap of Study Area.

A Base map is a dataset displaying geographic as well as political information such as localities, roads, streams, lakes, or state and national boundaries. The Base map is intended basically to provide a simultaneous direct visual correlative perception of localities, control and command post and infrastructures. The Background map of the study area in JPEG format which was edged-matched in CorelDraw environment from

individual scan of part of the four topographic sheets, was used to create the Base map in ILWIS3.4 environment. The coordinate system was first created where the projection (UTM), ellipsoid (Clarke 1880), and the datum (Minna, Nigeria) for the Base map were chosen. The Tiepoints and the coordinates were entered by clicking on the individual points on the background map corresponding to the GPS observation point. This way the tiepoints and their corresponding coordinates (shown in table1) were entered. This is to pave way for the creation of a Georeference and thus activation of Georeference editor for entry of coordinates of every Ground Control Points (Table 1) on the Background map corresponding to the GPS observation points to create the georeferenced map/Base map (Figure 8) of the study area.

Table 1: Tiepoints

Tiepoint	N (m)	E (m)	Location
1	1026694.210	220846.166	Junction @ Jimeta Prison service
2	1035147.231	229337.083	Junction @ Drift Girei
3	1015003.022	230460.532	Junction @ Wuro Modibbo
4	1018600.343	228002.139	Junction @ Hokkatare
5	1020663.136	216864.838	Junction @ Karewa Bakare
6	1029922.741	221846.495	Junction @ Badirsa
7	1023773.312	226333.126	Junction @ Lake Kagu
8	1024331.161	220551.926	Junction @ Police RoundAbout
9	1025256.422	216258.976	Junction @ Kofare/Wuro Jabbe
10	1018537.560	224182.868	Junction @ RH Yola

Figure 8. Base Map of Study Area
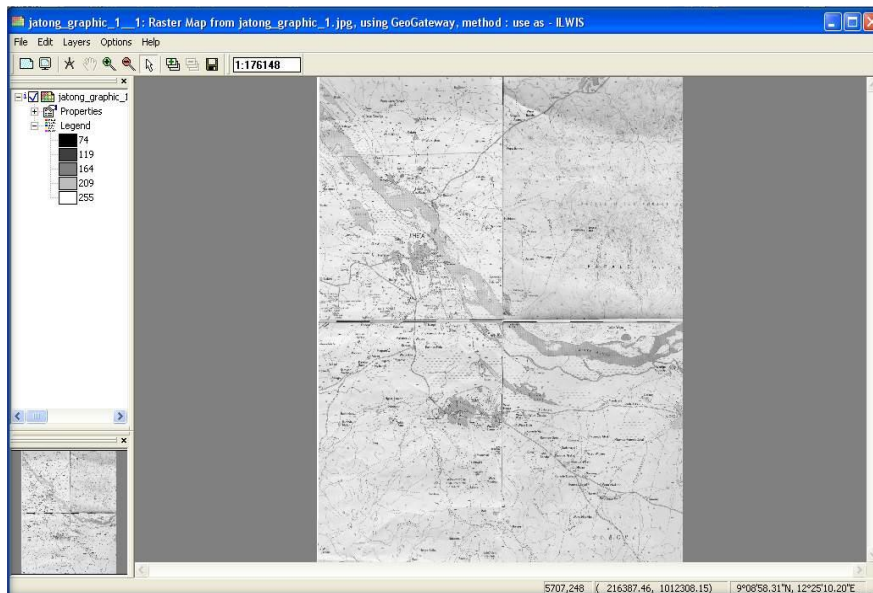
2.5   Line of Sight and Viewshed Calculation.

Line of sight and viewshed calculation are needed to establish intervisibility between two points, observation point and the target. Observation points were chosen on identified ridges and peaks because they have been known to command higher visibility (Young-Hoon et al, 2004). Viewshed tool using elevation grid data provides for specification of the observation point location (X, Y), height of the observation point (tower), radius and atmospheric correction factor of 1.333 specified by default. All the cells within the specified search radius that have unobstructed line of sight to the observer point are colored with user specified color, blue while cells that cannot be seen from the observation point are coded black. Six observation points (Jambutu, Rumnde Mallum, Madumari, Didango, PoliceSTN, Badirsa) were chosen and viewshed calculations done on each point at observer height of 100m to create individual viewshed map for individual observer position.

2. 3. RESULTS AND DISCUSSION

Line of sight and viewshed analysis were simultaneously through the viewshed analysis tool done at six different observation points to provide intervisibility scenarios. The extract of the result of line of sight and viewshed analysis for tower height of 100m for six observation points is hereby presented. Table 2 shows viewshed calculation in respect of area coverage for each of the observation point. In Table 2, Didango covers the largest area of 143.672 Km2 at an elevation of 229m above mean sea level while Rumnde Mallum covers the least area of 113.101Km2 at 177m above mean sea level.

Table 2: Viewshed Calculation Area Coverage

S/NO	Name	X	Y	Height	Visible Area	% visible
2	Jambutu	217219.095	1027787.553	155.000	113.703	75.5
4	Rumnde Mallum	216837.462	1018282.310	177.000	113.101	75.1
6	Madumari	223751.492	1016400.237	180.815	115.058	76.4
8	Didango	225888.457	1025324.096	229.000	143.672	95.4
10	PoliceSTN	220283.657	1024507.180	198.000	142.769	94.8
12	Badirsa	221955.359	1029919.924	208.000	139.606	92.7

Figure 9 is the viewshed map of Jambutu including an overlay of the viewshed on the base map purposely to show the localities not visible to the observation point. All the infrastructures (Schools, Banks, Hospital, military installation, Airport, Shopping complex) are visible from Jambutu observation point. Areas not visible are shown in the overlay.

Figure 9. Jambutu Viewshed Map
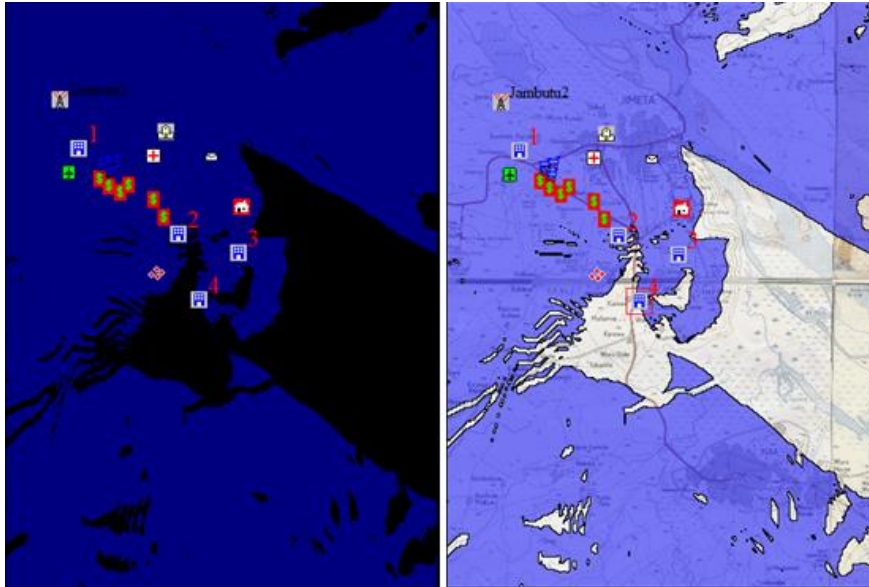
While Figure 10 is Rumnde Mallum binary map with areas such as the banks, Shopping complex, Post office, Hospital are not visible, School 1 partially visible and School 2, 3, 4, Military installation, Hotel all visible, Madumari viewshed map, Figure 11 is visible at School 2,3,4, the Military installation and the Hotel. Localities not visible can be seen in black color and on the overlay.

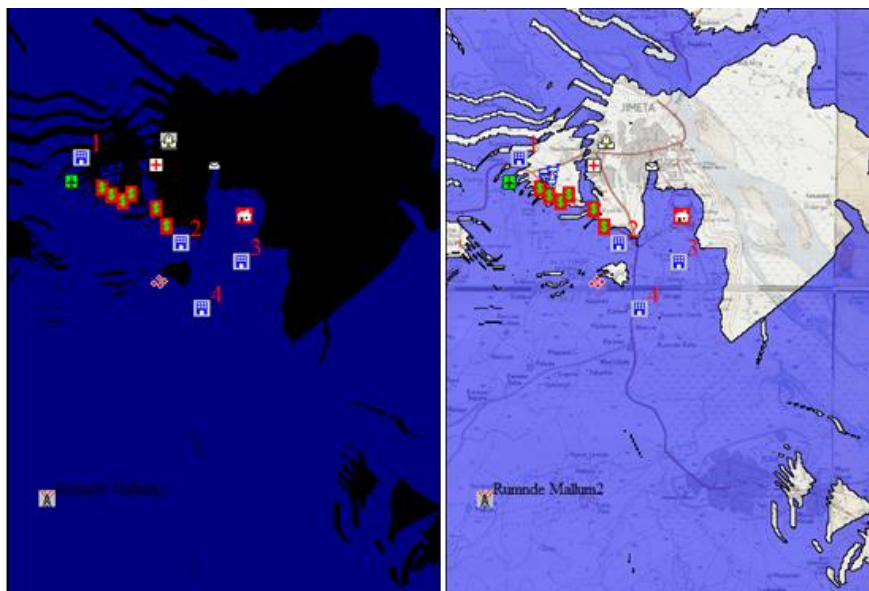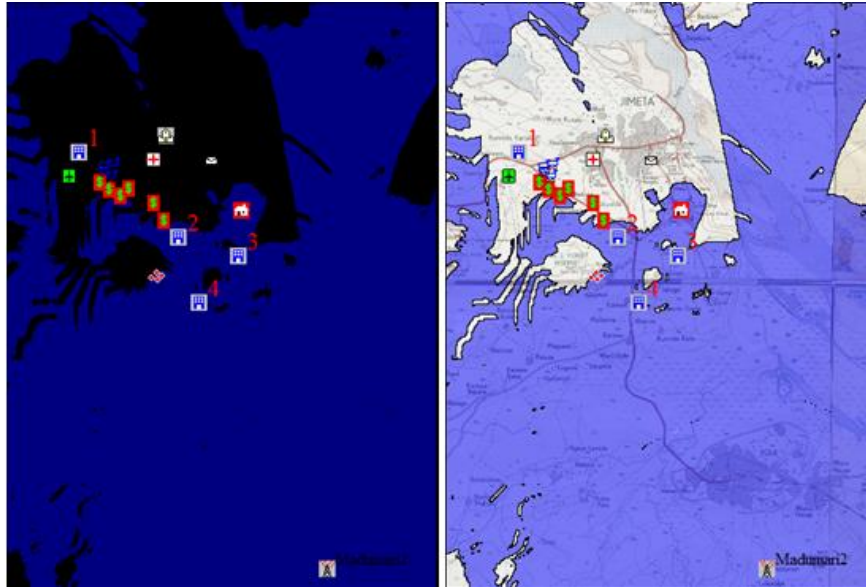**Figure 10. Rumnde Mallum Viewshed Map**

Fgure 11. Madumari Viewshed Map

While in Didango viewshed map (Figure 12), all the infrastructures are visible except School 4 and the Airport that are fairly visible, in PoliceSTN viewshed map (Figure 13) all the infrastructures are visible from the observation point. Similarly, Badirsa viewshep map (Figure 14) has all the infrastructures visible except School 2 and 4 that are fairly visible.
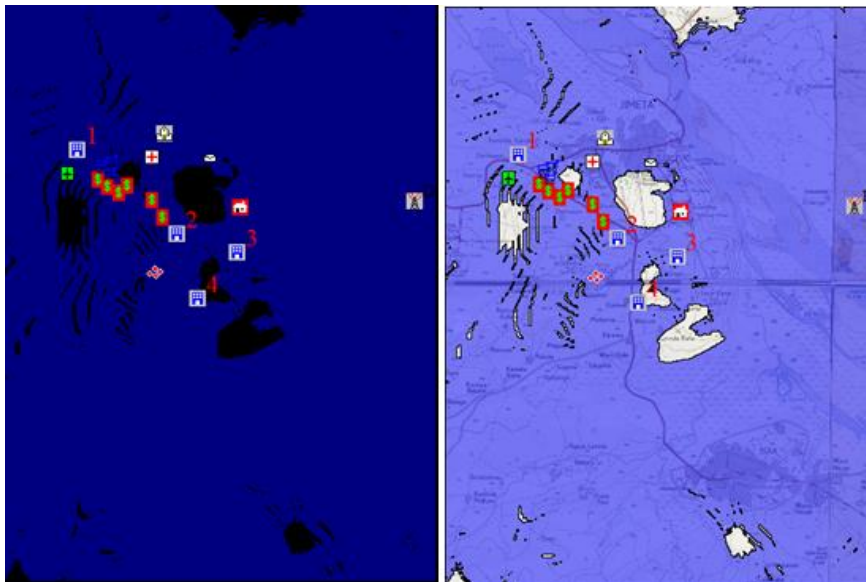
Figure 12. Didango Viewshed Map

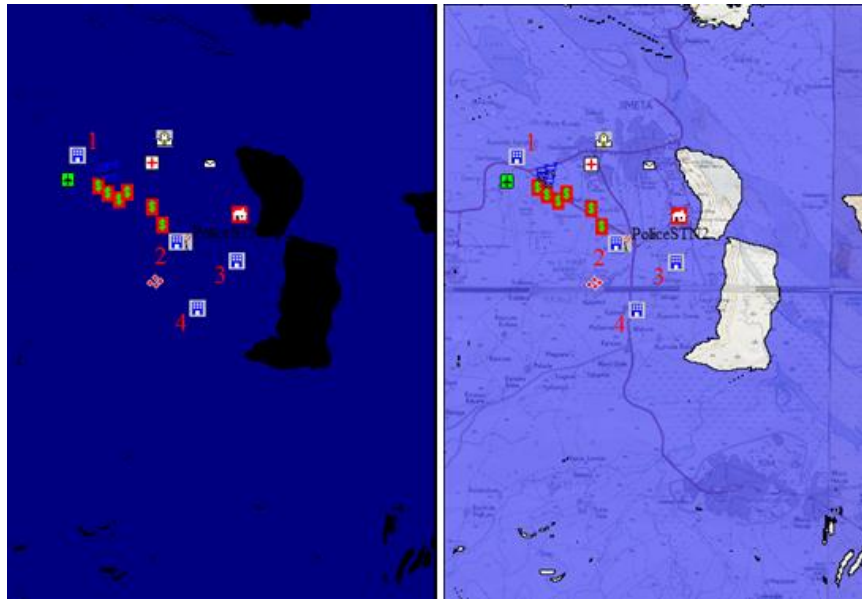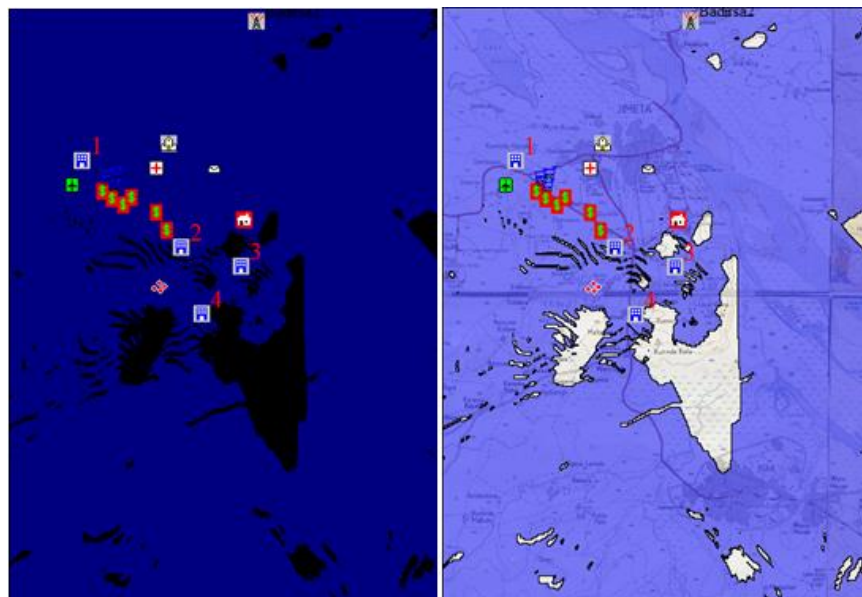**Figure 13. PoliceSTN Viewshed Map**

Figure 14. Badirsa Viewshed Map

3. 4. CONCLUSION

Geographic Information System tool, Viewshed Analysis creates a raster, recording the number of times each area can be seen from observer locations. It does not only determine which target can be seen from the observation tower, but also can determine which observers can see which observation locations. This is important in decision making process for example where to site a critical infrastructure in respect to already determined observation points. It can be seen that large area coverage is principally determined by factors such as height of observation tower, clear line of sight to determine optimal observation points such as Didango, PoliceSTN. With viewshed analyzed map, planners and decision makers have ample opportunities to make reliable planning and decisions on where to place a watchtower to keep surveillance and security on critical infrastructures real-time. The implication of this study is that,

optimal positions for watchtowers capable of wide view of facilities can be properly and reliably addressed through GIS implying therefore that, to keep updated, even the position of past watchtowers needs reassessment where necessary redefinition in line with modern science to keep track and to timely confront security challenges to critical infrastructures.

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