Geospatial Techniques in Water Distribution Network Mapping and Modelling in Warri Port Complex (Nigeria)

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SUMMARY

A well planned and adequately mapped water distribution network plays an immense role in the provision of potable water supply. A good water distribution system is fundamental to environmentally sustainable development in any country and is also important in the control of water borne diseases.

In this study, the use of Global Positioning System (GPS), Total Station Instrument in combination with Remote Sensing imagery in developing Warri port complex water supply network is discussed. In order to carry out the acquisition of geospatial data for the water infrastructure development, control points were established within the port complex by the method of Differential GPS survey. These control points were used in running secondary total station traverses through the proposed water distribution pipeline routes. The total station survey was carried out at millimetre (mm) level accuracy to capture break in slopes while support levels were run between the total station traverse routes. The processed geospatial data were input into Microsoft Excel software, and script files were created. The script files were exported into 3D Civil CAD from where vector models were generated. The distribution layout vector plan was exported into the topographical model generated from the satellite imagery. The geospatial database was exported into Haestad Water CAD environment for the water distribution network analysis and design.

The output of the study was the water distribution network with the position of air valves, sluice valves, wash out, end caps, fire hydrants etc. located. The interpretation of the geospatial database with analytical tools allowed the water distribution network to be planned more economically and effectively.

1.0 INTRODUCTION

Water is vital for man's existence and without it, there would be no life on earth. As a resource to any nation, it should be well planned, developed, conserved, distributed and managed. Its infrastructure should be properly maintained to avoid future water problems. The total water requirement is on the increase and the per capita water consumption is also on the increase due to the increase in population and civilization(Al- layla et al, 1978; Audu and Anyata, 2010; Audu and Ehiorobo, 2010; Audu and Edokpia, 2010**)**. Under the most optimistic scenario, the world's population is expected to grow from more than six billion in 2000 to at least eight billion by 2025. This growth, 90 percent of which will occur in urban areas will intensify the demand for potable water and water of sufficient quality for use in the industry and waste treatment (Lacquemanne, 2000).

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?"

Cullen (2005) opined that "a modern society has been victim of its own success. A higher quality of life has meant greater demands on our services as people use more water and burn more energy. Data collection and distribution, however, has not moved on". The challenges are: securing adequate and potable water for people, securing water for food, protecting the ecosystems, creating awareness among the financing water infrastructure. These challenges have continued to demand innovation and state- of- the- art technology needed for drastic changes in the location, planning, collection, distribution and management of water infrastructure (Cullen, 2005; Audu and Ehiorobo, 2010; Audu and Ukeme, 2013). The technological advancement in the nation (Nigeria), which has led to tremendous growth in water distribution system, has not been translated to improved water supply as private boreholes with little or no treatment abound, water borne diseases are on the increase and low pressures are evident in many states of the nation (Izinyon, 2007).

The aim and objectives of this study are to examine the location of NPA water distribution pipeline routes; determine the geo-spatial information required for the planning and design of a comprehensive NPA water distribution network and to produce the vector models of the water infrastructure.

2.0 WATER DISTRIBUTION SYSTEM

Although the size and complexity of water distribution system (WDS) may vary dramatically, they all have the same basic purpose, to deliver water from the source (or treatment facility) to the consumer (Beecher, 2000). The source of water commonly determines the nature of collection, purification, transmission and distribution works. Common sources are rainwater, surface water and ground water. A water distribution system consists of a complex network of interconnected pipes, services, reservoirs, hydrants and other appurtenances including valves and flow meters which deliver water from the treatment plant to the consumer (Chadwick and Morfett, 1993; Nathanson, 1997; Walski et al. 2003 and Izinyon, 2007).

The distribution components form a large proportion of total investment in any water supply system (Rao, 2002). Water distribution system account for 40-70% of the total cost of water supply scheme (Sarbu and Borza, 1997; Nathanson, 1997 and Izinyon, 2007), hence its proper planning, design, operation and layout is of great importance. Water distribution network contains all the various components of a water system and defines how the components are interconnected. These components include water reservoir, water pipes, water pumps, storage tanks, junctions and valves. According to Lansey and Mays (2000), a water distribution system consists of three major components: distribution piping network, pumps and distribution storage. The components of water distribution system and their modelling purposes are shown in Table 1.

Adequate water supply and distribution systems are not only fundamental to environmentally sustainable development in any country but also are important in the control of many water borne and water related – diseases such as cholera, diarrhoea, typhoid and para–typhoid fever, hepatitis, etc.

Table 1- Components of Water Distribution System and Modelling purposes (Walski et al, 2003)

Component	**Type of Network Modelling Element**	**Primary modelling purpose**
Reservoir	Node	Provides water to the system
Pipe	Link	Conveys water from one node to another
Pump	Node	Raises the hydraulic grade to overcome elevation differences and friction losses.
Storage Tank	Node	Stores excess water within the system and releases that water at times of high usage.
Junction	Node	Removes (demand) or adds (inflow) water from/to the system.
Valve	Node or Link	Controls flow or pressure in the system based on specified criteria

2.1 Geo-spatial Information in Water Distribution System

A network of pipes, pumps, valves and other appurtenances are required to move water from the source to the consumer (Walski et al, 2003). Water distribution components form a large proportion of total investment in any water supply system (Rao, 2002). These components include water reservoir, water pipes, water pumps, storage tanks, junctions and valves. Douglas et al.(1995) reported that a pipe, which conveys the flow of water from one point to another in a pipeline network, is the primary water distribution network component. The principal characteristics of pipe are the pipe material, length, diameter and pipe carrying capacity factor (C- factor). Water pipeline systems need some periodic inspection for effective performance of the system.

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). Geo-spatial 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 geo-spatial 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).

3.0 THE STUDY AREA

The study area is situated at Warri Ports Complex of the Nigerian Ports Authority, Warri, in Warri South Local Government Area of Delta State, Nigeria. It lies within the tropical rainforest zone and is bounded by National Coordinates 16700mN to 16850mN and 361500mE to 367000mE. The port complex occupies an area of about 120 Hectares and the main jetty is about 1.94km long. Existing facilities at the port include Administrative buildings; Finger Jetty; Terminals A, B, and C; Control Tower; Fire Service Station; Magistrate Court; Religious Centres (Church and Mosque); etc. The satellite imagery of the study area, which was used during reconnaissance survey and had assisted in locating important features within the port area is shown in Fig. 1.

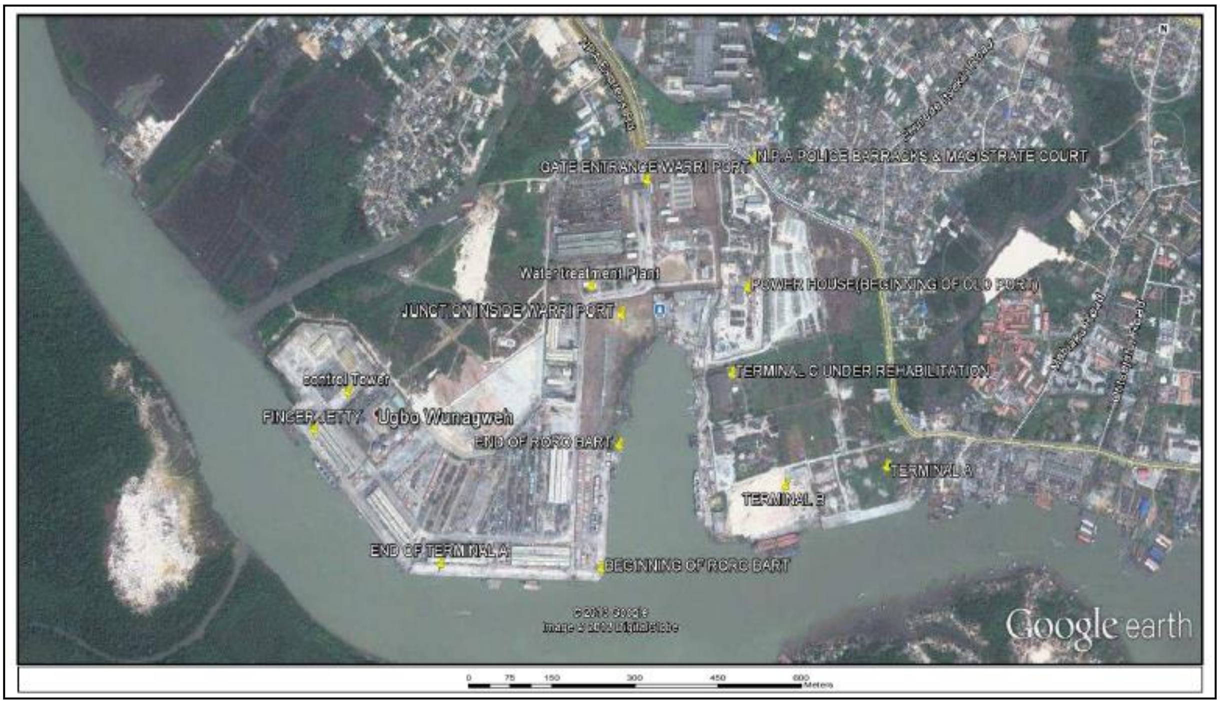

Fig. 1. Satellite imagery of NPA Warri Ports Complex (Source: Google Earth)

3.1 Data Collection, processing and modelling of Water pipeline Distribution Network

During the reconnaissance survey, it was discovered that there were no control points existing within the port area as those earlier established by some Construction Companies were obliterated during construction. Using SHELL GPS Control Station (CBLI) at NPA-DSC Express way near the DSC Township community in Warri as a reference station, three (3) control points (NPA 1, NPA 1A, NPA 1B) were established at the port site in the vicinity of the water headworks using Global Positioning System (GPS) receivers and relative (differential) positioning technique, i.e., the method of Differential GPS(DGPS).

These control points were used in running secondary total station traverses through the proposed water distribution pipeline routes. The total station survey was carried out at millimetre (mm) level accuracy to capture break in slopes while support levels were run between the total station traverse routes in order to prepare ground profiles of the proposed water pipeline routes. During the survey, all details within the pipeline routes were recorded. Profile levelling was carried out with the aid of an automatic levelling instrument with the levels taken. The geo-spatial data of all the components of the water distribution pipelines such as water pipes, water valves, storage tanks, water pumps were acquired using the established GPS controls and Geomatics techniques and instruments.

The post processing of the GPS data was carried out using the THALES GNSS Solution software. The computation and adjustment of the traverse survey of the proposed pipeline routes were also carried out using the inbuilt software in the Total station instrument. The acquired elevation data of the components of the water distribution system were reduced using the height of instrument method. The accuracy of the traversing and the levelling operations were within the permissible accuracy. The processed geo-spatial information of the NPA water distribution scheme was input into Microsoft Excel software and script files were created. The script files were exported into AutoCAD 3D Civil software, where the geo-spatial information of the various components of WDN, were modelled in the CAD software as vector models. The distribution layout vector plan was exported into the topographical model generated from the satellite imagery. The geospatial database, which was designed and created, was exported into Haestad Water CAD environment for the water distribution network analysis.

The water distribution network analysis using the Haestad water CAD was based on traverse lines representing length of pipes, intersection points as well as grow elevation obtained from DEM generated from the topo-map and from ground levelling. Analysis of DEM database with the Haedstad CAD was used to determine where pressures are low and head losses high.

These were used to identify if pipe sizes were adequate or not for delivering the required flow rates to various section of the port.

4.0 RESULTS AND DISCUSSION

4.1 Results

The WGS 84 coordinates of the GPS reference station and the established GPS Controls at NPA site are presented in Table 2. The plan and profile for the pipeline route 1 is presented in Fig. 2. Table 3 shows the Geo-spatial Information and the Estimated Borehole Capacity in the Study Area. The Attribute information of the components of NPA Water Transmission and Distribution pipelines are presented in Table 4. The contour map of the study area is shown in Fig. 3.

Table 2 WGS 84 Coordinates of the GPS Reference stations in Minna Datum and Established Controls at NPA site

Station ID	East (m)	North (m)	Height (orthometric) (m)
CBL 1	376 194.180	166 859.940	4.270
NPA 1	366 330.062	168 055.404	3.008
NPA 1A	366 238.369	168 133.840	2.589
NPA 1B	366 441.071	168 058.694	2.440

Table 3 Geo-spatial Information and the Estimated Borehole Capacity in the Study Area

Borehole (BH)	Service Area	Coordinates		Status/Proposed work	Proposed Yield (m^3/hr)	Proposed Yield (m^3/day)
		Easting (m)	Northing (m)			
BH1	New Port	366 097.259	168050.883	NF/Reactivation	70 m^3/hr	1400 m^3/day
BH2	New Port	366 033.392	168029.223	NF/Reactivation	70 m^3/hr	1400 m^3/day
BH3	New Port	366 455.782	167 992.213	NF/Reactivation	70 m^3/hr	1400 m^3/day
BH4	New Port (Standby)	366 027.041	168139.879	New Construction	70 m^3/hr	1400 m^3/day
BH5	Old Port (Standby)	366 767.493	167 493.883	New Construction	70 m^3/hr	1400 m^3/day

NF –Not functioning

Table 4 Attribute information of the components of NPA Water Transmission and Distribution pipelines

System Component	Pipe Material	Pipe Diameter	Hazen – Williams factor (C)	Deign Period (years)
Transmission pipes	uPVC	200mm	140-150	30
Distribution Pipes	uPVC	250mm (Mains 200mm (Sub- mains)	140-150	30
Distribution system Appurtenance	Gate values, Endcap, Washout valves, Air relief valves, Water metres and Hydrants			

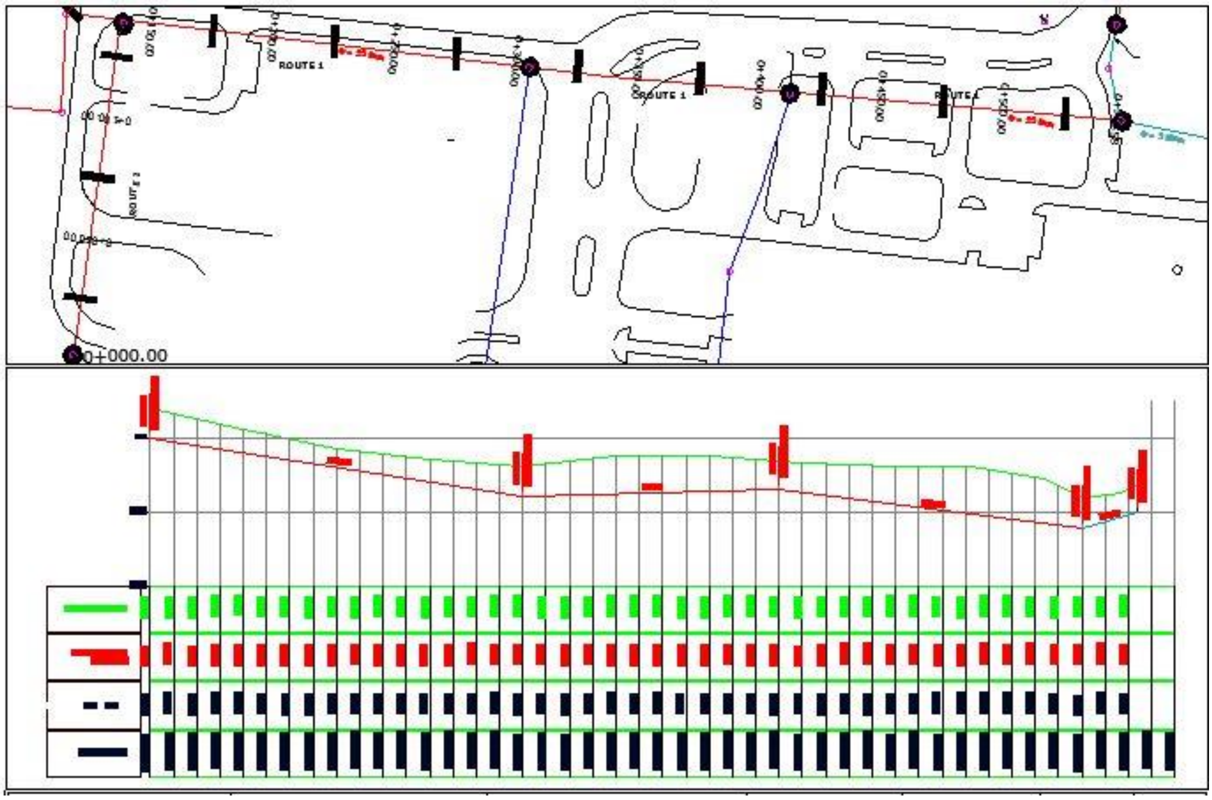

Fig. 2 Vector plan and profile of water pipeline Route 1

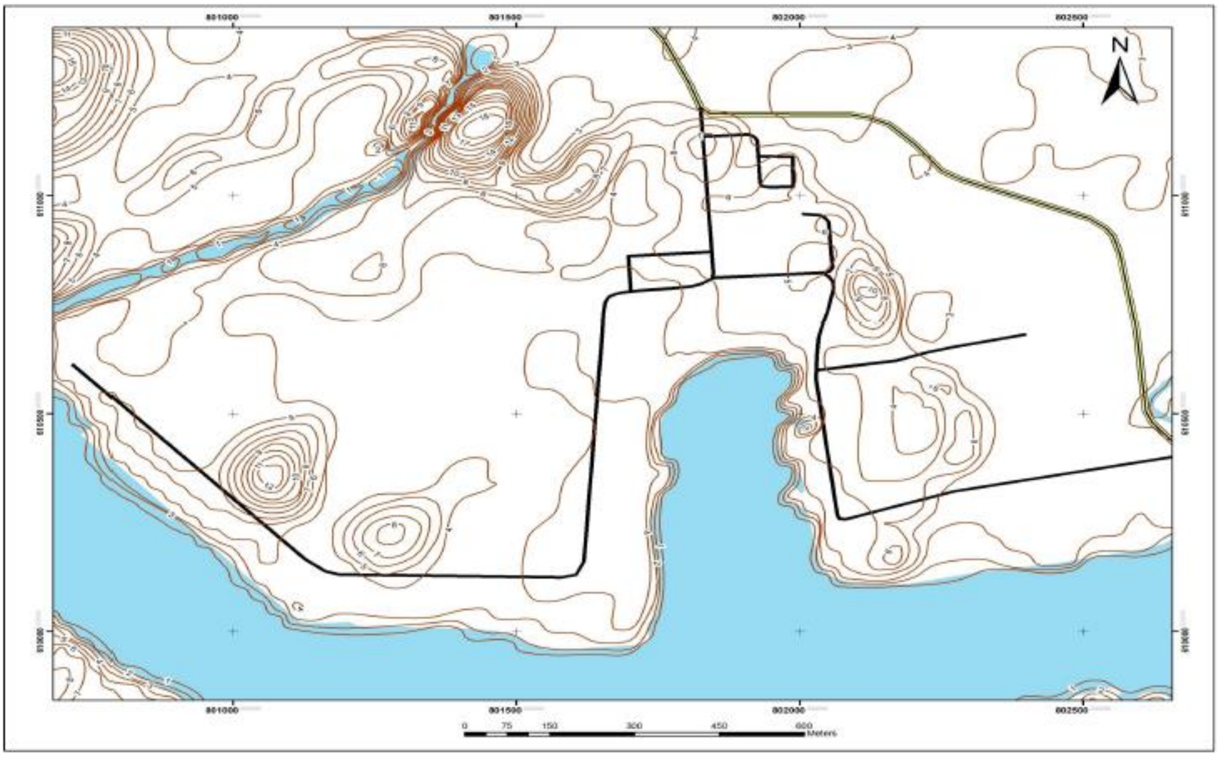

Fig. 3 The contour map of the Nigerian Port Authority (NPA) site, Warri

4.2 Discussion

This study has established three GPS controls (NPA1, NPA IA, NPA IB) (Table 2) in the study area. These controls provided the needed control stations for the traverse and detailed survey of the water pipeline routes at Warri NPA site. Besides, they shall be used as reliable control points for future survey works within the study area and its environs. Establishment of controls, where none exists, is in accordance with survey principles when carrying out any survey work. Controls are survey points, survey stations, reference monuments of known coordinates whose positions and elevations in relation to their origin are known and other survey work of lesser quality and accuracy are related to them. The practice of using control framework as a basis for further survey operations is often called 'working from whole to the part'. It prevents the accumulation of errors in any survey work. The commonest system of control is by coordinates- planimetric coordinates for the horizontal controls and height recording from an adopted datum for the vertical controls (Scofield and Breach, 2007).

The rectangular coordinates, shown in Table 2, played significant roles in the location and geo-spatially positioning of the entire water distribution network of the study area. Besides, the various components of NPA water distribution system can be planned, designed, constructed and maintained on the basis of the computerised information, which includes coordinates as well as other information concerning topography, geology, drainage, population inter alia. According to Audu and Ehiorobo (2010), most engineering infrastructure such as waterlines, railways, highways, buildings, dams and powerlines located on, beneath or above the surface of the earth are spatial objects. The most convenient and most used method of describing their positions is by their rectangular coordinates (McCormac, 2004).

The remotely sensed data, the digital satellite imagery (Fig.1), acquired during this study, has provided reliable, up-to-date information of the study area and aided in determining the most desirable and economic location of the NPA water distribution pipelines.

The vector plans and profiles for the NPA water pipeline routes (Fig.2) were used in the preparation of the estimates for the construction of the water distribution system and the tender for the contractors. They are part of the tender documents that provide valuable information for the bidders as well as form a reference manual for use during the execution of the project. The plans are the drawings that contain all details necessary for proper construction of the water distribution network, while the vertical alignment sometimes referred to as profile indicate the natural ground surface and the centre line of the water infrastructure with details of the vertical curves. The profile also helps in computing the estimated earthwork quantities. Nicholas and Lester (1999) noted that "plans, profiles and specifications are part of the contract documents for the construction of water distribution system, highways, railways etc. They are therefore considered as legal documents in the construction industry. Furthermore, they are used for the preparation of the construction's estimates and the contractor's bids."

Terrain elevations, shown in Fig.3, play major roles in the distribution and flow of water in the natural landscape of the study area. Moreover, they contribute immensely in the determination of the actual location of NPA ground level storage reservoir and the elevated storage tank. The ground elevations are very useful when evaluating the hydraulic grades and operating elevations within the pressure systems. The produced contour map and the profile levels were used for the pipeline network design.

As the existing boreholes have been non-functional for a long period (more than 7 years), it is proposed that the boreholes (BH1, BH2 and BH3) should be rehabilitated, reactivated and equipped to bring them to maximum yield shown in Table 3. Moreso, this study has proposed that two additional boreholes (BH4 and BH5), with one suitably located in the New Port area and the other in the Old Port area, should be constructed to serve as buffer and standby for the existing boreholes. The estimated borehole capacities are given in Table 3.

The design period, the pipe materials, pipe carrying capacity and the pipe diameter for both the transmission and distribution pipelines are presented in Table 4. Unplasticised Polyvinyl Chloride (uPVC) pipes were proposed for the transmission and distribution pipelines because they are nowadays not only most preferred pipe materials for water supply piping but also due to their strength and resistance to internal pressure; are not subject to corrosion or deterioration by electrolysis, chemicals or biological activities; are exceptionally smooth, minimizing friction losses in water flow. Furthermore, they are lightweight, very smooth surface finish, ease of installation and repair, and up to 150mm in diameter of the pipes may be site-bent slightly to accommodate ground contours or changes in direction (Rao, 2002).

CONCLUSION

The importance of accurate and up-to-date geo-spatial information in the planning, location, design and development of water distribution infrastructure has been highlighted. This study has examined the use of a modern technology, Geo-spatial information and Geomatics techniques in the planning and development of water distribution system of the Nigerian Ports Authority.

The results of the study revealed that with the provision of accurate, up-to- date geo-spatial information, the physical location of NPA water infrastructure on or beneath the earth’s surface can be determined. Moreover, with the help of the modern geomatics (surveying) techniques and state-of –the art instruments such as Electronic Total Station (ETS), the Global Positioning System receivers and satellite remote sensors, regular updating of the geo-spatial information of the components of the water systems in the study area can be carried out. Since we live in a dynamic world with increasing population, urbanization and industrialization, the geo-spatial information (the water distribution systems maps) should be regularly updated using geomatics technology and equipment including Electronic Total Station (ETS), GNSS receivers, or satellite remote sensors.

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