ASSESSMENT OF PUBLIC WATER DISTRIBUTION USING GEOGRAPHIC INFORMATION SYSTEM IN YOLA, NIGERIA

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This Thesis is dedicated to;

To my country, **Nigeria**……..

To my late **Parents, Muhammad and Maisaratu** for their moral training……..

To my wife, **Fatima**, who has dedicated tremendous patience, Encouragement and support during my Masters study……

To my children, **Muhammad, Al-Amin, Umar Farouk and Mustafa……**

Who have given me so much happiness in my daily life……

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ABSTRACT

Public water supply is capital intensive and requires a significant investment, effective management and public participation. The task is most challenging in developing countries with lower income, where less attention is given to provision of infrastructure and inefficient management of the system is ever present. However, the issue of inadequacy of water supply and ineffective distribution system in most of the cities in developing countries has been compounded by rapid increase in population. This research focuses on assessment of public water distribution in Yola, Nigeria using geographic information system (GIS). It is aimed at analyzing water distribution system in Yola with a view to optimize the distribution. The study considers elevation, population density and availability of space as well as centrality within the densely populated areas as criteria for the analysis. Five different datasets were used for the study; street data, existing pipeline network, parcels (open spaces), elevation and population data. Yola geodatabase is the source of spatial data generated using ArcGIS 10.2.1. The existing water distribution network was digitized on the street map to define the areas covered by the network; digital elevation model (DEM) was also generated using ArcGIS 10.2.1 to visualize the topography of the study area. A suitability model with elevations, available spaces and population density as inputs, was developed to determine suitable locations for reservoirs in order to ensure smooth flow from the reservoirs to consumers under gravity. Shortfall in water supply for Yola was also determined by computing water supply deficiency for each administrative ward within the study area. Findings from the study provided three alternatives and the first alternative with three reservoirs is considered the most suitable. Reservoir locations in the first alternative were determined based on the top most level of the set criteria, to ensure total coverage of the study area. This study concluded that suitability analysis using spatial analyst extension provides suitable location for reservoirs to ensure optimal water distribution system.

ABSTRAK

Sistem bekalan air awam perlukan modal yang intensif dan pelaburan yang besar, pengurusan yang berkesan dan penyertaan awam. Tugas ini adalah paling mencabar di negara-negara membangun yang berpendapatan rendah, di mana perhatian yang kurang diberikan kepada penyediaan infrastruktur dan disamping sistem pengurusan yang tidak cekap. Walau bagaimanapun, isu kekurangan bekalan air dan sistem pengagihan yang tidak berkesan di kebanyakan bandar di negara-negara membangun telah diburukkan lagi oleh peningkatan pesat penduduk. Kajian ini memberi tumpuan kepada penilaian semula sistem pengagihan air awam di Yola, Nigeria menggunakan sistem maklumat geografi (GIS). Ia bertujuan untuk menganalisis sistem pengagihan air di Yola dengan tujuan untuk mengoptimakan pengagihan. Kajian ini mengambil kira ketinggian, kepadatan penduduk dan kesediaan ruang, serta keutamaan dalam kawasan padat dengan penduduk sebagai kriteria untuk analisis. Lima set data yang berbeza yang digunakan untuk kajian ini ialah; data jalan, rangkaian saluran paip yang sedia ada, tapak kosong, ketinggian dan taburan penduduk. Yola geodatabase adalah sumber data spatial dijana menggunakan ArcGIS 10.2.1. Rangkaian pengagihan air sedia ada telah didigitalkan pada peta jalan untuk menentukan kawasan yang diliputi oleh rangkaian; model ketinggian berdigit (DEM) juga dijana menggunakan ArcGIS 10.2.1 untuk menggambarkan topografi kawasan kajian. Model kesesuaian dengan ketinggian, ruang yang terdapat dan kepadatan penduduk sebagai input, telah dibangunkan untuk menentukan lokasi yang sesuai untuk takungan; ini meningkatkan aliran yang lancar dari takungan kepada pengguna berasaskan graviti. Kekurangan bekalan air untuk Yola juga telah ditentukan dengan mengira kekurangan bekalan air untuk setiap mukim pentadbiran dalam kawasan kajian. Tiga alternatif penyelesaian dihasilkan dan alternatif yang pertama dengan tiga tangki reservoir dianggap lokasi yang paling sesuai sebagaimana ditentukan berdasarkan kriteria yang telah ditetapkan, untuk memastikan litupan keseluruhan kawasan kajian. Kajian ini menyimpulkan bahawa analisis kesesuaian menggunakan *spatial analyst extension* menyediakan lokasi sesuai untuk tanghi reservoir untuk memastikan sistem pengagihan air yang optimum.

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INTRODUCTION

1.1 Background of the Study

Water is one of the basic necessities of life. It is very important as it is the major constituent of both plants and animals (Chakhaiyar, 2010). The demand for portable water supply and distribution increases with urbanization which is rapid in most of developing countries. In recent times, the rate and dimension of urbanization has increased, which resulted to having more than 50% of the world population living in urban areas within which 64% of them are in developing countries (UNDP, 2012). The increasing rate of population and water demand has compounded the issue of water sources depletion in many parts of the world. Towns and cities in developing countries are currently facing serious challenges of efficiently managing the scarce water resources, urbanization, and infrastructural decay, as well as the issue of sustainability of conventional water management (Zeraebruk *et al.*, 2014).

An effective water distribution system requires adequate supply of water into the system, functional pumping facilities as well as efficient distribution network. Factors such as effective water distribution system, rapid population increase and scarce resources largely affect the prevalent water stress in mostly urban areas of developing countries (Zeraebruk *et al.*, 2014). Poorly installed water distribution network coupled with lack of proper operations and maintenance always results in distribution network failure.

Water distribution system is a complete system of its own with sub-systems that must be linked from intake down to end users. Failure of a sub-system will adversely affect the system, as put in by Yazdani *et al.* (2011) that when one or more component of the system is affected, the consequences are disruption of water services just like it occurs in other infrastructural systems.

The high rate of unaccounted for water losses or Non-Revenue water (NRW) in the water distribution network occurs as a result of ineffective management of the system. According to World Bank (2006), 16 billion cubic metres of water are delivered to consumers for zero revenue while 32 billion cubic metres of untreated water leaks from urban water supply system globally. About 50% of these losses occurs mostly in developing countries where consumers suffers intermittent supply while the authorities responsible for the supply are battling for supplementary incomes to fund extension of services (World Bank, 2006). Water managers are usually faced with the challenges of increased self-sufficiency; such as controlling energy demands and environmental impacts, safeguarding high quality, public trust and cost effectiveness in the water supply system, as well as eluding negative impacts on human health (Rygaard *et al.*, 2010).

The recent development in technology has lessen the amount of work involved in engineering construction and projects in terms of costing of materials and suitability, hence it is important or vital that the planner makes assessment of the relevant requirements involved in any project in accordance with the specified standards. However, determination of suitable locations for water facilities falls into the category of utility planning called suitability analysis. Modern software systems e.g. ArcGIS, TNTmips, Idrissi, etc. tend to bridge the gap between discipline, specific application and geographic information system (GIS) in a way that they are fully integrated (Burrough, 1986).

GIS is defined as “an organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyse and display all forms of geographically referenced information”

(ESRI 1992). GIS technology has been widely used in various fields, such as agriculture, business geography, ecology, electricity and gas, emergency management and public safety, environmental management, forestry, health care, education, mining and geosciences, real estate, remote sensing, telecommunications, transportation and water distribution. Technological developments brought by GIS and the growing accessibility and quality of digital terrain models (DEMs) have significantly extended the application capabilities of DEMs to many hydrologic, water resources and environmental investigations (Moore *et al.,* 1991).

Over the years, digital representation of elevation has been the source of the information (Afshar *et al.,* 2006; Gershon and Duckstein, 1983; Jenson and Domingue, 1988). Parameters like canal location of drainage splits, extent of canal and slope were traditionally acquired from maps or field investigations (Garbrecht and Martz, 1992). However, suitability analysis in this study involves extensive data collection and processing such as; street data, elevation data, existing distribution pipeline network plan, existing land use map, and distribution standards to determine the suitable location of service reservoirs.

1.2 Problem Statement

Provision of water in good quality and adequate quantity is indispensable for the survival of human beings, plants and animals, anything short of that result in water related diseases. For decades, water supply and distribution has been a problem in most developing countries. Yazdani *et al.* (2011) observed that lives are being endangered and economic growth restricted as a result of increasing water stress in many developing countries. Also, Kala *et al.* (2007) noted that disparity will likely hit additional areas as population grows because many parts of the world experience water deficit. Water supply cannot reach some areas due to expansion caused by increase in population and even some networked areas suffer insufficiency. Although, the level of global availability of pipe water connection is on the rise, longstanding and ailing network characterized the cities of numerous developing

countries of the world and the consequences is unreliable supply of lower quality (UNDP, 2006). This phenomenon is expected to worsen if unchecked, as put in by UNDP (2014), that more people live in urban areas than in rural areas with 54 % of the world's population living in urban areas in 2014 and is expected to reach 66 % by 2050. Kala *et al.* (2007) reported that "the rapid expansion of towns and cities is caused by rural-urban migration". For example, between 1950 and 1990, the number of cities of the world with population of more than 1 million increased from 78 to 290 and this is expected to exceed 600 by 2025 (Serageldin, 1995). In some cases the various wards/sections of the cities in developing countries are provided with water on rotational basis because the supply of the whole city is below requirement. As proclaimed by Totsuka *et al.* (2004), the use of irregular provision and shifting supplies for most hours of the day and regulating the consumers' ability to get water is one of the coping strategies in a situation of inadequate water resources.

The little water quantities conveyed through pipes at relatively low pressure characterized intermittent water supply and is prominent among developing countries (Totsuka *et al.*, 2004). Some of the settlements in most developing countries are linear settlements because provision of infrastructure does not cover areas that are far from the transportation routes. Ufoegbune *et al.* (2010) lamented that those settlements situated along the transportation routes in Nigeria, are the ones usually provided with water supply networks. Vairavamoorthy *et al.* (2007) also insisted that the increasing rate of population especially in developing countries has worsened the declining of available water resources throughout the world. The available water resources have already been exploited while expanding the existing sources or developing new ones increases in terms of cost (UNESCO, 2003).

Presently, Yola is facing almost all the water distribution problems facing most of the developing countries of the world. These ranges from inadequacy of water supply into the distribution system as well as inefficient distribution system, for instance; there is only storage tank (reservoir) serving the entire town, which was meant to serve a very small population about 40 years ago. The water distribution network only covered the built up areas then when the population was small and the new areas of expansion due to increase in population were left out. In the hierarchy

of distribution, there were only principal feeder mains and small mains because there is only one service reservoir, trunk main that connects central distribution tank and other reservoirs is not there. And even within the areas served by the network, there were rusted and broken pipes which lead to loss of water due to leaking and unhygienic water due to particles sneaking into the broken pipes. The situation was compounded by poor operations and maintenance. In addition, there is a total lack of database that will guide the operators to determine the number of consumers and the water demand within their area of operation.

From the above analysis of water distribution problems, Yola water distribution problems can be categorized thus; inadequacy of the existing water supply, with only one reservoir of 10,000M^3 capacity supplying just about 30% of the daily water demand for Yola. Another problem is ineffective distribution network and inadequacy in the provision of reservoirs to serve the entire study area due to expansion caused by increase in population, as the existing water distribution network only covers about 60% of the study area. The existing distribution network obtained from Adamawa state water board was on traditional paper map. There is also the problem of operation and maintenance of water facilities causing wastages and pollution due to leakages from broken and rusted pipes. Therefore, this research explores ways of optimizing distribution using GIS.

1.3 Research Gap

Different authors wrote on GIS application in water resources planning. Based on the reviewed literature however, less attention is given to optimal water distribution system which covers both database and the physical facilities. A study conducted by Huo *et al.* (2006) emphasized the importance of linking land use codes and historical billed water demand using GIS to project water demand data of Cape Coral, in south west Florida, United States of America. Here the system is in place, the information on land use/consumers premises is at hand as well as historical billed water demand. Similarly, Ufoegbune *et al.* (2010) considered the geographical

position as well as elevation of various facilities of water board including reservoirs, pumping stations and the water distribution pipeline to propose an effective plan for water distribution network for Abeokuta Metropolis in Nigeria. In addition, Panagopoulos *et al.* (2012) linked morphological slope, road network, population density and proximity to water sources, to prioritize the planning of a National water management system in necessary zones for water authorities in Mytilene, Greece. In this study also, the system is in place and the research was for improvement. Furthermore, Babah *et al.* (2012) investigated the "fundamental water problems related to the environment and health quality of water distribution". In the city of Nouakchott Mauritania, using the level of enlightenment of consumers to assess the water they drink and how clean is their surroundings, how reachable are they to water and sanitation, cost of a cubic meter of water, water contamination , water and sanitation linked diseases and preferences of the households as variables. Based on the above, previous studies focused mostly on water quality and supply without much attention to effective water distribution system that ensure even distribution across an area, considering variables such as population, elevation, proximity and other variables.

The approach adopted by those researchers also aimed at achieving optimal distribution at the end but some aspects of the system were functional, while in the case Yola being the study area, there is only one reservoir and based on the present population, one reservoir is not enough to cater for the town. The distribution network pipes were rusted and broken therefore is just like laying new pipeline. Information about the consumers is not available; the map of existing distribution network is in traditional paper format and therefore need to be converted to digital for easy manipulation and updating. Therefore, this research uses GIS to first of all represent the existing network in digital format. A suitability model was also developed to determine suitable location for reservoirs using DEM, population density, and availability of open spaces, as well as the optimal locations based on refined criteria. All these can be analysed, adjusted, or modified in GIS environment whenever the need arises because expansion may be required as the population is growing. Also the information on the consumers, i.e. location, requirement etc. which forms the database can be built upon the findings of this research in future.

1.4 Research Questions

This research seeks to answer the following questions;

1 What is the condition of the existing distribution network in the study area?

2 How effective is the existing reservoir in terms of supply coverage in the study area?

3 What are the suitable locations for reservoirs in the study area?

4 How water distribution can be optimized in the study area?

1.5 Research Aim and Objectives

The aim of this research is to assess water distribution system in Yola, Nigeria with a view to optimize urban water distribution. This aim can be achieved through the following objectives;

1. To analyze the existing water distribution network in the study area.
2. To examine the adequacy of reservoirs in terms of water supply and distribution in the study area
3. To determine suitable locations for reservoirs in the study area.
4. To determine optimal level of distribution to achieve maximum efficiency

1.6 Research Design

The research design explain how the research was carried out, describing the procedure used in data collection and the data collected. Also in the research design, the data analysis procedure as well as the software used in the analysis is being described. The research design comprises of five sections namely; literature review, data collection, data input, data analysis and the results and findings. Figure 1.1 below shows the flow chart of the research design for the purpose of this thesis.

Literature review section covers two aspects; the first one is urban water distribution and the second is GIS application in water distribution. Under the urban water distribution aspect, literature on water sources, supply, distribution, quality and demand were reviewed. Also reviewed were the literatures on GIS application towards solving water distribution problems, for instance the techniques used in data analysis and the literature covers terrain analysis, suitability analysis and proximity analysis.

Data collected for this research are secondary data; these includes existing water distribution network, street data, elevation data, open spaces data and population and household data. At the data input stage, the data collected were incorporated into the ArcGIS 10.1 software for processing. The existing distribution network was digitized on the street map to delineate areas covered by the existing network. Open spaces map was rasterized and reclassified so can be input into the suitability model and population density was obtained using minor roads. Digital elevation model (DEM) was also classified on ArcMap and prepared for analysis. Distribution pattern was also established based on the water demand, as determined by population.

Having the data integrated and processed, the data was analysed. A suitability model was developed with multiple inputs such as reclassified DEM, reclassified open spaces map and road density map. The model was run in order to determine suitable locations for reservoirs. Water demand for service areas were also calculated based on the population and number of reservoirs required.

In the results and findings section, the results and findings of this research were outlined. The findings include; suitable location for reservoirs, suitable service (catchment) areas for water distribution, based on the daily water demand and number of reservoirs. Alternative locations for reservoirs were also found based their criteria set and most suitable was selected.

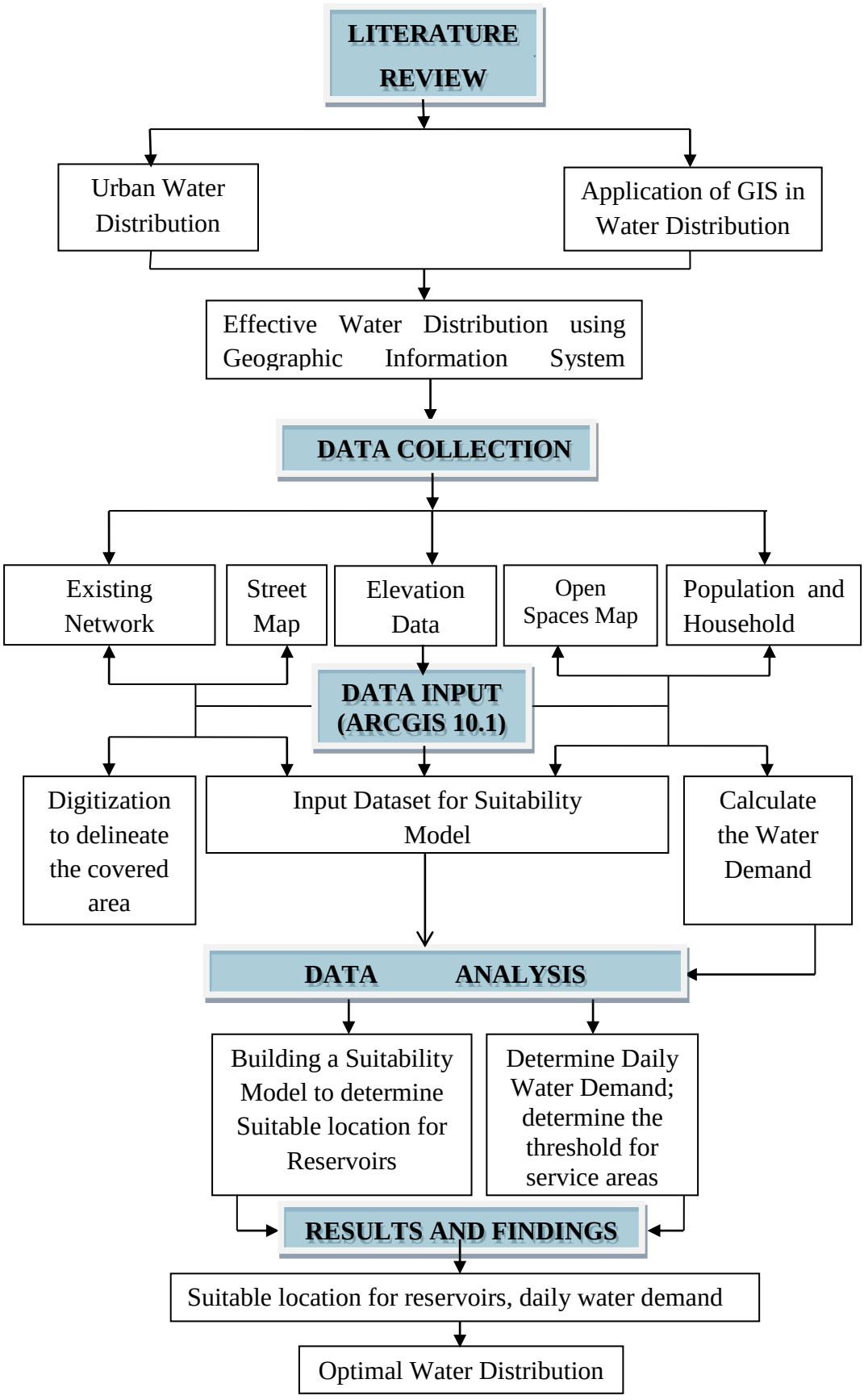

Fig. 1.1 Flow chart of Research Design

1.7 Scope of the Study

The research is intended to covers water distribution system in Yola, the capital city of Adamawa state in North Eastern part of Nigeria. The research also targets public water distribution in Yola based on reassessment of water distribution facilities across the study area. It is concerned with assessing the water requirement based on the population to be developed into decision making by the water authorities for designing daily water demand of Yola. However, agricultural and industrial land uses are not within the study area. Five different datasets were used for the study these include: street data, existing pipeline network data, open spaces map, elevation data and population data. Suitability model was developed to determine suitable locations for reservoirs based on elevation, population density and availability of open spaces. Data were collected, input, managed, manipulated and analyzed using GIS software to develop the model for effective urban water distribution in developing countries.

1.8 Significance of the Study

Water is essential for the survival of human beings, plants and animals, in good quality and adequate quantity. The use of water has a great impact on the social, political and natural environment, because of its fundamental importance to development and basis for ecosystem functioning (Braga, 2001). This research explores contemporary methods of achieving optimal water distribution system. As water supply and distribution has been a problem over decades especially in developing countries, exploring such contemporary methods will go a long way in providing solution to the lingering crisis as argued by Vairavamoorthy *et al.* (2007) that "Providing adequate water supply to the rapidly growing urban populations is a challenging task for governments throughout the world". The outcome of the research will serve as a platform for effective water distribution as it affects most developing countries. A functional database to guide operators in urban water distribution is essential for maximum efficiency. Therefore, since most if not all of

the water distribution systems we have in most developing countries lack a functional up to date database to guide the operators, this study will also guide researchers on optimal water distribution.

1.9 Thesis Organisation

This research thesis is organized into five chapters; these are introduction, literature review, study area and methodology, data analysis and results and finally conclusion and recommendations. The introduction chapter comprise of sub sections which include; background information which identifies and describes the history and nature of the research problem with reference to the existing literature on water resources planning. Statement of research problem indicates the root of the research problem being studied, for instance, identify the real issue, and examine the extent to which previous studies have successfully investigated the problem. Conceptual framework examines the thesis title and research problem; identify the variables in this research, review related literature to find out how scholars have addressed the problems identified and discuss the assumption of the chosen theory and point out its relevance to this research.

Research questions outline the questions that arose in the course of relating the real issue with other researchers' view on the issue. The aim of this research outlines the goal to be achieved at the end of the study and objectives state the stages to be followed in order to achieve this aim. Scope of the study outline the extent or the area the research intended to cover and the problem the research will attempt to solve. The importance of the outcome of this is given in the significance of the study.

The literature review is divided into two parts; urban water distribution and GIS application in water distribution. In urban water distribution, literatures on water management, supply, distribution, demand and quality were reviewed in order to examine what other researchers reported about these aspects. GIS application in

water distribution explores other researchers' applications of the GIS technology in water distribution and the benefits of using GIS in water distribution as well as case studies on the policies of using GIS in water resources planning. Literature on the techniques used in analysis in this study was also examined. This chapter also discusses about the benefits of using GIS in water resource planning and case studies and also presented in literature review chapter.

The study area in chapter three outlines the location of the study area on the earth surface, the relative position of the study area in the country. Also included in the study area are land uses and population density. Methodology is the process used in data collection for the purpose of this research. These include; the types of data required the sources from which the data were obtained, the procedure of obtaining such data and the process of data preparation for analysis.

Data analysis and results chapter presents the analysis of the data collected on the course of this research, the software used in the analysis as well as the techniques used in the process of analysing the data fall under this chapter. Data collected and analysed are; street data, existing pipeline network data, open space map, elevation data and population data. Suitability model was developed to determine suitable locations for reservoirs based on elevation, population density and availability of open spaces. Data were collected, input, managed, manipulated and analyzed using GIS software. Three alternatives were provided and the first alternative was considered most suitable having met the top most level of the criteria set. Also indicated in this chapter were the results obtained from the analysis and the findings.

Chapter five concludes the thesis by summarizing the points made in the introduction and literature review; briefly reviews the research methods and design used, discusses the implication of the research findings, outline the limitations of the research in terms of scope or weaknesses and offer suggestions for future research related to this research. Also in in this chapter, recommendations were made based on the analysis and inform the reader what action should be taken as a result of the findings of the research.

REFERENCES

Afshar, M. H., Akbari, M., Mariño, M. A., & Asce, H. M. (2006). Simultaneous Layout and Size Optimization of Water Distribution Networks : *Engineering Approach*, *11*(4), 221–230.

Babah, I., A., Deida, M., F, Blake, G. & Froelich, D. (2012) Fresh water distribution problematic in Nouakchott, *Science Direct, Procedia Engineering* 33 (2012) 321-329,

Biswas, A. K. (2006). Water Management for Major Urban Centres. *International Journal of Water Resources Development*, *22*(2), 183–197.

Braga, B. P. F. (2001). Integrated Urban Water Resources Management: A Challenge into the 21st Century. *International Journal of Water Resources Development*, *17*(4), 581–599.

Burrough, P.A., (1986). Principles of Geographical Information Systems for Land Resources Assessement. Oxford: Clarendon.

Census, (2006). National Population Commission (NPC), Federal Republic of Nigeria. 2006 Population and Housing Census.

Chakhaiyar, H. (2010). Periwinkle Environmental Education Part IX, Jeevandeep Prakashan Pvt Ltd.

Chandio, I. A., Matori, A., Lawal, D. U., & Sabri, S. (2011). GIS- based Land Suitability Analysis Using AHP for Public Parks Planning in Larkana City. *Canadian Center of Science and Education*,

COF-COF, Canada. http://cof-cof.ca/surface-water-treatment-plant-flow-diagram/ Accessed on 19/10/2015.

Davis, W. (2003) Water demand forecast methodology for California water planning areas-work plan and model review *and Management Consultants, Ltd., Carbondale, IL*. Retrieved from http://scholar.google.com/scholar Accessed on 06/10/2015.

Dawoud, B. M. A., Wonderen, J. Van, & Houqani, H. Al. (2005). An ArcGIS Database for Water Supply / Demand Modeling and Management in Abu Dhabi Emirate, UAE, A Paper Presented at the 5th Gulf Water Conference, Kuwait 2005.

Design Criteria for Portable Water Distribution System, *Colorado Department of Public Health and Environment.* September 1, 2013. Available at; https://www.colorado.gov/pacific/sites/default/files/WQ-ENG-POL%20Design%20Criteria%20for%20Potable%20Water%20Systems.pdf

Djebedjian, B., Yaseen, A., & Rayan, M. A., (2006), Optimization Of Large Water Distribution Network Design Using Genetic Algorithms, *Tenth International Water Technology Conference, IWTC10 2006, Alexandria, Egypt,*

Durga Rao, K. H. V. (2005). Multi-criteria spatial decision analysis for forecasting urban water requirements: A case study of Dehradun city, India. *Landscape and Urban Planning*, *71*(2-4), 163–174.

ESRI website, (2012) ArcGIS Network Analyst, http://resources.arcgis.com/en/help/main/10.1/index.html#//002s0000000400 0000 Accessed on 29/12/2014 09:05

Eusuff, M., & Lansey, K. (2003) Optimization of water distribution network design using the shuffled frog leaping algorithm. *Journal of Water Resources Planning and Management, 129*(3), 210–225.

Fratini, C. F., Elle, M., Jensen, M. B., & Mikkelsen, P. S. (2012). A conceptual framework for addressing complexity and unfolding transition dynamics when developing sustainable adaptation strategies in urban water management, 2393–2401. doi:10.2166/wst.2012.442 pp 2397-2398

Freeze, R., A. and Cherry, J., A (1979) Groundwater Prentice- Hall, Englewood Cliffs, NJ, 604pp Available at; https://books.google.com.my/books/about/Groundwater.html?id=feVOAAAAMAAJ&redir_esc=y. 05/09/2015

Garbretcht, J. & Martz, L. W, (1992). Channel Network Delineation and Watershed Segmentation in the TOPAZ Digital landscape Analyst System. *GIS for Water Resources and Water Resources Management*, 7-16.

Garbriel, I., O. & Donatus, M., O. (2010). Hydrologic Characteristics of the Benue River wetland in semiarid Yola area, Northeast, Nigeria. *Asian Journal of Earth Sciences*, ISSN: 2152 - 3509.

Gershon, M., & Duckstein, L. (1983). Multiobjective Approaches to River Basin Planning. *Journal of Water Resources Planning and Management*, *109*(1), 13–28.

Hamblen, C. S, David T. S, M. ASCE and Ximing Cai, (2006). Digital Floodplain Mapping and an Analysis of Errors Involved. *World Environmental and Water Resources congress 2006*, ASCE (pp. 1–10).

Hanson, R.E. (2011). Utilities Engineering Standards and Construction Specification Manual.ftp://ocfl.net/divisions/Utilities/pub/PlanReview/ManualOfStandardsAndSpe cs/Manual_Approved2011. Accessed on 05/04/2015 14:50

Hardoy, J. E., (2003). Water and Sanitation in the World's Cities:Local Action for Global Goals, Earth Scan 2003, pp505.

Hill, J. M., Harlow, C. a, & Zimmerman, P. (1983). Geographic information systems as applied to the manipulation of environmental data. *The Environmentalist*, *3*(1), 33–38. Retrieved from http://www.sciencedirect.com/science/article/B7P6N-4F20033-3F/2/d477553e25be907a2ba8dc9a6da582a8

Holder, A. (2006). The Nature of Mathematical Programming, *Mathematical Programming Glossary*, Published by the INFORMS Computing Society http://glossary.computing.society.informs.org/ver2/mpgwiki/index.php?title=Main_Page. Accessed on 10/04/2015

Huo, J., Alfred M., & George, R., S. (2006). Application Of GIS To Plan Long-Range Water Supply Facilities By Linking Land Use And Water Billing Data Of City Of Cape Coral In Southwest Florida. *Water Environment Foundation*, 1319–1327, pp1321.

Indian Water Works Association (IWWA), (2000) International Seminar on Intermittent Drinking Water Supply System Management: Technical Papers. Proceeding for the International Seminar on Intermittent Drinking Water Supply System Management, Mumbai, India.

Jain, T., R. and Khana, O., P. (2006) Business Economics, VK Educational Publishers, ISBN 81-87344-57-1.

Jenson, S. K., & Domingue, J. O. (1988). Extracting Topographic Structure from Digital Elevation Data for Geographic Information System Analysis, *54*(11), 1593–1600.

Jung, J. K., Sinha, S. K., & Whittle, L. G. (2013). Development of a Water Infrastructure Knowledge Database. *Journal of Infrastructure Systems*, 130418214148000.

Kanta, L. & Zechman, E. (2014). Complex Adaptive Systems Framework to Assess Supply-Side and Demand-Side Management for Urban Water Resources, *Journal Of Water Resources Planning And Management,* © ASCE, 2014.140:75-85.

Khaleelullah, M., Hajera, I., Ali, J., M., Madhurya, P.,L., Poojam, M.and Ziace, S., H. (2015) Water Supply and Sanitation Services. School of Planning and Architecture, Jawaharlal Nehru Architecture and Fine Arts University

Kingdom, B., Liemberger, R. and Marin, P. (2006) "The challenges of reducing Non-Revenue Water (NRW) in developing countries, how the private sector can help: A look at performance-based services contracting." Water Supply and Sanitation Sector Board discussion paper Series, Paper No. 8. Available: www.sitersources.worldbank.org, World Bank Dec. 2006.

Kumar, M. and Biswa, V. (2013). Identification of Potential Sites for Urban Development Using GIS Based Multi Criteria Evaluation Technique. A case Study of Shimla Municipal Area, Shimla District, Himachal Pradesh, India. *Journal of Settlements and Spatial Planning.* Vol. 4 No. 1 (2013) 45-51.

Kumar, M. and Shaikh, V., R. (2012). Site Suitability Analysis for Urban Development Using GIS Based Multi Criteria Evaluation Technique. *Journal of Indian Society of Remote Sensing.* (June 2013) 41(2):417–424, DOI 10.1007/s12524-012-0221-8

Labadie, J. W, and Herzog, M. T, (1999) Optimal Design of Water Distribution Networks with GIS http://proceedings.esri.com/library/userconf/proc99/proceed/papers/pap756/p 756.htm. Accessed on 01/04/2015 09:50

Liljenstrom, H. & Svedin, U. (eds.) 2005 Micro Meso Macro – Addressing Complex Systems Couplings. World Scientific Publishing Co. Pte. Ltd, Singapore.

Madhavan, K. D. (2005) "Mapping & Maintenance of Water Distribution System and Sewer Collection System Network using Remote Sensing and GIS", http://www.gisdevelopment.net/application/utility/others/mi05323pf.htm, Accessed on 12/10/2013 18:20

Manoli, E., Arampatzis, G., Pissias, E., Xenos, D., & Assimacopoulos, D. (2001) Water Demand and Supply Analysis Using a Spatial Decision Support System *Architecture*, *3*(3), 199–209.

Marvin, S., Graham, S., and Guy, S. (1999). "Cities, Regions, and Privatized Utilities." http://www.amazon.ca/Cities-Regions-Privatised-Utilities-Marvin/dp/0080435823. Accessed on 10/04/2015

McIntosh, A. C., (2003), Asian Water Supplies, Reaching the Urban Poor, Asian Development Bank and International Water Association, pp 29.

Moore, I. D., R. B. Grayson and A. R. Ladson, (1991), "Digital Terrain Modeling: A Review of Hydrological, Geomorphological, and Biological Applications," Hydrological Processes, 5(1):3-30. http://onlinelibrary.wiley.com/doi/10.1002/hyp.3360050103/pdf Accessed on 7/12/2014 14:38

Muro, M., & Jeffrey, P. (2006). A Review of Participatory Test and Evaluation Approaches for Water Management, *Water Science and Technology: Water Supply*, Vol 6 No 5 pp 1-8, doi: 10.2166/ws.2006.829, IWA Publishing 2006.

Murray, A., T., Gober, P., Anselin, L., Rey, S., J., Sampson, D., Padegimas, P., D. & Liu, Y. (2012) Spatial Optimization Models for Water Supply Allocation, *Water Resour Manage (2012) 26:2243–2257*, Springer Science+Business Media B.V. 2012,

National Water Supply and Sanitation Programme (NWSSP) (2000). National Water Supply And Sanitation Department Federal Ministry Of Water Resources, Federal Republic Of Nigeria

National Oceanic and Atmospheric Administration (2007) http://www.srh.noaa.gov/bmx/?n=gis Accessed on 16/07/2015.

Nwankwo, G., I. and Anyaogu, C., N. (2000) Hydrologic Characteristics of a Small Tropical Riverine Wetland at Ulakwo, Imo State. Hydrogeology Journal 8 pp 644-653

Panagopoulos, G., P., George, D., B., Hariklia, D., S. & Faini, A., M. (2012) Mapping Urban Water Demands Using Multi-Criteria Analysis and GIS, *Wate Resour Manage (2012) 26:1347–1363,* Springer Science+Business Media B.V.2012,

Quigley, J. (2011). Distribution System Optimization, *Pennsylvania Department of Environmental Protection,* http://www.depweb.state.pa.us/portal/ server.pt/community/about_dep/13464/office_of_the_secretary/585259

Rygaard, M., Binning, P. and Albrechtsen, H. (2010) "Increasing water self-sufficiency: New era, new challenges." Journal of Environment Management Vol. 92, pp. 185-194.

Sabru, L., (2010). Optimization of Water Distribution Networks, Proceedings of The Romanian Academy, Series A Volume 11, Number 4/2010, Pp. 330–339

Saldarriaga, J., Paez, D., Cuero, P., & Leon, N., (2013). Optimal Design Of Water Distribution Networks Using Mock Open Tree Topology, *World Environmental and Water Resources Congress 2013*: Showcasing the Future © ASCE 2013. 869–880.

Serageldin, I. (1995). Toward Sustainable Management of Water Resources, Directions in Development, The International Bank for Reconstruction and Development, The World Bank.

Shaw, D. A., Pietroniro, A., & Martz, L. W. (2012). Topographic analysis for the prairie pothole region of Western Canada. *Hydrological Processes*, *3114*(June 2012), n/a–n/a. doi:10.1002/hyp.9409

Singh, S. K., Chandel, V., Kumar, H. & Gupta, H. (2014). Rs & Gis Based Urban Land Use Change and Site Suitability Analysis For Future Urban Expansion Of Parwanoo, Planning Area, Solan, Himachal Pradesh (India). *International Journal of Development Research*, Vol. 4, Issue, 8, pp. 1491-1503.

Steiner, F. R, and Butler, K, (2006). Planning and Urban Design Standards, *American Planning Association.* John Wiley and Sons, 2006.

Stiles, G. (1996) "Demand-side management, conservation, and efficiency in the use of Africa's water resources." *Water Management in Africa and the Middle East: Challenges and opportunities*, IDRC, Ottawa.

Sule, B . F , Ayanshola , A . M and Salami, A . W. (2010). Water Consumption Patterns in Ilorin , Kwara State , Nigeria Department of Civil Engineering , University of Ilorin , P . M . B 1515 , Ilorin , *Nigeria International Conference on Sustainable Urban Water,* (July), 26–28.

Tang, T. & Keyser, G. (2007). Spatial Analysis Of Household Water Supply And Demand In A Distributed Geographic Network In The Towns Of Amherst And Clarence Newyork, *Middle States Geographer, 2007, 40:133-141*.

Tarboton, D. G., & Ames, D. P. (2004). Advances in the mapping of flow networks from digital elevation data. *World Water Congress 2001,* (435), 1–10.

Thomas, C. W., Judson, W. H., Lehn, O. F. & William, M. A. (1998). Ground Water and Surface Water: ASingle Resource. U.S Geological Survey Circular 1139, Denver, Colorado,. ISBN 0-607-89339-7.

Todd, D. K (1995) Ground water hydrology. J. Wiley and Sons Singapore. Pp 95 Available at http://as.wiley.com/WileyCDA/WileyTitle/productCd-EHEP000351.html

Todini, W. (2000) Looped Water Distribution network Design Using a Resilience Index Based Heuristic Approach. Elsevier Science, Urban Water 2 (2000) 115-122

Totsuka, N., Trifunovic, N., & Vairavamoorthy, K. (2004). Intermittent urban water supply under water starving situations, 505–512.

Tremblay, A., T., Paull, J., G., Rodgers, W., R., and Wermund, E., G. (1994). GIS Database for Water Management on the Rio Grande Delta Plain", Bureau of Economic Geology, The University of Texas, GIS/LIS, p778-786

Tsihrintzis, V. A., Hamid, R., & Fuentes, H. R. (1996). Use of Geographic Information Systems (GIS) in water resources: A review. *Water Resources Management*, *10*(4), 251–277. pp 1. Retrieved from http://www.springerlink.com/index/10.1007/BF00508896

Tully, Y. (2007) Land Use/Water Supply Analysis Guidebook, Comprehensive Water Planning, By Northern Califonia Water Association. Available at; http://www.norcalwater.org/res/docs/NCWA-guidebook-final.pdf

Turel, M. & Frost, J. D. (2011). Delineation of slope profiles from Digital Elevation Models for landslide hazard analysis, *GeoRisk*, 829-836

Ufoegbune, G. C, Oyedepo J. A. & Awomeso, A. O. E. (2010). Spatial Analysis of Municipal Water Supply in Abeokuta Metropolis, South Western Nigeria. *REAL CORP*, (May), 18–20.

UNDP, (2006). Beyond scarcity, United nations Development Programme, Human Development Report 2006, 1–24.

UNDP, (2014). World urbanization Prospects, The 2014 Revion. Department of Economic and Social Affairs, United Nations New York.

UNPD (2012) World Urbanization Prospects, the 2011 Revision. Department of Economic and Social Affairs Population Division United Nations New York. (Accessed 06.09.15).

UNESCO, (2003). World Water Resources at the Beginning of the Twenty First Century, Cambridge University Press.

UNICEF, (2000). Global Water Supply and Sanitation Assessment 2000 Report, WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation pp 1

Vairavamoorthy, K., Gorantiwar, S. D., & Mohan, S., (2007). Intermittent Water Supply under Water scarcity situation. *International Water Resources Association*, *32*(May 2013), 121–132, pp 122

Wilson, J. P., Mitasova, H., & Wright, D. J. (1999). Water Resource Applications of Geographic Information Systems, URISA Journal, 61-79

World Bank (2012): What a Waste: A Global review of solid waste management .Urban Development Series Knowledge paperhttp//document World bank.org/curated/en/2012/03/16537275/waste global review-solid waste management (Assessed on 06 /09/2015.1-

Yazdani, A, Otoo, R. A., & Jeffrey, P. (2011). Resilience enhancing expansion strategies for water distribution systems: A network theory approach. *Environmental Modelling Software*, *26*(12), 1574–1582.

Zemba, A. A. (2010). Analysis of Urban Surface Biophysical Descriptors and Land Surface Temperature Variations in Jimeta. *Global Journal of Human Social Science,* 10(1).

Zeraebruk, K. N., Mayabi, A. O., Gathenya, J. M., & Tsige, Z. (2014) Assessment of Level and Quality of Water Supply Service Delivery for Development of Decision Support Tools : Case Study Asmara Water Supply. *International Journal of Sciences: Basic and Applied Research (IJSBAR)*, *14*(1), 93–107.