Application of Geospatial Technology for Efficient Water Distribution Network in Undulating Terrains of Enugu urban, Southeast Nigeria

Amos Iloabuchi Ugwuoti (amos.ugwuoti@unn.edu.ng)
University of Nigeria https://orcid.org/0000-0001-8347-0654
Oliver C Ojinnaka
University of Nigeria
Eziyi O Ibem
University of Nigeria
Victus N Uzodinma
University of Nigeria

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Abstract

Rapid urbanization has continued to exacerbate pipe borne water supply challenges in many urban areas in sub-Saharan Africa, including Nigeria. Hence, innovative systems and strategies are needed to support effective planning of surface and underground facilities for efficient water distribution network in this region. This research is aimed at using geospatial technology to develop an efficient water distribution network for urban areas with undulating terrain using Enugu, southeast Nigeria as a case study. Data sourced from physical observations and maps of the existing water distribution network, location of the reservoirs and booster points, and settlement pattern of Enugu revealed that the existing water distribution network was inconsistent with terrain configuration of the city and lacked provisions for future expansion. Consequently, in developing a new water distribution network, evaluation of the terrain of the city from spot heights dataset extracted from LIght Detection and Ranging (LIDAR) Satellite image was done. Based on the data obtained, the city was divided into 12 water distribution zones, with reservoirs sited at points of highest elevation to allow pipe borne water reticulation by gravity using Geographic Information System (GIS) tools. A combination of radial and dead-end water distribution standard systems was applied in the production of water distribution network map for Enugu urban with provisions made for future expansions. The efficiency of this distribution network was tested and confirmed to be suitable with United State's Environmental Protection Agency domain software EPANET for water distribution model; and thus recommended for adoption in Enugu and other cities with undulating topography and water distribution challenges.

1. Introduction

Access to safe drinking water and sanitation is a universal human right. In July 28, 2010, the United Nations General Assembly recognized the human right to water and sanitation through Resolution 64/292 (Lancet, 2020). In 2015 also, the global community set a measurable target in the form of Sustainable Development Goal (SDG) 6, which left countries with the instruction to ensure availability of sustainable amount of water and sanitation for their citizens and residents by 2030. In pursuant of this goal, it has become very necessary for cities, regions and countries to develop and adopt strategic approaches to solving the challenges associated with water poverty within their jurisdictions.

As is true for many residents of urban areas in Nigeria, the inhabitants of Enugu urban in Enugu State, have over the years been confronted with scarcity of potable water supply. The situation is very peculiar because there are no streams within the city for the extraction of surface water and underground water cannot be obtained in large quantity due to the coal deposit dominated aquifer in the area. A study by Ezenwanji et al. (2016) compared the quantity of water demanded and supplied in Enugu urban and noted that the current supply constitute only 44% of the quantity of water demanded by the residents. In the face of these, successive governments in Enugu State had intermittently struggled to overcome this challenge, but a sustainable solution is not in sight. The efforts of the government in addressing this challenge had given rise to the establishment of some water schemes in the last few decades. These include the 9th Mile crash boreholes programme at Udi Local Government Area (L.G.A), which is about 8.6 km from the city, the Ajali water scheme in Ezeagu L.G.A, about 21 km from Enugu urban, the Oji augmentation water scheme at Oji River L.G.A about 31.7km away from the city and the recent piped water extension within the city in 2014.

These attempts, though very laudable, had failed to produce the expected results as it has become increasing very difficult for the inhabitants of Enugu city to have access to safe water for domestic consumption. In fact, most residents of Enugu urban depend largely on water transported by commercial water vendors from privately-owned boreholes at 9th mile and contaminated shallow wells seen virtually in nearly all buildings and residential estates. A study by Ugwuoti *et al*. (2018) revealed that in greater part of the city, children and women are saddled with the responsibility of hulling water from the shallow wells to flats in multi-storey buildings for domestic use. This situation has been attributed to poor optimization in the allocation of the available water (Ezenwanji et al., 2014); and thus there is a need for the adoption of new techniques that will help in ensuring that water is effectively supplied to the residential, commercial and industrial and areas of the city.

The existing studies have examined the various water distribution systems are: the ring, the grid-iron, the radial and the dead-end systems and their suitability for different city layouts (see Adeosun, 2014; Anisha et al, 2016; Kiewiet and Telukdarie, 2018). Others have focused on the institutional framework for effective water supply management system (Ezenwanji et al., 2016; Ngene et al.,2021). Yet other researchers have also examined the technologies for improving urban water reticulation (Boulos *et al*., 2014; Srivastava et al., 2021). It is however observed that that some of the recommendation such the integrated water resources management (Ngene et al., 2021) and the supervised control integrated with the real-time smart water network (Boulos *et al*., 2014) are currently not feasible in Enugu urban as their functionality depends largely on well-calibrated facility information and accurate spatial distribution of demands. Ugwuoti et al. (2018) had reported that the infrastructure for water distribution in Enugu urban are haphazardly located without proper planning and this has made most of them not functional as only three of the eleven water tanks in Enugu urban were functional.

The available information indicates that water supply challenge in Enugu urban has not necessarily been triggered by dysfunctional institutional framework but by negligence to terrain configuration and poor distribution network system. Based on this, Ugwuoti *et al*. (2018) have contended that accurate spatial distribution of water cannot be attained without a proper consideration to topography/ undulation of the city terrain in sitting water distribution facilities. Moreover, very little is known of the most suitable water distribution system in areas of undulating terrain like Enugu. It was on this premise that this research sought to examine the application of geospatial technology in mitigating the effect of undulating terrain in efficient water distribution network in Enugu urban, South east, Nigeria. The two specific objectives were to: 1) survey the existing water distribution facilities in Enugu urban southeast Nigeria, 2) develop an efficient water distribution network for Enugu urban using geospatial technology. Therefore, this research will inform stakeholders on how geospatial technology can be applied for efficient water distribution system in urban areas and cities with undulating topography.

2. Study Area

Enugu is a word that means ‘hill top’ in Igbo language. Enugu urban is the capital city of Enugu State, southeast Nigeria (see Fig. 1). Enugu urban comprises three Local Government Areas namely, Enugu North, Enugu South and Enugu East (Fig. 2). The city is located between Lat. 06°, 26’ and 06°, 30’ N and Long. 07°, 27’ and 07°, 37’ E and lies east of Niger Delta. With a population of 996,481 (2017 Census projection), it is one of the largest cities in Nigeria and the West African sub-region. Its importance dates back to the colonial days when it served as the capital of the now defunct Eastern Region of Nigeria. Subsequently it became the capital of the East Central State. During the colonial era, Nigeria was one of the coal producing nations of the world because of the massive coal deposit in Enugu.

Topographically, Enugu is surrounded by the Udi hills and stands at an elevation between 125m and 380m above mean sea level with intervening hills and valleys. It has a mean daily temperature of 26.7ºC (80.1ºF) and experiences two main weather conditions: the rainy season and the dry season and a short harmattan season lasting a few weeks in the months of December and January. The average rainfall in Enugu urban is around 2000 millimetres (79in), which arrives gradually and finally becomes very heavy during the rainy season.

3. Urban Water Distribution Systems

Evidence in the literature reveals that in there has also been calls for institutional reform, water demand management technique and supply measures with professional community based management options (Ezenwanji et al., 2016). This has given rise to the advocacy for a paradigm shift in water management from the traditional sectoral approach to integrated water resources management (IWRM). (Ngene et al., 2021). It is also pertinent to note that IWRM is based on legal and institutional framework that are hinged on water governance and good policy formulation, and this has been widely employed in optimization of water supply and demand equilibrium in a functional water distribution system. These are products of proactive water management and distribution network system that has been based on integrating supervised control and acquisition systems with the network simulation models driven by real-time smart water network decision support adopted in city of Las Vegas, USA (Boulos *et al.*, 2014).

It has also been established in the existing study by Srivastava et al. (2021) that the utilization of datasets from earth observation satellites in combination with GIS, artificial intelligence and hybrid technique can be very useful in improving urban water distribution system. Based on this, four types of urban water distribution system network layouts have been identified and adopted in different countries. These distribution systems are: the ring, the grid-iron, the radial and the dead-end systems (Adeosun, 2014). The ring water distribution network layout system has its main distribution pipes form a ring around the distribution area, while its branches connect cross-wise to the main pipes and to each other. This system is suited for cities with well-planned streets and roads and has been adopted in China as reported by Kiewiet and Telukdarie (2018). The grid-iron water distribution layout system allows water supply to streets from many directions from the centrally located main. It is most suitable in cities laid out in rectangular plain (Municipal Water Supply systems 101: Types and Components., 2020). In the case of repair, only small fraction of water line is affected. Kiewiet and Telukdarie (2018) reported that this system has been applied in cities in Pakistan and Russia.

There is also the radial distribution network layout system, which is a zoned system whereby the entire distribution area is divided into a number of distribution districts, with each district having a centrally located reservoir. Each reservoir has distribution pipes that run radially towards the ends of the districts and provide seamless services without pressure head loss. It is also the most economical system when a combination of pumping and gravity flow is adopted as found in Britain (Kiewiet and Telukdarie, 2018). The dead-end system also known as the Tree distribution system has one main pipe that usually runs through the centre of the distribution area. The sub-mains divide into many branches from where provision is made for service connections, which make it possible for every street to be supplied water directly from the main pipe. This is usually adopted in cities where irregular development had occurred or for future extension to where such is envisaged as seen in Chirala Municipal in Prakasam District of Andhra Pradesh, India (Anisha et al, 2016) and in Egypt, Greece, Italy, North America and United Kingdom (Kiewiet and Telukdarie, 2018).

From the existing studies reviewed here, it evident that the adoption of each of the four types of urban water distribution system networks is usually a function of the road networks and terrain of the area. It can also be inferred from these studies that based on the peculiarities of locations two or more water distribution system networks can be combined. In this wise, in areas of undulating terrain, radial system of water distribution layout that as allows for the division of the area into districts and establishment of a reservoir at the most elevated points of each district can be more effective than any other system. Similarly, it is also possible that the dead-end system of water distribution network can be combined with the radial system to create room for future piped water connectivity and spatial growth of urban areas and cities. In this line of thinking, understanding the spatial or road/street layout and topographic variables is essential for the design and development of effective and efficient water distribution network/systems for any urban settlement.

4. Materials And Methods

The first information obtained was the map of the existing distribution network in the city. The map has four sheets one of which is as shown in Fig. 3, and it was sourced from the government agency- the Enugu State Water Corporation responsible for water distribution in the urban area. The map was produced in the year 1957 by DHV Consultants BV- a Netherlands based Company for the Federal Ministry of Water Resources and Rural Development, Nigeria. Although the map is old and requires updating, it contains vital information such as the sizes of pipes, relative positions of reservoirs and some land marks to guide users. It also shows clearly existing network pattern of the urban area at that time but has no details of some new estates such as Trans Ekulu, Thinkers Conner, Independence Layout Phase 2, Goshen Estate, Gulf Estate and others. This is simply because it has not been updated since it was first produced.

The second information obtained was another map showing the location of the reservoirs and booster points within the Metropolis serving different regions of the urban area. These facilities were coordinated with the help of the hand held Global Positioning System (GPS). The condition of the facilities was ascertained from direct observations and interactions with the water Engineers and written reports domiciled at Enugu State Water Corporation. Based on the available information gathered from these maps, it was found that the topography of the Enugu has some adverse effects on water reticulation in the city. In order to overcome these, LiDAR Light Detection and Ranging (LiDAR) satellite imagery was acquired and spot heights extracted from it along the water transmission lines at 50m intervals. This was done using Global Mapper version 13.0 and Arc GIS version 10.1software. The data (Satellite imagery) was first of all loaded into Global Mapper for faster extraction of Points. The software window for this process is as shown in the Fig. 4.

At the completion of raw data importation into Global Mapper software, the digital terrain model of Enugu Urban was displayed as point cloud. This point cloud was thereafter exported into ArcGIS software version 10.1 as shown in Fig. 5.

The data contains about 301 tiles and each tile contains several points. This made the process of extraction and interpolation for the gaps that can be seen on the figure very cumbersome. Heights along the main/ transmission lines were extracted at 50m interval. These values were brought into Excel spread sheet for proper organization. The Transmission lines were in most cases established along major roads within the metropolis. As a result, the names of the roads through which the lines pass to identify each transmission line were used. It is also important to note that most of the lines traversed several streets, so in such cases, a collection of the names of the streets through which the line passes were used to identify such transmission line(s). The extracted coordinates are based on the Universal Transverse Mercator (UTM) Zone 32 reference origin and World Geodetic System (WGS) 84 datum. A sample of the extracted coordinate is shown in Table 2. The profiles of the transmission lines were plotted with the height component of these coordinate to determine the possibility of water flow from the tanks at New Market area to the reservoirs in different parts of the urban area. The profile was plotted with Auto CAD Civil 3D software.

Between the year 1957 when the existing map of Enugu urban water distribution network was designed and 2021 when the current research was carried out, there have been several new installations and improvements on the water facilities in the urban area. To understand the current challenges facing water supply system in the area, a design of the map of the totality of the facilities was produced using information acquired from the satellite image and the coordinates of the facilities acquired by means of GPS during ground truthing. The coordinates of the locations and capacities of the existing facilities (Reservoirs, tanks etc.) were assembled as shown in Table i. These coordinates of existing facilities enabled the indication of the location of tanks and reservoirs in the map.

Table i: The existing water distribution facilities for Enugu Urban area

S/N	Tank	Location	Coordinates		Type	Capacity (m^3)	Ground level Height (m)	Comments
			Easting	Northing				
1	Nsude TwinTanks	Off Onitsha- Enugu road Expressway	321530	708668	Circular Concrete Ground Level Reservoir	2 x 5000	435.5	Receives water from Ajali and Oji River Water Production Facilities.
2	Agbaja Ngwo Balancing Tank	Ngwo Community	327274	711725	Circular Concrete Ground Level Reservoir	10,000	375	This is a Balancing Tank fed by gravity from Nsude Twin Tanks
3	High Pressure Tank	Iva Valley	330156	713753	Circular Concrete Ground Level Reservoir	3,000	293.8	Receives water from Agbaja Ngwo Tank and feeds 20,000m3 tank at New Market and distributes to Independence Layout
4	4 million Gallon Tank	New Market	331477	713383	Underground Rectangular	20,000	258.5	Fed from Iva Valley Head Works and Agbaja Ngwo reservoir and distributes to GRA area
5	1 million GallonTank	New Market	331484	713237	Underground Rectangular Tank	4,500	254.5	Tank receives water from Iva Valley Works and distributes to Ogui Road area
6	Terminal ZoneTank	New Market	331482	713147	Circular Concrete Ground Level Reservoir	20,000	248	Receives Water from Agbaja NgwoTank and Feeds Emene, South-East and Trans Ekulu Tanks by gravity. Leakage at tank base

S/N	Tank	Location	Coordinates		Type	Capacity (m^3)	Ground level Height (m)	Comments
			Easting	Northing				
7	North-East Tank	Emene	338137	714860	Circular Concrete Ground Level Reservoir	12,500	217	Feed distribution network to Emene, parts of New Haven and parts of Independence Layout
8	South-East Tank	Idaw River	332725	709242	Circular Concrete Ground Level Reservoir	12,500	236.6	Not in use due to defects in Base Slab
9	Elevated Steel Tank	Trans Ekulu	333816	716357	Rectangular Elevated Steel tank	100	219	Receives boosted supply from the Braithwaite tank for distribution to immediate surroundings
10	$400m^3$ Tank	Trans Ekulu	333816	716357	Braithwaite Steel Tank	400	219	Receives water from $20{,}000m^3$ Tank at New Market and distributes to limited parts of Trans Ekulu Layout. Not in use due to loss of pressure in supply line from New Market reservoir

S/N	Tank	Location	Coordinates		Type	Capacity (m^3)	Ground level Height (m)	Comments
			Easting	Northing				
11	Akwuke Tank	Akwuke Town	330511	705769	Circular Concrete Ground Level Reservoir	200	221	Originally fed from Inyama Borehole Scheme (now defunct) and distributes to Akwuke and Awkunanaw. The concrete structure appears to be in good condition. Not in use
12	Amechi Tank	Amechi	335024	705339	Circular Concrete Ground Level Reservoir	1000	219	New tank not yet commission-ed. Designed to receive water from Amechi Awkunanaw plant and distribute to Amechi town
13	Coal Camp Tank	Coal Camp	331681	710940	Rectangular Concrete Tank	4,500	244	Tank in disuse due to lack of water reaching it from the terminal Tank
14	Ibagwa Nike Tank	Ibagwa Nike	336410	722144	Circular Concrete Ground Level Reservoir	200	221	Tank not connected to any pipework and has not been put into use since it was built
15	Gariki Tank	Gariki	333622	705218	Rectangular Underground Concrete Tank	100	225	Tank in disuse.

With all the facilities in place, it became very clear from the map of the existing facilities that the distribution network did not agree with any of the four: grid iron, ring, radial and dead-end standard water distribution network layouts. Considering the undulated topography of Enugu urban area, the most suitable water distribution layout is radial system. The natural relief of Enugu Urban area is such that radial system is the most appropriate water distribution network layout for the city. Its application has not only allowed proper management of water resources within the zones but has reduced the economic requirement of water distribution as water flows through the pipes from the reservoir to the houses by natural gravity. This has eliminated the use of pumps and its attendance routing maintenance in the system.

Using the map of the existing facilities and in consideration of the topographic view of the urban area, the, city was divided into 12 zones with each of the three Local Government Area having four zones. In each of these zones, the most elevated central point was considered for the sitting of reservoir from where water is reticulated to all parts of the zone by gravity. The map showing these zones was produced in ArcGIS software environment which allowed for the integration of datasets from the satellite imagery, the ground truthing and the map of the existing facilities. The efficacy of the designed water distribution network was tested using EPANET software. This software, consist of a computer program that does simulations of hydraulic behavior within a pressure pipe network (Sultana et al., 2019). The confirmation of the efficacy of the network was made possible by adopting the following Hezen Williams specifications in the software: PVC pipes of 130. Base demand of -333.33 at the first node linking the reservoir. The road junction were automatically the nodes, while the heights of points and the distances extracted from the satellite imagery were inputted adequately

5. Results And Discussion

The coordinates of the transmission lines were extracted at 50m interval. This interval was chosen irrespective of the expanse of the work done to capture the rugged undulation of the topography of the area. A sample of the list of the coordinates are as depicted in Table ii.

Table ii: A Sample of Coordinates extracted from LIDAR Satellite imagery

SN	Name	Easting	Northing	Height
1	Ogui Road	333273.578	711727.243	199
2	Ogui Road	333302.296	711768.173	198
3	Ogui Road	333331.014	711809.103	197
4	Ogui Road	333359.732	711850.033	197
5	Ogui Road	333388.45	711890.963	198
6	Ogui Road	333417.169	711931.893	198
7	Ogui Road	333445.887	711972.823	198
8	Ogui Road	333474.605	712013.753	198
9	Ogui Road	333503.323	712054.683	198
10	Ogui Road	333532.041	712095.613	197
11	Ogui Road	333560.759	712136.543	197
12	Ogui Road	333589.426	712177.509	198
13	Ogui Road	333617.843	712218.648	197
14	Ogui Road	333646.26	712259.788	198
15	Ogui Road	333674.678	712300.928	197
16	Ogui Road	333703.095	712342.067	198
17	Ogui Road	333731.512	712383.207	199
18	Ogui Road	333759.929	712424.346	199
19	Ogui Road	333788.347	712465.486	199
20	Ogui Road	333816.764	712506.625	199
21	Ogui Road	333845.181	712547.765	199
22	Ogui Road	333873.598	712588.904	198
23	Ogui Road	333902.015	712630.044	196
24	Ogui Road	333930.433	712671.184	195
25	Ogui Road	333958.85	712712.323	195
26	Ogui Road	333987.524	712753.283	194
27	Ogui Road	334016.256	712794.204	198
28	Ogui Road	334044.987	712835.125	198
29	Ogui Road	334073.719	712876.045	197
30	Ogui Road	334102.45	712916.966	197

The coordinates (Easting, Nothing and Height) helped to understand the profile of each transmission line in the city. The plotting of the profile was in Auto CAD Civil 3D software. The profile depicts that water can flow from the source tanks at New market to all the reservoirs in the different regions of Enugu urban (See Fig. 6). It is important to mention that Fig. 6 is a superimposition of the profile on the Google map for proper visualization.

The red line shows the transmission line from New Market tank through one of the major roads- Ogui road in Enugu Urban. The profile also reveals the most elevated point suitable for sitting of a reservoir along the transmission line. The transmission lines run from the terminal tanks at the New Market area of the city to the existing reservoirs. Figure 7 shows the transmission lines in purple color and other facilities as depicted in the legend of the map. Coal camp tank

All the pipe borne water distributed within the urban area are from the 4 million gallons, 1 million and 20,000m^3 tanks at New-market area of the city. All the water sourced from Ajali, Oji and 9th mile is assembled into these tanks for onward transmission to the end users. The closest parts of the city to New Market is the Government Reserved Area (GRA) and Ogui New Layout. These two zones, in the design were made to source water from the 20,000m^3 tank, while the other ten zones are served by a combination of 4 million and 1millon gallon tanks also at New Market area. Since Enugu urban is made up of three Local Government Areas, these LGAs were divided into four zones as shown in Table iii.

Table iii: Summary of the zoning and the locations of the reservoirs

S/N	LGA	ZONES	COORDINATES		HEIGHT	REMARKS
			EASTINGS	NORTHINGS		
1	**ENUGU NORTH**	GRA				Serviced by New market tanks
		Ogui				
		Coal camp	331605.02	711044.72	242.000	Reservoir
			332000.4	712302.5	254.398	New Booster
		Independence Layout	335808.5	711858	232.918	New Reservoir
2	**ENUGU SOUTH**	Achara Layout				Reservoir
		Gariki	333556.6	705762.7	220.106	Reservoir
		Amechi	335037.3	705286.5	212.799	Reservoir
		Akwuke	330427.2	706007.4	231.604	Reservoir
3	**ENUGU EAST**	Trans Ekulu	334218	717040.6	219.297	Reservoir
		Thinkers Corner	337128.4	714940.4	217.400	Reservoir
		Amorji Nike	337145	720910.1	232.943	New Reservoir
		Ibagwa Nike	336748.1	721885.8	252.799	Reservoir
Source: Author's Fieldwork (2021)						

In consideration of the topography, settlement pattern and the operation of radial system of water distribution network, a map showing the districts/zones and the respective locations of new reservoir were produced as shown in

Fig. 7. Apart from the reservoirs, the map also indicates the location of booster pump where there is an upshot of elevation that resists a free flow of water from the New Market to the Coal Camp reservoir.

In sitting the new reservoirs, consideration was also given to the locations the transmission lines. The goal was to design a functional distribution network that would save cost for Enugu State Water Corporation. Hence, the consideration given to the topography, existing transmission lines and the settlement pattern of the urban area. Figure 8 is a map showing an integration of the existing and new locations of water distribution facilities in Enugu urban.

Zones, such as Amechi, Akwuke, Amorji and Ibagwa are villages that have emerged to be part of the urban area. Increase in urban migration has made the city growth to expand into these settlements, and thus they had integrated them into these three Local Government Areas that make up Enugu urban. To accommodate the existing settlement pattern in these villages and also maintain a standardized layout of water distribution, a combination of radial system and dead-end systems of water distribution network layout was employed. In both situations, the reservoirs were stationed at points of highest elevation, while tree- like dead-end design was implemented to follow the settlement pattern of the villages with provisions for future expansion.

Figure 9 is a composite map showing a new design of water distribution network for Enugu urban area. The map shows the road network on which the water distribution network links are laid, the demarcation of the zones and the interaction of all functional facilities needed for efficient water distribution in this city.

The base map, Fig. 9, clearly depicts the advantages of the new design over the existing one. It shows an introduction of a booster station at a vantage point between the New market tank and coal camp tank. The existing tank at coal camp is properly positioned in terms of terrain elevation but it has not been receiving water from the source thanks because of the terrain configuration between the two thanks. To resolve this, a booster station has been appropriately located along the transmission line between the two tanks to ensure adequate water supply. With the help of geospatial technology, the zoning of the distribution areas was synchronized with the locations of the existing reservoirs for easy implementation and reduction in cost of management With these results, water can be conveyed from the source thanks at new market effortlessly to all the reservoirs in the zones. The base map also makes it very easy for the authorities of the agency in charge of water distribution in Enugu urban area, to assign different reservoirs to different source tanks for their respective supply of water. The water in the reservoirs at the most elevated point of the zones are reticulated by gravity to the inhabitants of the zones. This is very effective and reduces cost for the government and the end users. This is because, when water flows from a higher elevated point to a lower point by gravity, it requires no pumping cost. This design also gives room for proper management of water in the urban area. Each zone could be assigned to be managed by a unit of Enugu Water Corporation, to ensure quick responses to maintenance of facilities and demand of the end users.

6. Conclusion

This research aimed at demonstrating how geospatial technology can be used to develop an efficient water distribution network for urban areas with undulating terrain using Enugu, southeast Nigeria as a case study. The study found that water distribution in Enugu, Nigeria has been constrained by the undulating terrain and poor distribution network system leading to perennial water supply challenge in this city. To address this challenge, a proper evaluation of the existing distribution network was done by means of updating the existing map with the location of the existing facilities obtained through ground truthing and GIS. Remote sensing technology was used in extracting heights of points on the terrain from LiDAR satellite image and the design of a new map suitable for adequate water distribution network was done in ArcGIS software environment. Resulting from these was the division of the entire urban area into

12 zones following radial standard water distribution layout system and a combination of the dead-end standard water distribution network system to carter for future city expansion. The radial layout system permits zoning of distribution areas and location of the reservoirs at the center of the area. The efficiency of this water distribution system was tested in EPANET 2.0 software and the results revealed that it can be adopted in urban areas or cities where undulating topography possess a significant challenge to effective distribution of water. Moreover, this system is very economical and efficient as water distribution is majorly by gravity and each district or zone can be put under an administrator for adequate management. However, the success of the distribution system is incumbent upon availability of adequate volume of water from the intake sources.

Declarations

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*A**uthor's Contribution***

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Ugwuoti,Amos, Ojinnaka Oliver, Uzodinma, Victus and Ibem, Eziyi. The first draft of the manuscript was written by Ugwuoti, Amos and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Figures

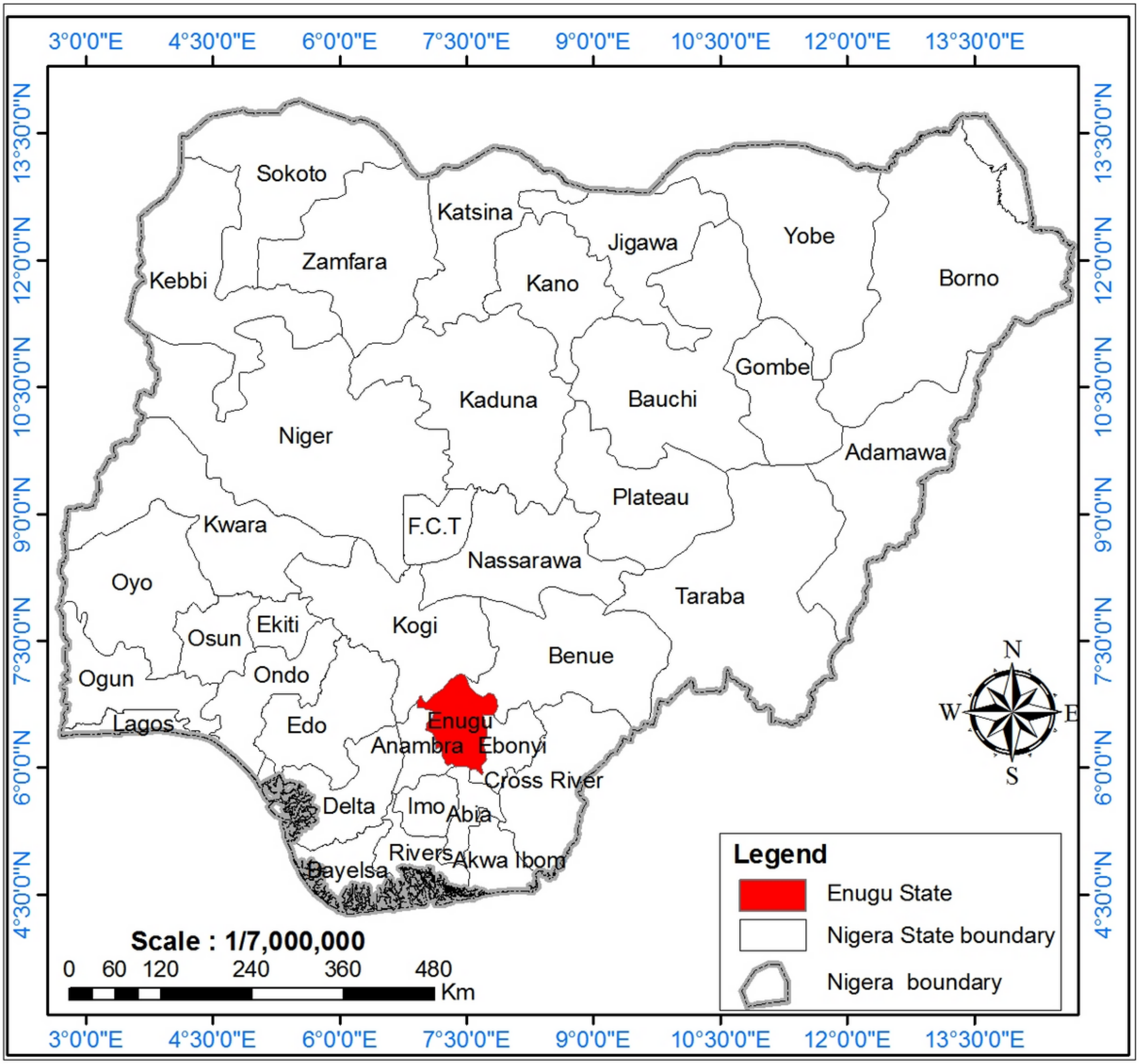

Figure 1

Map of Nigeria showing Enugu State in red colour

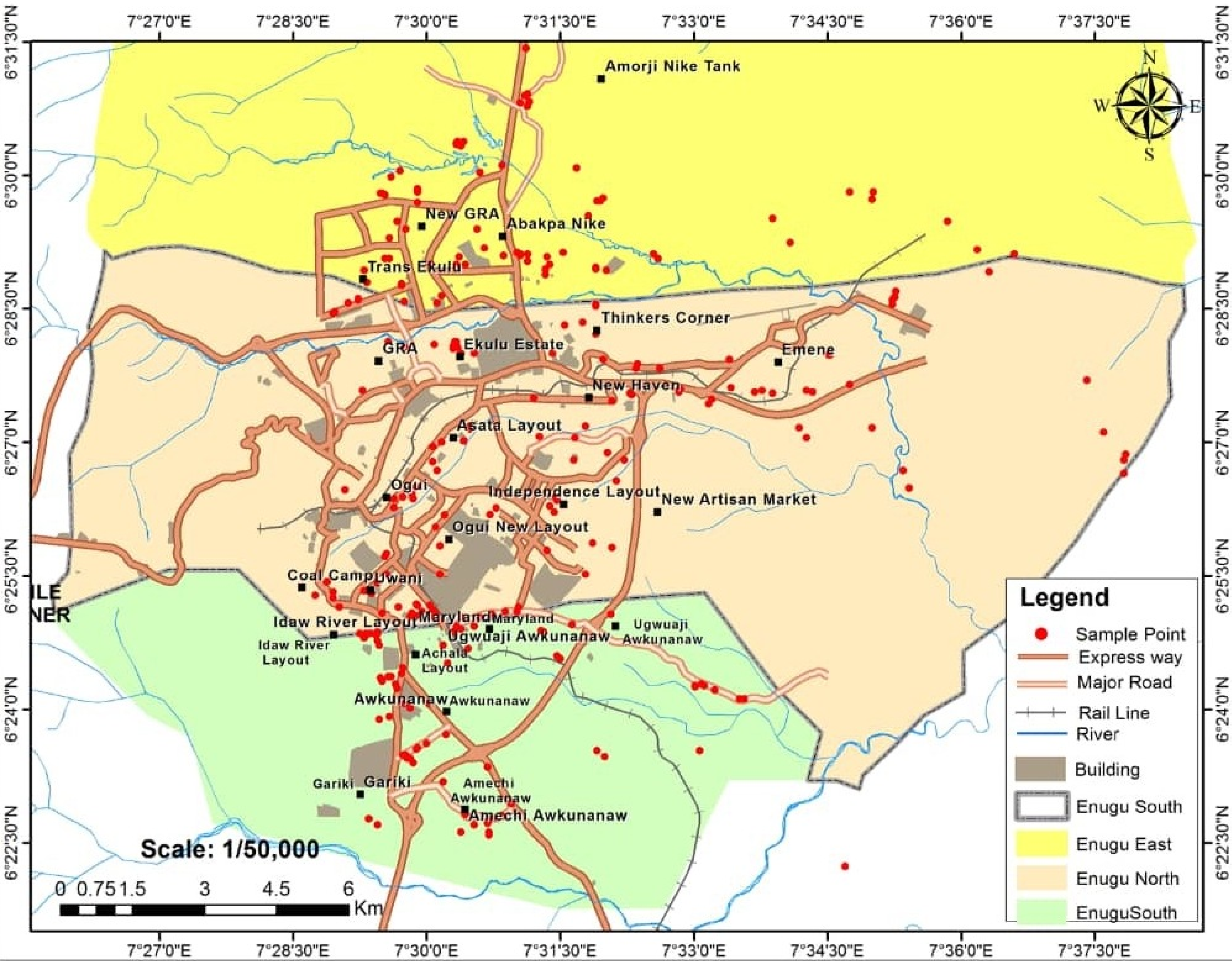

Figure 2

Map showing the three LGAs of Enugu Urban

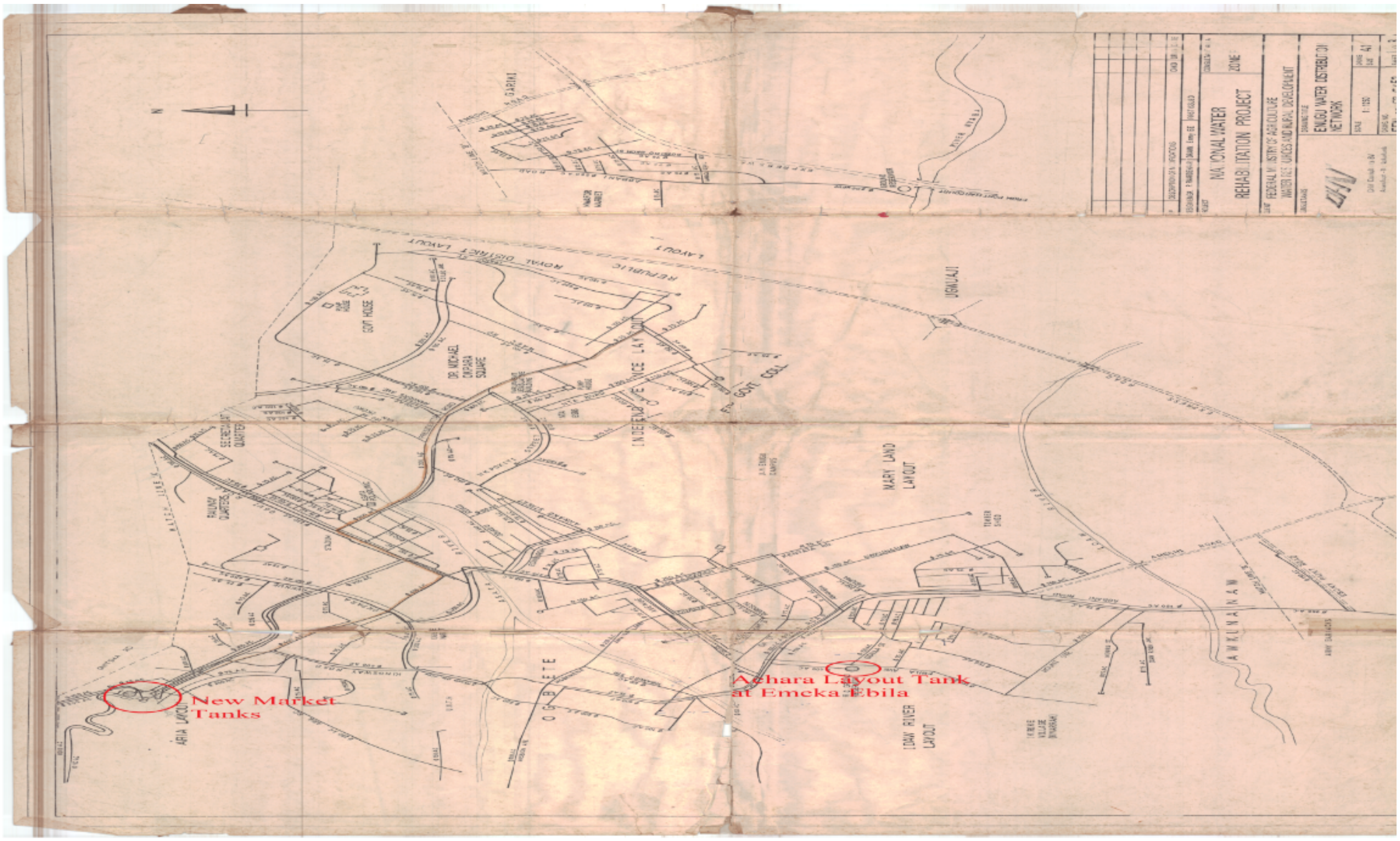

Figure 3

A sheet of the existing water distribution network map of Enugu Urban Area Source: Enugu State Water Corporation

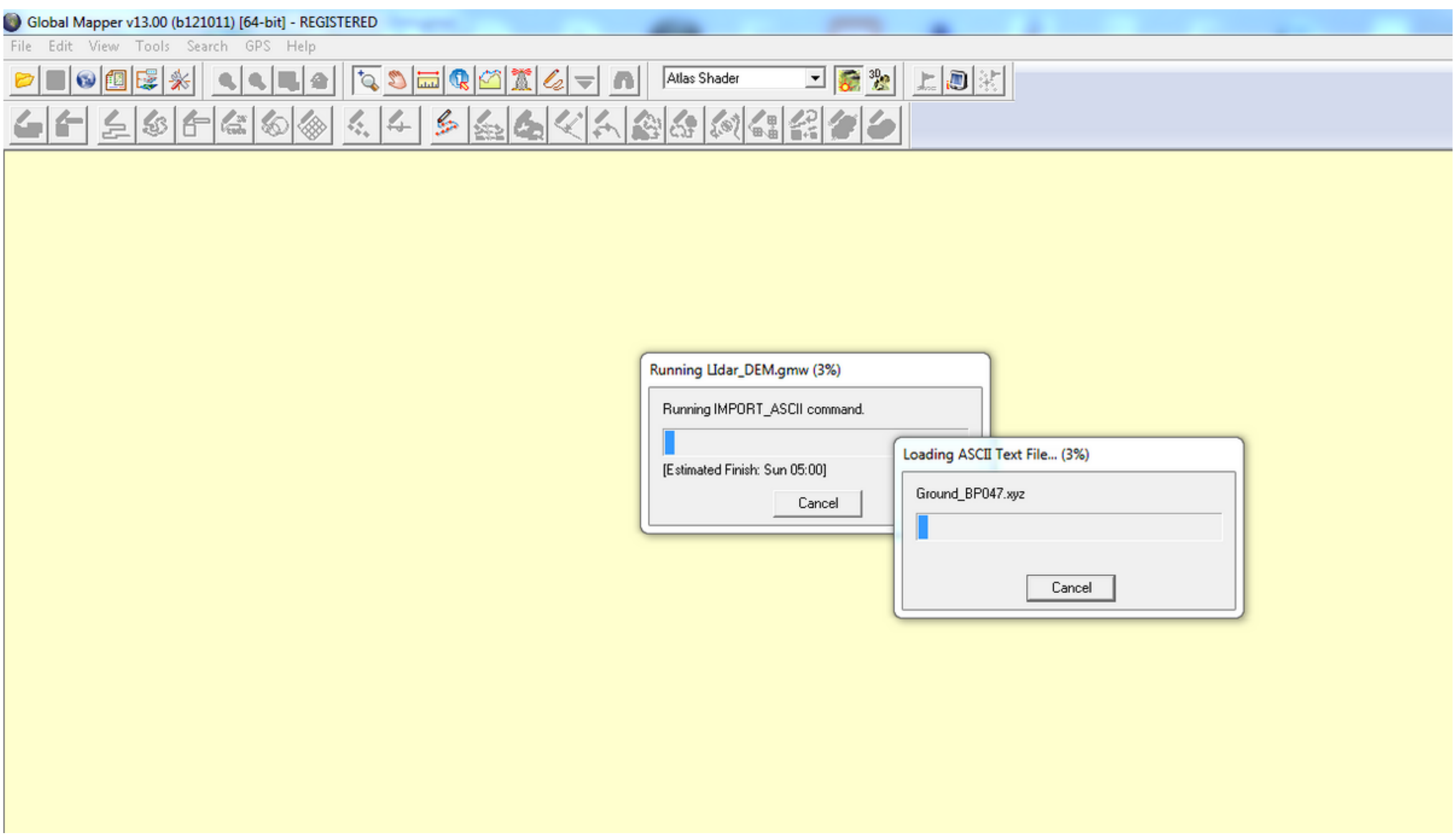

Figure 4

Importation of data from LiDAR image into Global Mapper Software

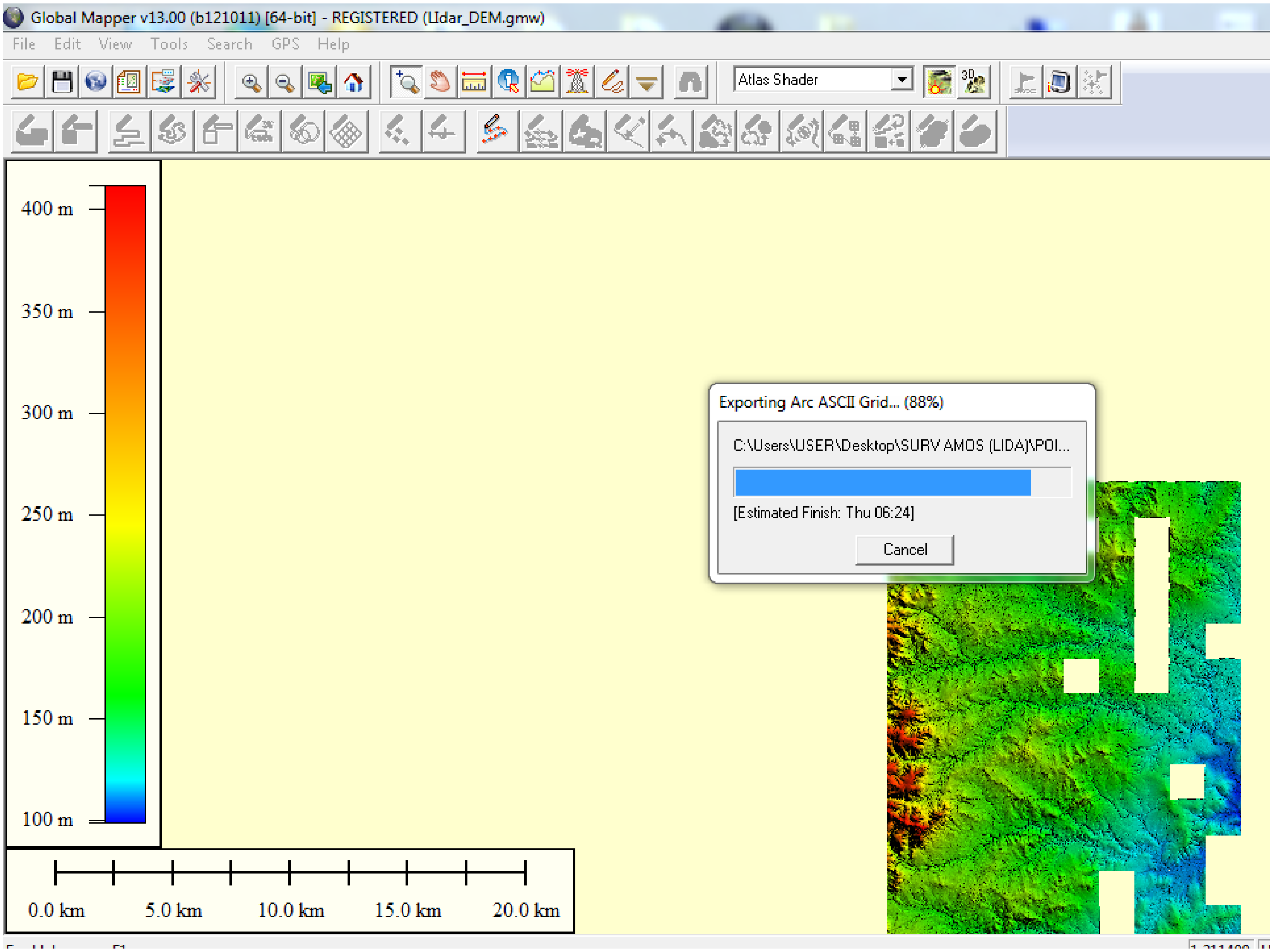

Figure 5

Exporting of point cloud from Global Mapper to Arc GIS

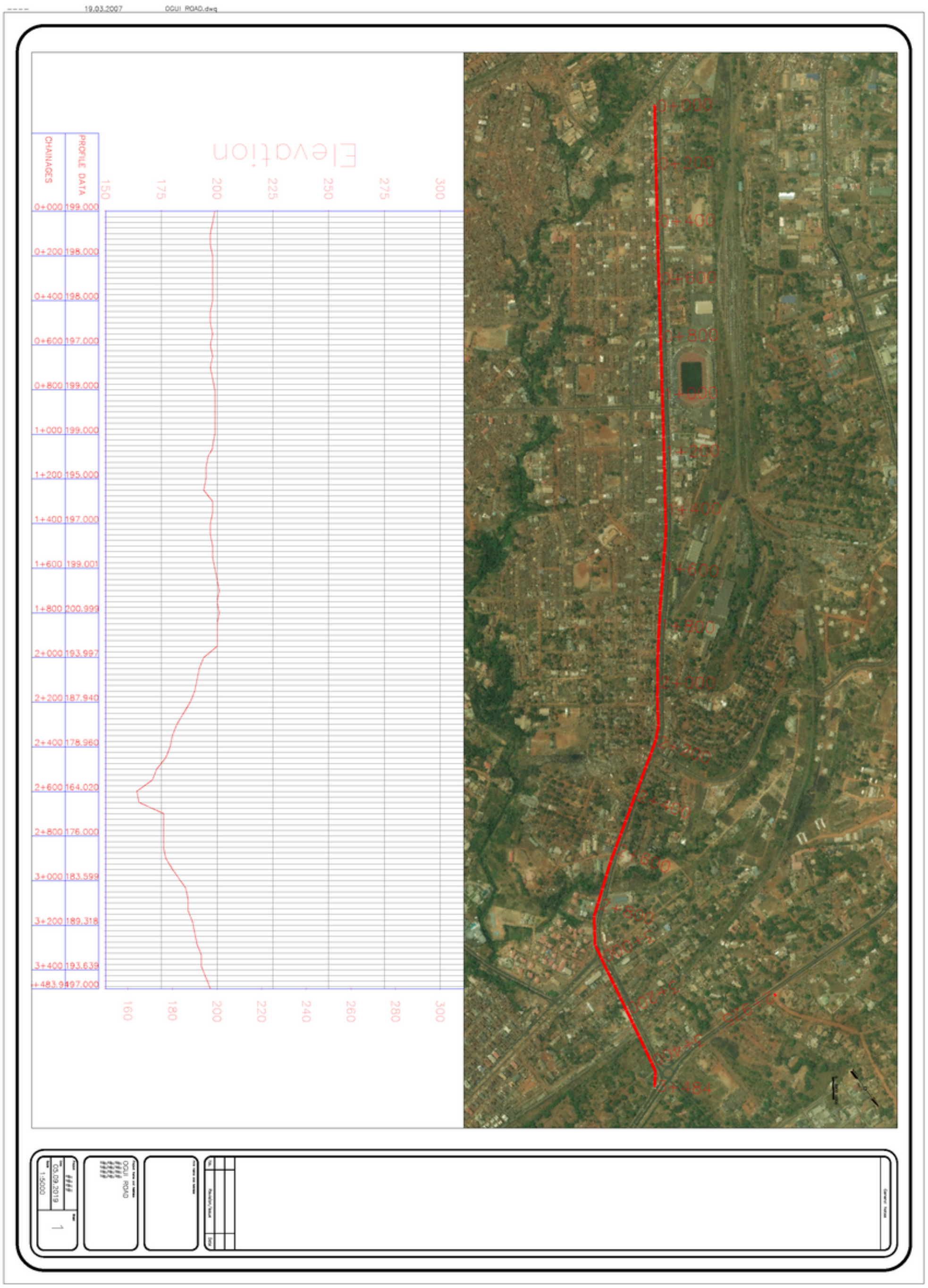

Figure 6

The plan and profile of a section of the water transmission line on Ogui road

Source: Author’s Field work (2021)

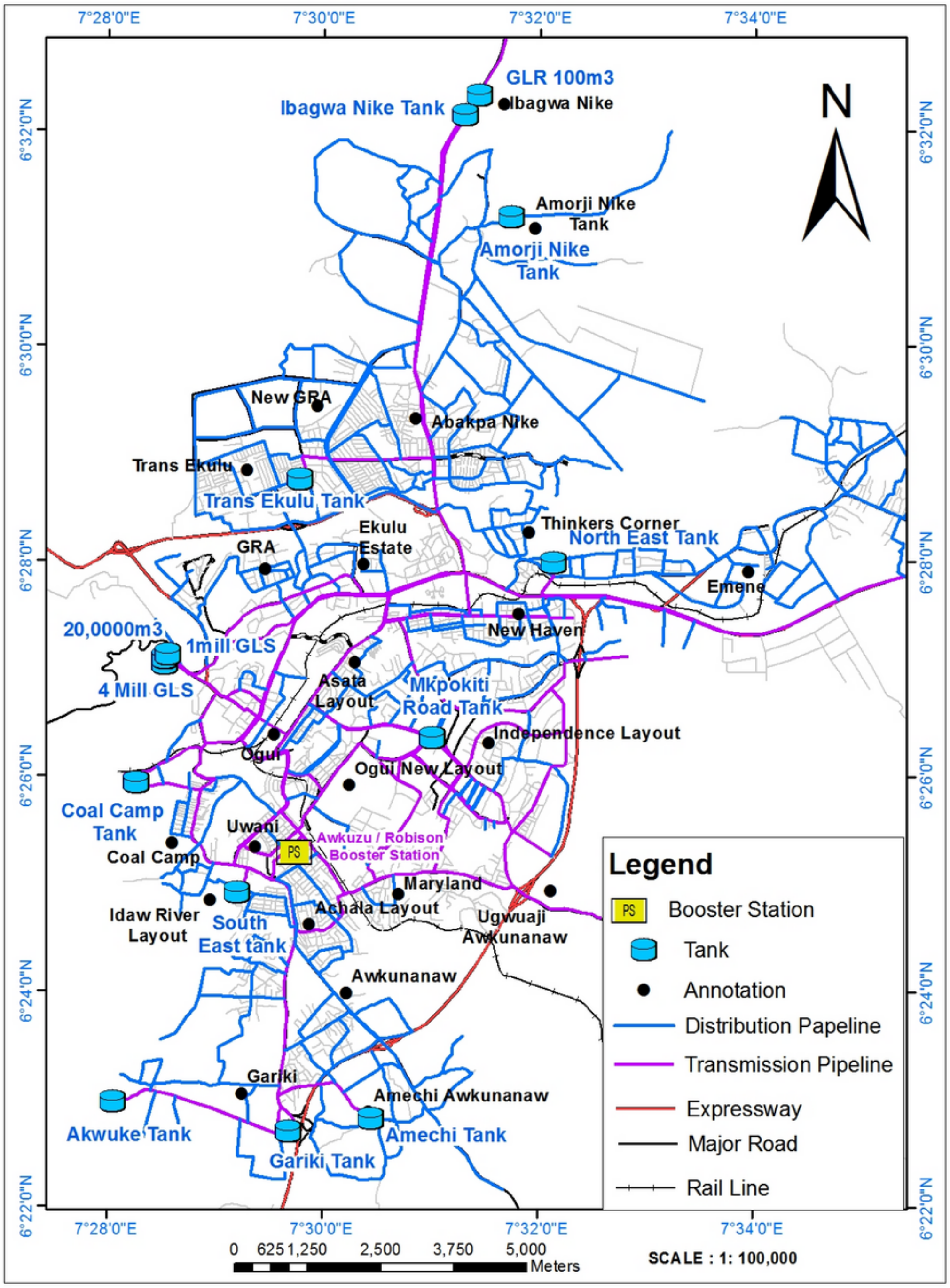

Figure 7

Map of the existing piped water distribution network in Enugu urban

Author's Fieldwork (2021).

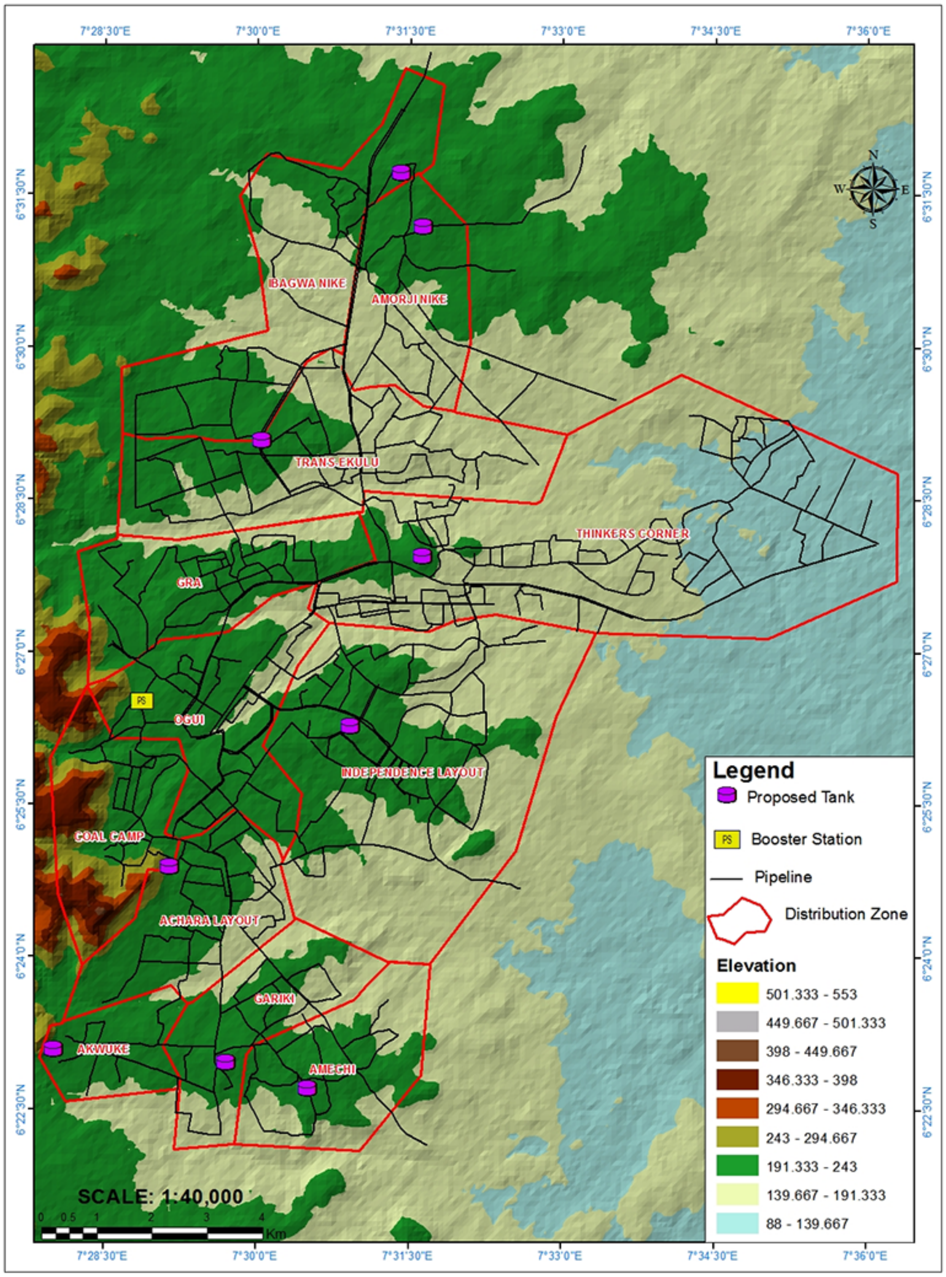

Figure 8

Figure 7: Map of the zones showing locations of water reservoirs based on the topography of the area

Author's Fieldwork (2021).

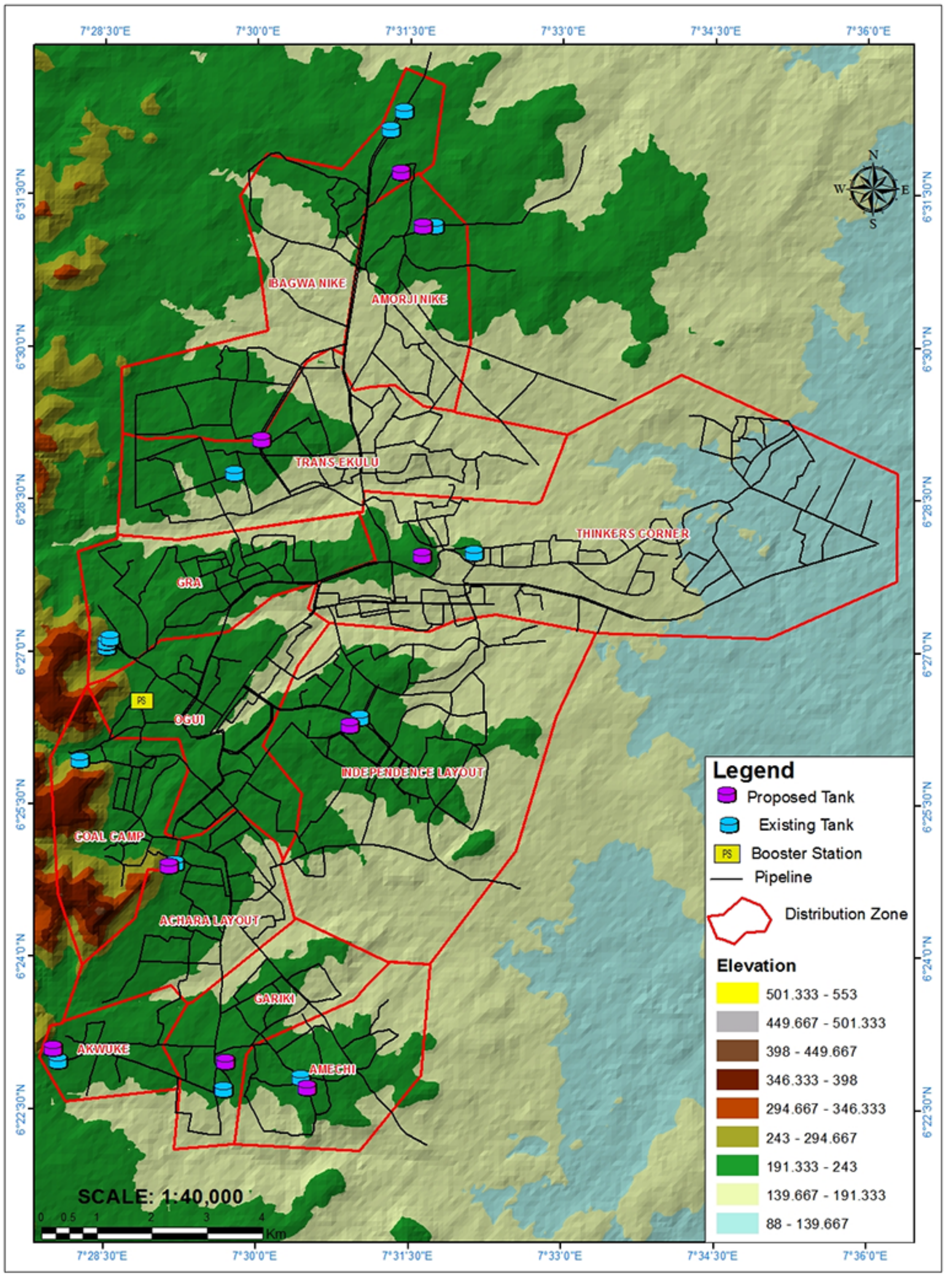

Figure 9

Figure 8: Map showing the Existing reservoirs and the proposed ones

Author's Fieldwork (2021)

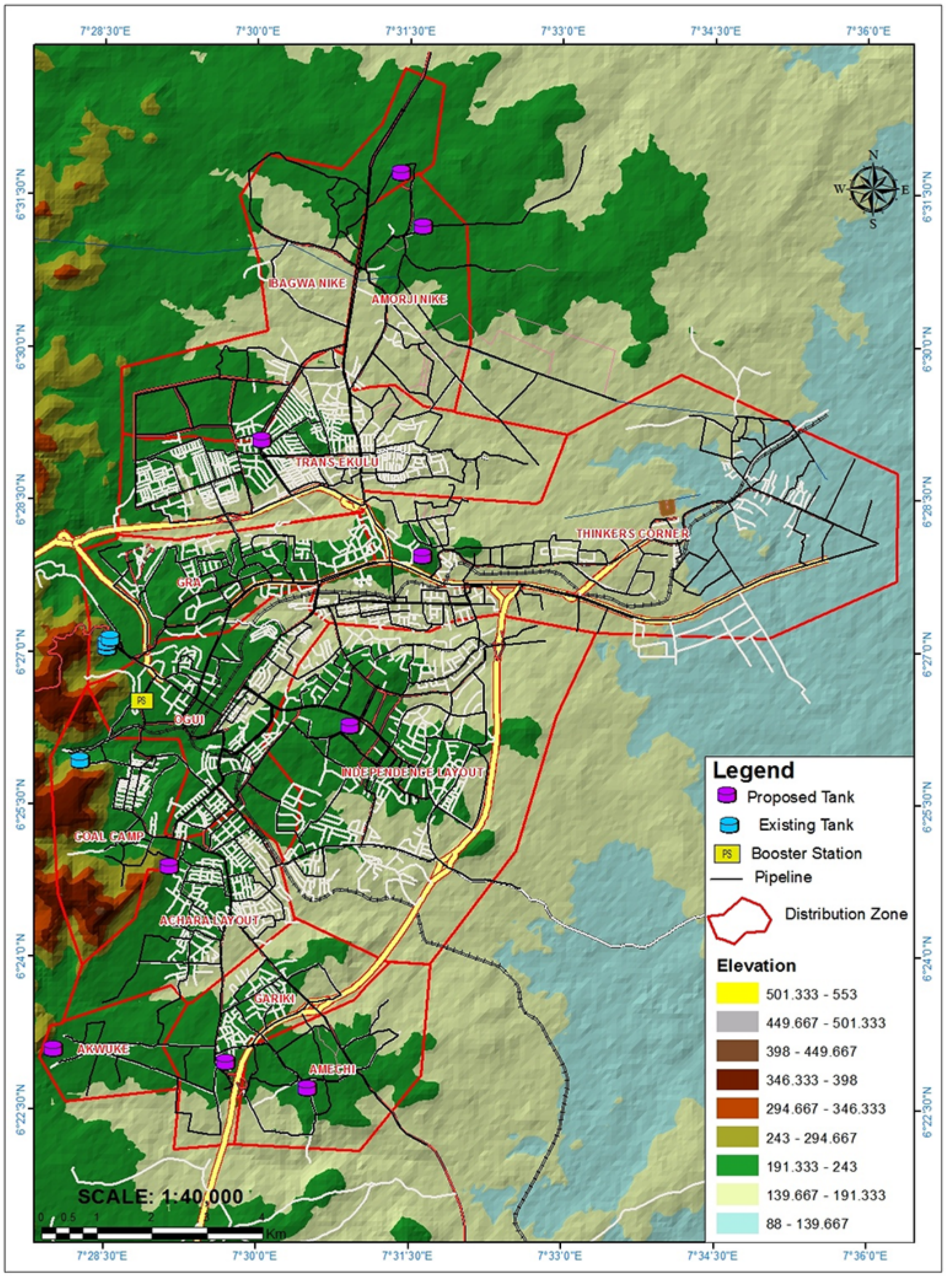

Figure 10

Figure 9: Base map showing the zones, positions of the reservoirs to the nearest most elevated point, transmission line, distribution lines and road network in Enugu urban.

Author's Fieldwork (2021)