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GEOSPATIAL MAPPING OF BURIED SERVICES: WATER DISTRIBUTION SYSTEM OF EDO STATE POLYTECHNIC, USEN AS CASE STUDY.

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ABSTRACT

Geospatial mapping is a spatial visualization method that enables the creation of customized maps to address specific requirements. Its primary aim is to show items with geographic coordinates in a geographical framework, providing a representation of the physical world on a map. Various approaches, solutions, and Geographic Information Systems (GIS) software can be employed to analyze existing geospatial data and geographical and terrestrial databases. Potable water supply is fundamental for food production, and therefore human existence. Lack or shortage of fresh water can impact negatively on the ecosystem and predispose human and animals to dangers such as water-borne diseases and even death. Water distribution systems are key to the provision of potable water to the public. The location records of these facilities assist in their maintenance, protection and provision of steady supply of potable water. The map and location coordinates in Nigeria Transverse Mercator (NTM) of the water distribution network of Edo State Polytechnic, Usen is in figure and table respectively. Edo State Polytechnic water distribution network has a total length of 4,008.607m as shown in figure 5, and coordinates for its various pipes shown in table 2.

INTRODUCTION

Water pipes are usually buried underground, and, therefore, direct monitoring and inspection for obtaining adequate data for use as a basis for deterioration forecasting analysis is difficult (Rogers and Grigg, 2009; Liserra et al., 2014; Shin et al., 2016; Tscheikner-Gratl et al.,2016; Salehi et al., 2018). Therefore, predictive models have been developed to predict the likelihood of pipe failure proactively and assist in the asset management plans (Lim et al., 2008; Herstein et al., 2010). The pipe failure can have an impact (among others) on the level of service (Giustolisi et al., 2016). The magnitudes and the scales of the impacts depend on many factors, amongst which, geographic location of pipe failure, the time of pipe failure and its duration and the topology and complexity of the WDN are some of the most important (Bicik, 2010). In some cases, a WDN may fail to meet the objectives, and the failures can be categorized into the following types (Ostfeld et al., 2002; Ozger, 2003):

Modern societies rely on a complex network of critical civil infrastructure systems such as road networks, water distribution systems (WDSs), sewage networks, oil and gas networks, electric power systems, etc., which are extensive, often interdependent, and designed for long service life and intended to deliver basic necessities/amenities and services for the safety, security, prosperity and social wellbeing of societies. Water is one of these basic necessities of life. It is very important as it is the major constituent of both plants and animals (Chakhaiyar, 2010). Water is one of the most crucial and non-substitutable resources of our planet earth. Adequate quality, 'Potable' water is a basic need for human life (Bantie, 2011).

The crucial importance of water to so many aspects of human health, development and well-being led to the inclusion of a specific water-related target in the Millennium Development Goals (MDGs). At the same time, every target of the MDGs depends on the achievement of the water and sanitation target: eradicating extreme poverty and hunger; achieving universal primary education; promoting gender equality and empowering women; reducing child mortality; improving maternal health; combating HIV, AIDS, malaria and other diseases; and ensuring environmental sustainability.

Geographic Information System (GIS) is a computer system for capturing, storing, querying, analyzing, and displaying geospatial data. GIS can also be defined as a process of systematic gathering, storing, analyzing, and presenting of geographic information to gain insights, make informed decisions, and solve spatial problems. It involves data collection, mapping, and the use of software tools to extract valuable insights for various applications.

Failure of a sub-system will adversely affect the system. Failure in WDSs can be caused by the effect of imposed loads (ground and live loads), extreme environmental condition, aging, fatigue, deterioration due to chemical attacks, etc. These failures can occur in unpredictable locations and may cause cascading effect to other systems (electricity, transport, buildings, etc.) resulting in urgent emergency situations (Grigg, 2007, 2013; Shuang et al., 2016).

Therefore, effective asset management in the water supply sector is vital for providing uninterrupted services and it is dependent on the knowledge of the precise geographical location of the distribution network.

Research has shown that more than 80% of all information can be geographically referenced (Dangermond, 1999). Parker (1996) on the other hand showed that about 85% of all information has some spatial contents. The role of Geo-spatial analysis cannot be overestimated as a determining factor in today's policy making for a better world; it must form the basis of any strategy for economic development of a region (Haarsma, 2008). Geospatial information is the basic ingredient for the physical planning, design and development of infrastructure (Ehiorobo and Audu, 2007). Geo-spatial information, which exists in real world in terms of space (with location) and time, can be represented in the form of maps, databases and statistical representation (Akinyede and Borroffice, 2004). Coordinates are geospatial information used to represent the location of natural or man -made features on the

earth 's surface. They are set of values that define a position within a spatial reference (ESRI, 2000). Geo-spatial information plays a significant role in the planning, design, location and maintenance management of water distribution infrastructure (WDI). Furthermore, most components of water infrastructure are referenced to the surface of the earth (Audu and Ehiorobo, 2010).

Water distribution systems (WDSs) are among the most critical civil infrastructure systems. Reliable and safe water supply is essential for the prosperity and continued well-being of the society. Hence, adequate maintenance, repair, and renewal of the vast physical assets in WDSs are of paramount importance especially in places with a widespread deterioration of critical water infrastructure assets. However, due to limited information about their location, water utilities struggle to keep their asset management strategies in pace with aging of components.

They consist of pipes, nodes (pipe junctions), pumps, valves, and storage tanks or reservoirs.

They are costly and complex infrastructures which are meant to distribute water uninterruptedly over a long planning horizon. Once laid, pipes cannot be reinforced without making large investments.

Even a simple water main break can lead to sinkholes, damage or failure to adjacent structures (e.g. gas, oil, road networks, etc.), disruptions to transportation and commerce, impediments to emergency response, and sometimes human casualties (Little, 2012; ASCE, 2017).

In 2005, the Institution of Civil Engineer's (ICE) Geo-spatial Engineering Board, United Kingdom (UK), while examining "buried services in a conference, deliberated extensively on the problems of location, identification and geo-spatial positioning of a wide range of buried services such as water, sewers, gas, electricity, etc. The question from the Director of UK Water Industry's Research Body, Farrimond (2005), buttresses the fact that the location and geospatial positioning of engineering infrastructure, which include water infrastructure, is not only a major problem in developing countries but also in industrialized nations of the world.

Farrimond asked "can we do something today to make these assets easier to find in a hundred years' time?"

STATEMENT OF THE PROBLEM

Inadequate information about the location and geospatial positioning of water distribution infrastructure components of the study area underneath the earth's surface.

Absence of as-built drawings that show how the water distribution infrastructure are on the ground or beneath the earth surface.
Recurrent pipe burst due to construction works and other activities.

AIM AND OBJECTIVES OF THE STUDY
The aim of this study is to facilitate adequate maintenance management for water distribution system to improve and sustain the quality and quantity of potable water distributed to the consumers in the study area through the following objectives:
1 Determine the geospatial positioning of the existing water distribution system (WDS) of Edo State Polytechnic, Usen.
2 Create a data base of the geospatial position/location of the existing WDN of the study area.

LITERATURE REVIEW
Geospatial Mapping
Geospatial mapping is a spatial visualization method that enables the creation of customized maps to address specific requirements. Its primary aim is to show items with geographic coordinates in a geographical framework, providing a representation of the physical world on a map. Various approaches, solutions, and Geographic Information Systems (GIS) software can be employed to analyze existing geospatial data and geographical and terrestrial databases
The GPS measurement is usually stored in computer memory in the GPS receivers, and are subsequently transferred to a computer running the GPS post-processing software. This software computes baselines using simultaneous measurement data from two or more GPS receivers. These post-processed measurements allow more precise positioning, because most GPS errors affect each receiver nearly equally, and therefore can be cancelled out in the calculations.
DGPS measurements can also be computed in real-time study by some GPS receivers if they receive a correction signal using a separate radio receiver as in RTK (Real Time Kinematic) surveying).

Water Distribution Systems
Water distribution systems are infrastructure designed and constructed to adequately satisfy the water requirement for a combination of domestic, commercial, industrial and firefighting purpose. The distribution system consists of a network of pipes with appurtenances to transport water from the purification plant to the consumers' tap. It also includes the design and operation of storage, service or balancing reservoirs (Punmia,1995). It is used to describe collectively the facilities used to supply water from its source to the point of usage (WATER ONLINE, 2014). Water distribution systems are characterized by a massive array of pipes and boundary devices.
A water supply network consists of engineered hydrologic and hydraulic mechanisms (Anonymous,2005). These include water resources, pumps, treatment plants, reservoirs, pipes and their accessories (Babovic *et al.*, 2002; Chin, 2006) and other equipment for operation and management.
A water supply distribution system consists of a complex network of interconnected pipes, services, reservoirs, hydrants and other appurtenances which include valves and flow meters to deliver water from the treatment plant to the consumer (Chadwick and Morfett, 1993; Nathanson, 1997 and Izinyon, 2007). Madueke (2006) opined that water distribution system is a collection of hydraulic control element (pipes and valves) that direct water from the supply location to the demand site. A distribution system also made up of distribution zones. A distribution zone is a part of distribution system in which all consumers receive drinking water of identical quality from the same sources, with the same treatment and usually at the same pressure (Bukar, 1992).
Water distribution systems are buried infrastructure, and therefore it is extremely difficult to locate problem areas.
Designing and operating a water distribution system is the most important consideration for a lifetime of expected loading conditions. Water distribution system must be able to assist the

abnormal conditions such as pipe breakages, mechanical failure of pipe, valves and control systems, power outages and inaccurate demand projections. (Dipali et all, 2017)

Water Distribution System Integrity

Water distribution network integrity is a measure of the extent of the ability of a water distribution system to fulfil its purpose. That is the ability of the network to sustain continuous delivery of potable water to the consumers at the right quantity, quality and pressure. There are three parameters to measure WDN integrity which include:

Hydraulic Integrity

Hydraulic integrity of water distribution system is a measure of the ability of the water distribution system to be able to provide the flows and pressures required for the required level of service. It is primarily determined from pressure measurements in the system. Ideally, reservoir water levels and system pressure should be monitored continuously. Unexpected changes to pressure may indicate problems such as closed valves or pipe bursts in real time. Typical measuring points include critical points in the network, such as the furthest and highest points, as well as the suction and delivery sides of pumps and control valves. Flow rate should also be measured at critical points such as sources, bulk supplies, both inlets and outlets of reservoirs, transfers to other municipalities and consumers. Critical measurements should be communicated to the system control room through a SCADA or alternative communication system, and in advanced cases, this data is used in combination with a hydraulic network model of the system to continuously monitor the hydraulic state of the system. Consumer complaints are a valuable source of information on system integrity and should be monitored.

Maintaining Hydraulic Integrity

To maintain the hydraulic integrity of water distribution systems and ensure the best possible water quality, residence times in the system should be kept as short as possible and large fluctuations in flows and pressures, as well as low flows and pressures should be avoided. Hydraulic modelling is an important operational tool and can be used to investigate alternative operational methods, for instance when taking a pipe or reservoir out of operation, anticipate future problems and training of operators.

Physical Integrity

This is a measure of the ability of the water distribution system components to be able to function as intended and provide a barrier between the water in the system and external threats.

Water Quality Integrity

This is a measure of the ability of the water distribution system components to be able to deliver water of acceptable quality to all its users (assuming that it receives source water of acceptable quality).

The different types of water distribution system integrity are not independent, but influence each other. For instance, a loss of physical integrity due to cracks in pipes may lead to a loss of hydraulic integrity through increased friction losses, and a loss of water quality integrity if polluted water outside the network is able to enter the pipes through the cracks. Ideally, there should be no change in water quality from the time it leaves the treatment plant until it is delivered to the consumer, but in reality, substantial changes may occur as a result of complex physical, chemical, and biological reactions.

Water Distribution System Performance Indicators

The purpose of water distribution system is to deliver water to consumer with appropriate quality, quantity and pressure. The performance of a distribution system can be judged on the basis of the

pressure available in the system for a periodic rate of flow and by the degree to which the following objectives are accomplished: The performance of a distribution system can be judged on the basis of the pressure available in the system for a periodic rate of flow and by the degree to which the following objectives are accomplished:
1 The system should be economically efficient. The initial cost of construction should be as low as possible.
2 The layout should be such that no consumer would be without water supply, during the repair of any section of the system.
3 It should be capable of supplying water at all the intended places with sufficient pressure head. It should provide the demand for water at an acceptable residual pressure during an acceptable portion of the time. The head should not be excessive. The exact specification of acceptable levels of pressure and time (e.g., provide demand flow at a minimum 30m pressure for 99% of the time) are often subject to regulations and vary with locality.

4 The system should be capable of providing emergency flows (e.g. for firefighting) at an acceptable pressure and should be capable of supplying the requisite amount of water during firefighting.
5 The system should have an acceptable level of reliability.

6 The system should provide safe drinking water and maintain a degree of purity. Water quality should not get deteriorated in the distribution pipes and should provide water that is acceptable to the consumer in terms of aesthetics. odour and taste.

7 All the distribution pipes should be preferably laid one metre away or above the sewer lines.
8 It should be fairly water-tight as to keep losses due to leakage to the minimum.
9 It should be capable of meeting the fire demand simultaneously.
10 It is should be easy to operate and maintain.
11 It should be laid such that it does not cause obstruction to traffic during repairs and maintenance.

Water Distribution System Layout
Water distribution pipes are generally laid below road pavement and typically follow road networks (John & Siby, 2015; Punmia et al., 1995). The topology of WDSs varies from simple tree-like structure to more complex networked structures. Punmia et al. (1995) described the four most common types of water distribution networks shown in Figure (2.1). Any of these layouts can be used separately or in combination with others. Detailed design and pros and cons of these layouts can be found in John and Siby (2015), and Punmia et al. (1995).

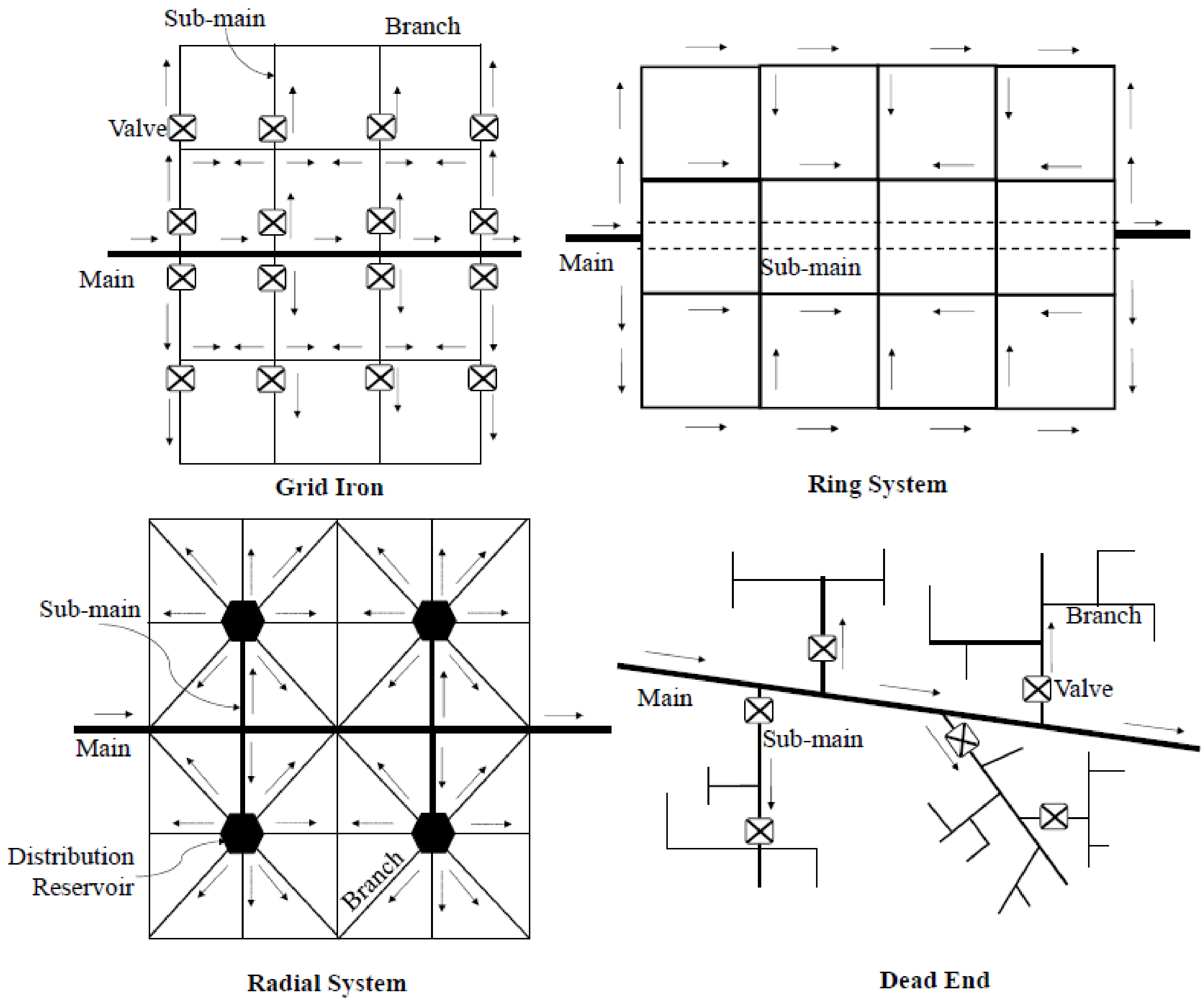

Figure 1: types of water distribution network

Excavation and Back Filling for Water Distribution System

Trench should be wide enough to allow good workman ship. Its width should be equal to external diameter of pipe and an additional of 40-50 millimeters. Extra excavation is done which is necessary at the bells or joints. Sufficient cover is necessary to protect the water pipes from the traffic load and to prevent freezing. Generally, pipes are placed at depth of 0.8-2.0 m from top of pipe. Back fill materials should be free from debris, rock, stones bricks etc., and should consist of good soil. Back fill should not be done in freezing weather or with frozen material. Partial back fill should be done before leakage test and complete backfilling should be done after tests. Special bedding material support must be provided adequately at the trench bottom.

Handling and Laying of Water Distribution Pipes

The following points should be taken into consideration while handling and laying water distribution pipes.

- All pipes and fittings should be checked before unloading at the installation site.
- Pipes and fittings should be dropped carefully from the truck so to avoid damage.
- If the cable with hooks is used in unloading, then hooks should be covered with rubber.
- If a fork lift is used, care is needed to avoid damaging the exterior coating, interior lining or the pipe itself.
- In moving pipes and fittings, they should never be rolled by bulldozer blades or any other equipment. Instead they must be rolled by hand.

Pipes and fittings in trench should be supported properly.
Jointing procedure should follow the recommendations of pipes and joints.
Stones found in the trench should be removed for a depth of at least 6 inches below the bottom of the pipe.
The bottom of the pipes should be leveled properly.

Pipe Deterioration

Pipe bursts are a regular occurrence in water distribution systems. Bursts commonly occur when the residual strength of a deteriorated main becomes inadequate to resist the force imparted on it (Skipwort et al. 2002). From a terminology point of view pipe bursts are commonly referred to also as breaks or failures and are linked to leaks when losses in water distribution networks are analyzed (Farley & Trow 2003).
The deterioration of pipes may be classified into two categories (Kleiner & Rajani 2001):
structural deterioration, which diminishes the pipe's structural resilience and its ability to withstand the various types of stresses imposed upon it.
functional deterioration of inner surface of the pipe resulting in diminished hydraulic capacity and degradation of water quality.
Construction related pipe failure.
The consequence of pipe failures is not only an economic burden (repair and other costs), but it can also have significant social (e.g. service interruptions, traffic delays, etc.) and environmental (e.g. lost water and energy) impacts.
Most studies in literature show a relationship between failure rates and time of failure (age of pipes), and some of them suggest a methodology to optimize the replacement time of pipes. Shamir and Howard (1979) reported an exponential relationship, Walski and Pellicia (1982) applied such exponential relationship to a data set stratified by material of pipe, and Clark (1982) developed a linear multivariate equation to characterize the time from pipe installation to the first break and a multivariate exponential equation to determine the breakage rate after the first break
The type of materials used within distribution systems are closely related to the urbanization period in which they were laid. Cast iron and asbestos-cement pipes were used within the first two "bubbles" of infrastructure with cast iron representing the majority. Cast and ductile iron were used in the third "bubble". The newest infrastructure or forth "bubble" represents the period in which PVC pipes were introduced.
PVC pipes have the lowest breakage rate at approximately 0.02 [breaks/km/year], ductile iron the middle at approximately 0.2 [breaks/km/year] and cast iron exhibits the greatest number of pipe breaks at approximately 0.6 [breaks/km/year]. PVC is pressure fitted at the joints and does not exhibit the leaky joint properties of the older methods.

Water Distribution System Energy and Hydraulic Grade Lines

The mechanical energy of a fluid depends on three parameters:
1) Its elevation (potential energy)
2) pressure (another form of potential energy)
3) velocity (kinetic energy).
The energy is commonly expressed per unit weight of fluid, which has convenient length units. In this form it is called energy head and it is typically measured in metres.
As water flows through pipes in a steady state, resistance to the flow is normally developed due to friction in the pipe. Energy is therefore required to enable the delivery of the water to the end of the pipe network. To determine the velocity of water at any point in the pipe network, Bernoulli's Theorem is applied, (Engineer Educator,2007)
The Bernoulli equation describes the energy head of a fluid as the sum of its elevation, pressure head and velocity head as follows:

$$Hs = Z + Hp + \frac{V2}{2g} \quad \text{---} \quad 1$$

Where Hs = Total system head (m)
Z = Elevation head (m)
Hp = Static head (m)
$\frac{V2}{2g}$ =Velocity head (m)

An important measure in water distribution systems is the hydraulic grade, which is the sum of the elevation head and pressure head. Thus, the hydraulic grade represents the fluid energy excluding the velocity head. In water distribution systems the velocity head is normally very small compared to the other two components, and thus the hydraulic grade is often used instead of the total energy. The energy line (EL) and hydraulic grade line (HGL) are obtained by plotting the energy and hydraulic grade above a longitudinal section of a pipe. The energy line always slopes downwards in the direction of flow, and the drop in the energy line represents the loss of energy in the system. The figure below shows the HGL of a system during minimum flow conditions (early morning hours when demand is almost nothing) and under peak flow conditions (when demand is at a maximum).

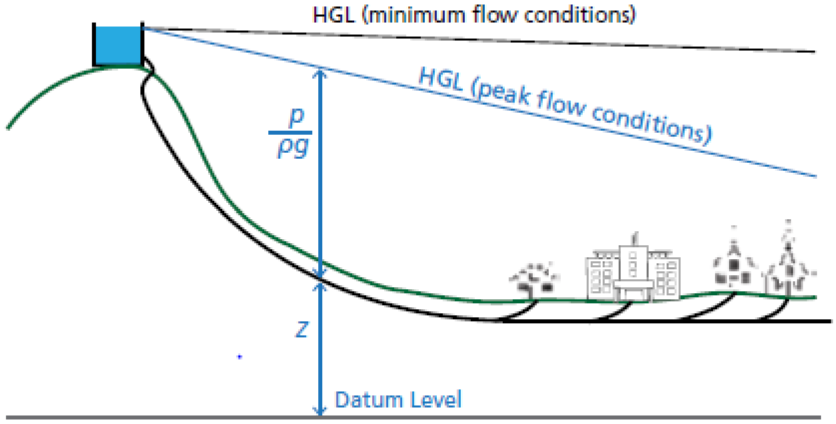

Figure 2: Energy line (EL) and hydraulic grade line (HGL)

The height difference between the pipe and HGL indicates the pressure head, and thus the figure shows how the system pressure is at a maximum in the early morning hours and at a minimum under peak demand conditions. The resistance to flow causes a pressure loss along the pipeline measured as the height of water column in metres and is commonly referred to as head loss. Head loss in distribution pipes is affected by the viscosity of the fluid, the diameter of the pipe, the pipe internal surface roughness, elevation changes with the system and the length of travel of the fluid (Pipeflow,2017)

METHODOLOGY

Description of the Study Area

The study area, Edo State Polytechnic, Usen is in Edo State of Nigeria. Usen lies within Ovia Southwest Local Government of Edo State. Figures 4 presents the map of Ovia South Local Government showing Usen. The study area, Usen is delineated by National Coordinates 303404.70 mN to 324434.53 mE.

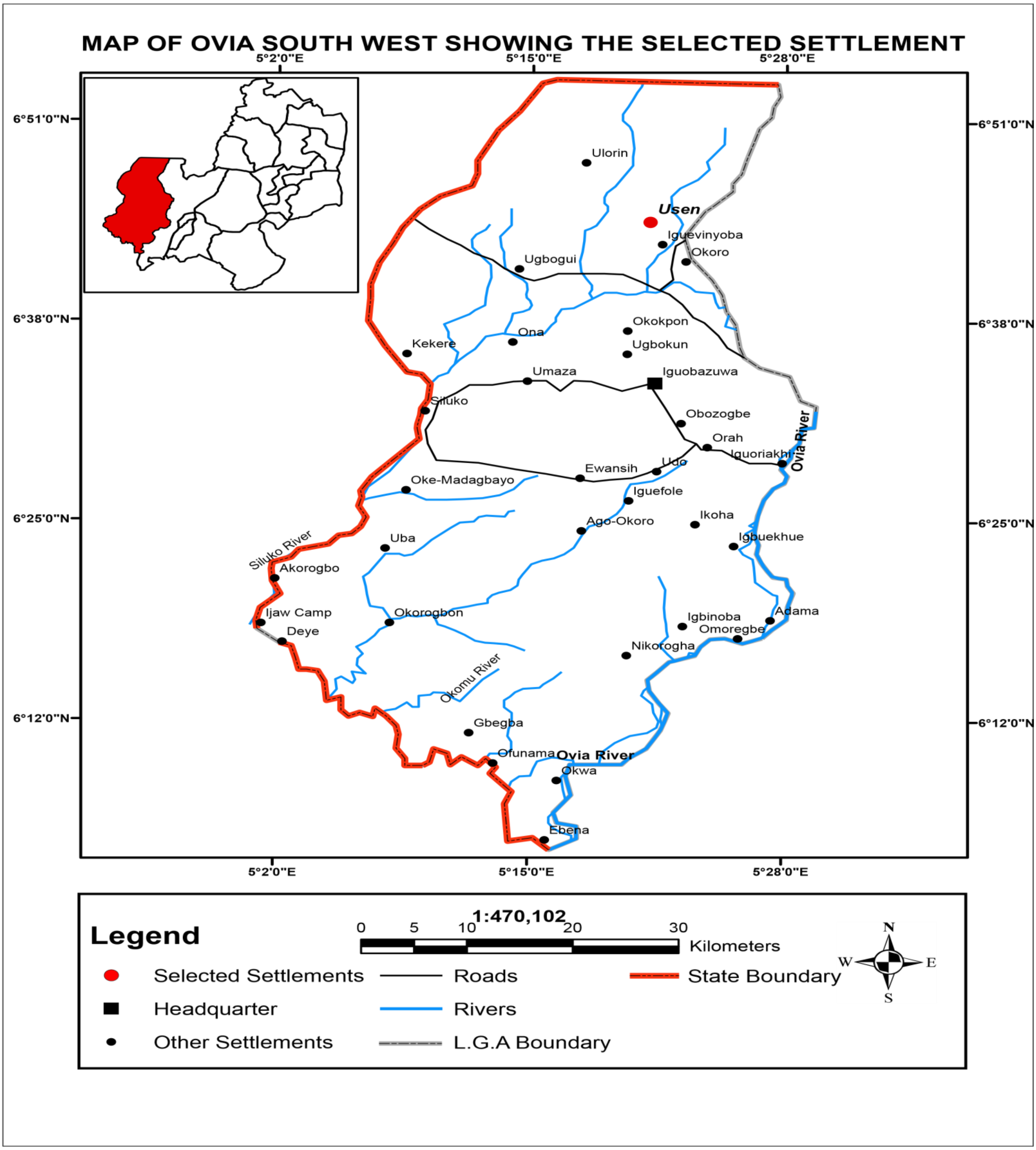

Figure 3: Map of Ovia Southwest Local Government Area.

Geospatial Data Collection

The geospatial data of the existing water distribution infrastructure components of the study area were acquired using Leica 300 Global Positioning System (GPS) receivers. The positioning of the water distribution network was carried out using the method of Differential Global Positioning

System (DGPS) and Geomatics techniques and instruments. This is an enhancement which provides improved location accuracy, in the range of operation of each system, from the 15-metre nominal GPS accuracy to about 1-3 centimeter in case of the best implementations. (Wikipedia)
Each DGPS uses a network of fixed ground-based reference stations to broadcast the difference between the positions indicated by the GPS satellite system and known field positions. These positions broadcast the difference between the measured satellite pseudoranges and actual (internally computed) pseudoranges. And the receiver station may correct their pseudoranges by the same amount.

Geospatial Data Processing

Geo-spatial data processing involves the post processing of the GPS data acquired. The GPS data of the water distribution network of the study area captured in geographical co-ordinates were converted to plane rectangular co-ordinates using INCA GeoMATRIX software. This software transformed the GPS data of the water distribution network in World Geodetic System 1984 (WGS'84) to plane rectangular co-ordinates. Thereafter the GPS data were used to generate a text file using Microsoft Excel. This facilitated the loading of the co-ordinates into the Automatic Computer Aided Design (AutoCAD) to model the water distribution network of the water works of the study area.

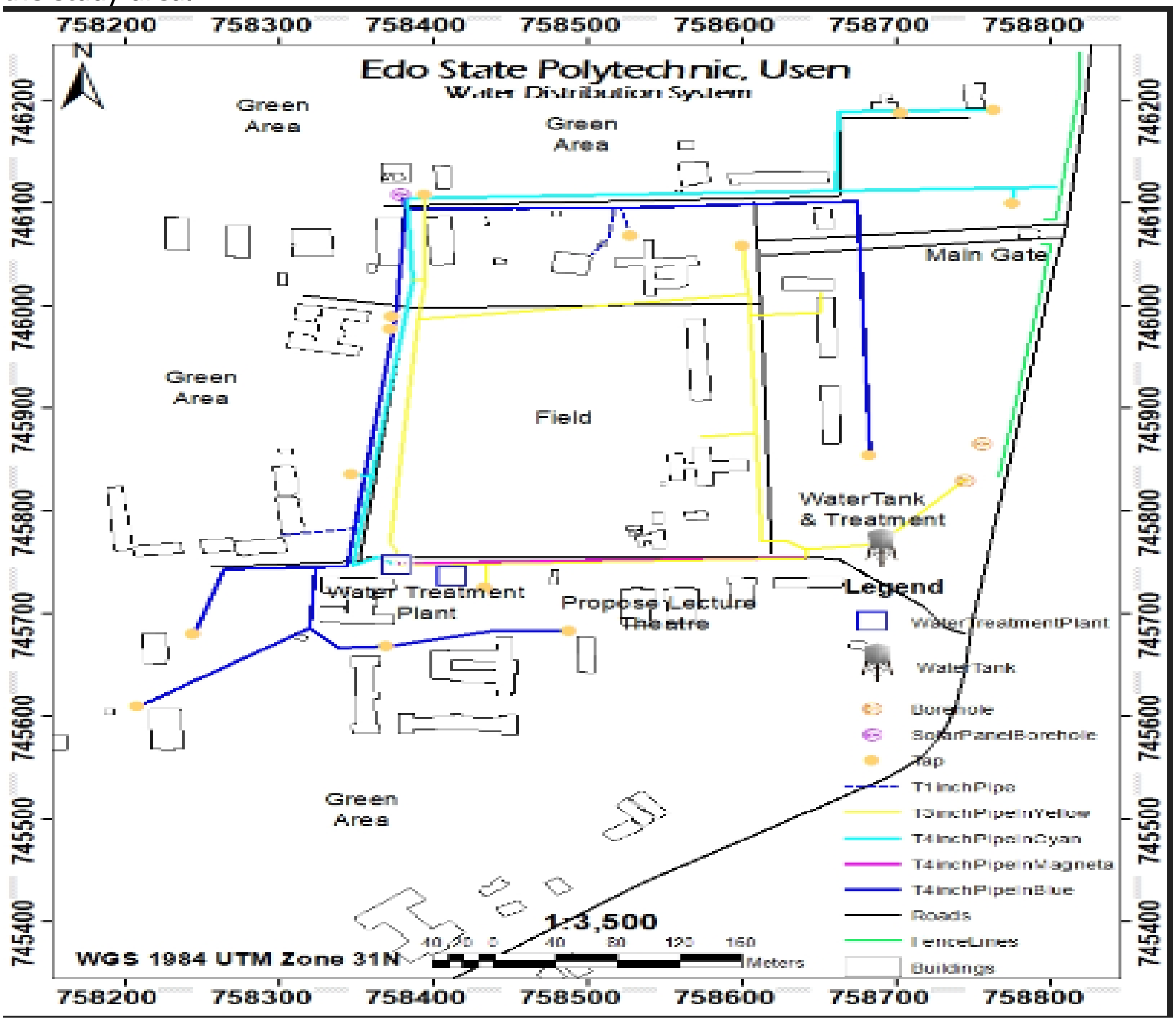

Figure 4: Geospatial Map of Water Distribution Network of Edo State Polytechnic, Usen.

Table 2: Geospatial Coordinates of Water Distribution Network of Edo State Polytechnic, Usen in NTM.

4 inches pipe solar (in blue)

S/N	X- CORDINATES	Y- CORDINATES
1	323686.000	303163.000
2	323686.994	303400.946
3	323664.000	303401.000
4	323530.697	303395.000
5	323386.291	303393.988
6	323386.489	303404.023
7	323386.292	303393.990
8	323380.000	303288.000
9	323379.000	303270.999
10	323353.000	303082.001
11	323301.000	303076.000
12	323353.000	303082.000
12	323348.000	303046.000
14	323332.000	303045.000
15	323286.000	303044.000
16	323248.000	302978.000
17	323286.000	303044.000
18	323332.000	303045.000
19	323324.036	302985.144
20	323209.999	302908.000
21	323324.036	302985.144
22	323342.000	302966.000
23	323375.001	302968.000
24	323441.907	302983.038
25	323492.313	302981.839

4 inches pipe (in magenta)

S/N	X- CORDINATES	Y- CORDINATES
1	323645.149	303053.476
2	323556.138	303052.365
3	323380.336	303048.575

4 inches pipe (in cyan)

S/N	X- CORDINATES	Y- CORDINATES
	323808.853	303414.060
	323782.002	303414.000
	323782.002	303393.002
	323782.000	303414.000
	323666.002	303413.000
	323671.000	303493.003

	323701.281	303493.743
	323768.002	303490.003
	323701.281	303493.743
	323671.000	303493.000
	323666.000	303413.000
	323603.000	303410.000
	323388.000	303404.002
	323391.000	303323.000
	323351.020	303047.291
	323353.000	303076.000
	323351.000	303047.000
	323369.630	303052.008
	323380.000	303046.000

3 inches pipe (in yellow)

S/N	X- CORDINATES	Y- CORDINATES
1	323749.000	303129.000
2	323693.000	303066.000
3	323646.002	303061.999
4	323633.000	303069.000
5	323617.002	303069.000
6	323613.002	303175.000
7	323578.000	303171.000
8	323613.002	303175.000
9	323609.586	303293.628
10	323651.000	303295.002
11	323651.002	303312.002
12	323651.002	303295.000
13	323609.586	303293.628
14	323608.953	303313.994
15	323605.001	303357.002
16	323605.001	303372.002
17	323605.134	303355.559
18	323609.000	303314.000
19	323395.000	303287.000
20	323400.000	303323.003
21	323400.950	303401.811
22	323400.000	303323.003
23	323391.000	303323.000
24	323400.000	303322.999
25	323395.000	303287.000
26	323376.000	303068.001
27	323380.000	303060.999
28	323380.200	303047.210
29	323438.066	303047.976
30	323438.001	303030.000
31	323438.066	303047.976
32	323556.000	303051.000

CONCLUSION

The geospatial data and maps aid in preventing pipe failure resulting from human activities like construction, and ease maintenance of the network.

RECOMMENDATION

Geospatial maps and data of water distribution network and other buried services should be determined and stored to prevent construction related pipe failure, and to ease repairs and maintenance of buried facilities.

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