ASSESSING USEFULNESS OF 2D AND 3D GEOVISUALIZATIONS USING ACCESSIBILITY ANALYSIS TO HEALTH FACILITIES. CASE STUDY IN THE GAMBIA

EBRIMA WALLY MANNEH

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SUPERVISORS:

Dr. Mila N. Koeva

Dr. Sherif Amer

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EBRIMA WALLY MANNEH

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SUPERVISORS:
Dr. M.N. Koeva
Dr. S. Amer

THESIS ASSESSMENT BOARD:
Prof.dr. P.Y. Georgiadou (Chair)]
Dr.-ing. Arch. Genet Alem (External Examiner, Technische Universität Dortmund)

ABSTRACT

Geovisualization involve graphical representation of real world phenomena such as cities, buildings and forest or abstract data with spatial reference applying various techniques including cartography and GIS. 2D and 3D methods of geovisualization are popularly applied in research and by experts including those in the planning domain as enhanced methods for displaying information. However, the usefulness of 2D and 3D methods of geovisualization is limited in research. Moreover, models often developed to assess such methods are based on a small geographic area or objects.

The objective of this study is to assess the perceived level of usefulness of 3D geovisualization compared to 2D among experts using models developed based on accessibility analysis to health facilities at Municipality level. The study use spatial and statistic data to analyze accessibility to health facilities in Kanifing Municipality, The Gambia, using GIS methods. The output of the analysis is visualized in 2D and 3D to comparatively assess the usefulness of the two methods among experts in terms of their effectiveness, efficiency and appropriateness. The study seeks to identify the challenges limiting the experts in applying such GIS based methods in their everyday practice. A review of literature was conducted to identify a method of accessibility analysis to apply. The study applied different methods including group discussion, task performance and interview to collect primary data for analysis.

The results show that there is high level of appreciation of GIS based methods of visualization among the experts. Majority of the experts (51%) perceived GIS methods to be very useful. 59% considered both the 2D and 3D methods of geovisualization to be applicable in their everyday work. Comparatively the findings of this study suggests little or no significant different between the 2D and 3D visualization of the output of the accessibility analysis in terms of their efficiency, effectiveness and appropriateness. The main challenges limiting the experts in applying GIS based methods of visualization are attributed to inadequate skills, lack of software, inadequate equipments and budget constraints.

Keywords: *Geovisualization, 2D and 3D visualization, Usefulness, Efficiency, Effectiveness, Appropriateness*

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1. INTRODUCTION

1.1. Background

Geovisualization involve graphical display or representation of different aspects of the real world such as an actual landscape, or part of it (including cities, roads and real objects such as buildings, trees, etc.) or abstract data with spatial reference such as population statistics. Geovisualization of data in 3D adds height (3rd-Dimension) to the graphic display of the information. 3D geovisualization is a popular method to represent spatial and non-spatial information, for effective and efficient dissemination (S. Bleisch, 2012). 3D geovisualization in the form of city models is one of the methods to represent the real world with spatial related information. Other types of geovisualization such as Google Earth enhance virtual navigation capabilities on a web based platform. Cities are creating and releasing 3D models that visualize the urban environment and these models have been widely used to assist urban management related applications such as urban planning designs, traffic control and navigation (Mao, 2010).

Increasing interest emerges from various domains including the military, agriculture, health and urban planning in the application of geographic information systems (GIS) methods to effectively and efficiently analyze, process and visualize spatial data (Yu, Sun, Peng, & Zhang, 2012). GIS based data can be displayed or visualized in either 2D or 3D methods, or by integrating both (Pullar & Tidey, 2001a). 3D visualization techniques have proven to be useful as an innovative method to explore and analyze various issues within the complex urban environment (Grigolon, Singh, Koeva, & Madureira, 2016; Wang, 2015; Xu & Coors, 2012; Batty et al., 2001; Pullar & Tidey, 2001a; Shiode, 2000). Gebrewold (2015) has incorporated 3D visualization in analyzing housing quality perception of condominium dwellers in the city of Addis Ababa, Ethiopia. Dynamic visualization of complex objects, including their interior and exterior views, such as heritage sites, was also done with 3D visualization (Koeva, 2016).

Experts use both 2D and 3D visualization techniques to model and display information related to planning practices such as zoning, town plans, infrastructure distribution and resource allocation. According to Mao (2010), cities such as Berlin in Germany have made 3D city models available to the public allowing participation of both experts and non-experts in planning and decision making processes. Such methods can also be useful to analyze and efficiently communicate to stakeholders, through visual models or maps, urban issues affecting the population such as accessibility to urban social services or slum conditions. This is because public or social services have a spatial character (Savas, 1978). This is also another important factor to consider since everyday life of people has long been affected by the availability and delivery of public (infrastructure) services such as electricity and water supply, transportation, waste disposal, recreation, health and education (Prud'homme, 2005).

Despite the growing use of 3D visualization methods, findings about its perceived usefulness are limited in literature (Herbert & Chen, 2015a). The perceived usefulness is simply defined as "the degree to which a person believe using a particular system would enhance his or her job performance" (Davis, 1989, p.320).

The methods to assess 3D visualization methods have been rather technical. "Urban planners are reluctant to use 3D visualization because of the complexity with regard to data integration and modeling, the cost, and the lack of appropriate skills available for incorporating 3D models into everyday planning processes" (Ahmed & Sekar, 2015 p. 394). Assessing 3D visualization methods involved developing models to represent a particular real or abstract phenomenon (Wang, 2015; Herbert & Chen, 2015a; Kjellin, Pettersson, Seipel, & Lind, 2010; Schobesberger & Patterson, 2008). The models generated to evaluate the usefulness of 3D visualization are often based on small geographic scale or objects such as buildings.

The focus of this study is to assess the perceived usefulness of 3D geovisualization by measuring its effectiveness, efficiency and appropriateness using simple visualization models or maps produced using GIS based accessibility analysis with ESRI ArcGIS 10.3.1 software. The accessibility to health facilities is analyzed in terms of their location (availability), distribution and distance from the residential areas within Kanifing Municipality region. Abstract information, in this case statistics about population and household distribution, was also included in the analysis. The same output of the analysis is displayed in 2D and 3D visualization maps and assessed among experts in a developing country, The Gambia, where GIS based methods of visualization is not fully practiced. Hence the choice to use simple 2D and 3D visualization models for this study.

1.2. Justification

There is an increasing demand among experts including planners in developing countries to establish urban information system (UIS) using both traditional data and digital 2D and 3D data to analyze and visualize urban scenarios for timely and better planning of urban areas (Maktav, Erbek, & Jürgens, 2005). The application of 3D visualization techniques is widely practiced particularly in the developed or technologically advanced societies. One of the reasons is that "the public acceptance of urban scenarios is much better when 3D animations and perspective views are used" (Maktav, Erbek, & Jürgens, 2005, p. 658). There is limited use or application of GIS techniques of information analysis and visualization among experts which has reduced or confined the visualization of planning practices to outdated traditional methods. This includes the use of manual tools and methods of surveying, recording, storage or visualization of information about land parcels. Therefore, geo-spatial factors such as the spatial distribution and location of public services in relation to population concentration and travel distance are missing out.

The rapid urbanization driven by rural-urban migration and due to natural growth has implications on accessibility to social services such as health, education, and other facilities in urban areas (WHO, 2015), which need to be analyze and communicated efficiently. This can lead to proper interventions, such as investment in basic infrastructure to improve lives and reduce poverty (World Bank, 2014). Health facilities are important basic social infrastructure. As analyzed in Obrist et al., (2007), accessibility to healthcare is one of major development challenges not only for developing but also developed countries

1.3. Research Problem

There is limited research on the perceived usefulness of 3D geovisualization. The methods applied or involved to assess the usefulness of 3D visualization are complex and technical which require experts or respondents with appropriate skill to evaluate them. According to Bleisch (2012b, p.129), "research efforts on assessing 3D visualization methods often focus on technology and processes and rarely evaluates the usefulness or the cognitive understanding of the results".

In The Gambia, there is still limited use of enhanced methods of information visualization such as GIS based methods. Knowledge of GIS methods of information analysis and visualization is often lacking among the experts. Planning practices such as zoning, land use or infrastructure management within the urban areas hardly incorporate GIS based 2D and 3D geovisualizations. Likewise, there is limited application of GIS methods in the analysis and visualization of statistical information.

1.4. Research Gap

The perceived usefulness or appreciation of 3D visualization method is not fully investigated. The main factors limiting experts to the use of non GIS based methods also required to be studied. As stated in Ahmed and Sekar (2015) the reluctance of planners to incorporate 3D geovisualization in planning practices is due to factors ranging from lack of skills to the cost of materials and complexity of the methods involved. However, whether such claim is also related to the low appreciation of GIS methods of visualization in 2D or 3D, need to be established.

The study therefore, aims to assess the usefulness of 2D and 3D geovisualizations among experts using visualization models of GIS based accessibility analysis. The added value or innovative approach is to develop 2D and 3D geovisualization models based on a large geographic area (Municipality region). This study seeks establish the main challenges limiting the experts in this case study in applying GIS methods in their everyday practice.

1.5. Research Objective

The main objective of this study is to assess the usefulness of GIS based 2D and 3D geovisualization as perceived by experts using models based on accessibility analysis of health facilities within Kanifing Municipality and to identify the challenges limiting their use of such methods.

1.6. Specific Objectives

1. To develop geovisualization models in 2D and 3D form that showcase accessibility to health facilities at Municipality level for assessing the two methods.
2. To investigate the challenges limiting the experts in applying GIS based 2D and 3D geovisualization methods in their everyday practice.
3. To comparatively assess the perceived level of appreciation and usefulness of the 2D and 3D geovisualization methods among the experts in terms of their efficiency, effectiveness and appropriateness.

1.7. Research Questions and Related Objective

Objective 1: To develop geovisualization models in 2D and 3D form that showcase accessibility to health facilities at Municipality level for assessing the two methods.

1. Which GIS analysis method can be applied to visualize in 2D the current accessibility situation to the health facilities in Kanifing Municipality?
2. Which GIS analysis method can be applied to visualize in 3D the current accessibility situation to the health facilities in Kanifing Municipality?

Objective 2: To investigate the challenges limiting the experts in applying GIS based 2D and 3D geovisualization methods in their everyday practice.

3. What are the main challenges limiting the experts in applying 2D and 3D visualizations methods for visualizing the kind of information about their work such as zoning, urban land use plans or statistics?

Objective 3: To comparatively assess the perceived level of appreciation and usefulness of the 2D and 3D geovisualization methods among the experts in relation to their efficiency, effectiveness and appropriateness.

4. What is the perceived level appreciation for the 3D geovisualization method of the output of the accessibility analysis to the health facilities compared to the 2D among the experts?
5. What is the usefulness in terms of efficiency, effectiveness and appropriateness of the 2D and 3D visualization models as identified with the experts?

1.8. Case Study Conceptual Framework

The conceptual framework for this case study constitutes two key concepts: geovisualization and usefulness, in terms of efficiency, effectiveness and appropriateness. Geovisualization is the graphic display of information with spatial reference combining approaches from different fields, including cartography and GI-Science (Kraak, 2005). Geospatial data including location of health facilities, residential areas, and statistical information (population and household) have been visualized in 2D and 3D graphic displays. The maps feature the spatial distribution of the health facilities, which represent the opportunities or destinations, and the distance to the population (origin) in relation to location of the facilities within the Municipality.

The visualization models were assessed for their usefulness as perceived by experts. The focus of the assessment is to measure the usefulness in terms of efficiency, effectiveness, and appropriateness of the 2D and 3D GIS models of the output of the accessibility analysis. The perceived usefulness of the 2D and 3D geovisualizations is considered in terms of how such methods can be enhancing as perceived by the experts and whether it can be applicable in their everyday work.

Figure 1 represents the conceptual framework for this case study. The geovisualizations showcase accessibility analysis to health facilities in Kanifing Municipality. The outputs of the analysis were developed into 2D and 3D models or maps in the form of printed posters and digital softcopy (computer base) to be assessed for their usefulness in terms of efficiency, effectiveness and appropriateness. "A model is a simplification of reality" (Dinand, Wietske, Ali, Zoltan, & Wouter, 2013). In this study the term 'model' is interchangeably used with map. The efficiency measure considers time taken by participants to complete an interpretation task. Effectiveness is measured based on the correct scores or error level obtained. On the other hand appropriateness is measured qualitatively using questionnaire. It is determined based on the complexity of task as stated by the participants. That is how difficult or easy they find in identifying the features represented in the maps.

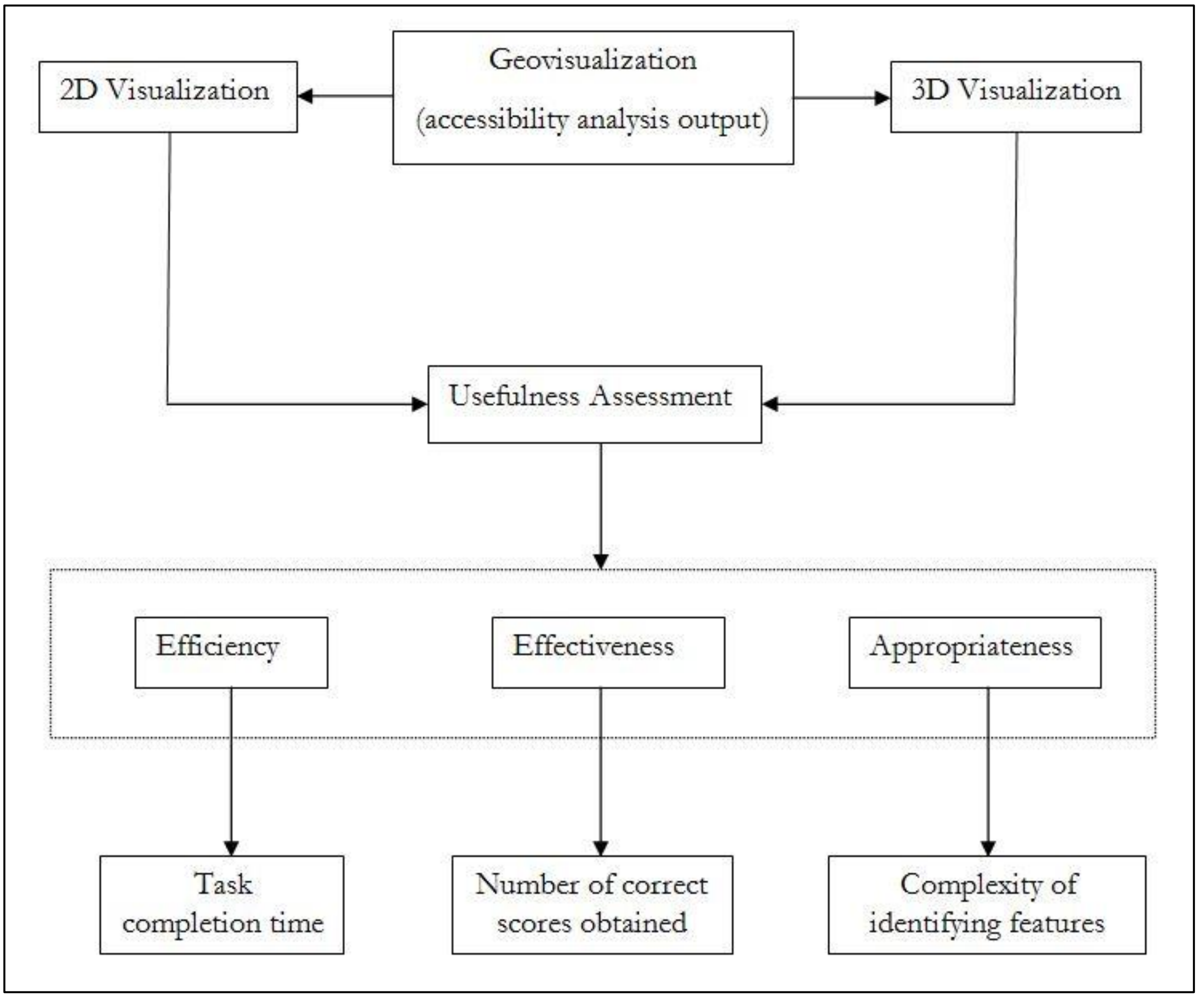

Figure 1: Conceptual framework for the case study

Table 1 shows how the main concepts are operationalized. The dimensions represent the elements or aspects of the key concepts considered for this study. The table show which specific method(s) are applied to produce the type visualization and to assess the efficiency, effectiveness and appropriateness dimensions of the usefulness concept. The specific aspects featured in the maps and topics included in the assessment are shown with corresponding outputs or indicators.

Table 1: Operationalization of concepts

Key Concept	Dimension	Method	Aspect/Topic	Output/Indicator
Geovisualization	2D and 3D geovisualization of accessibility analysis	- Location based analysis - Container analysis	Spatial location and distribution of health facilities	Maps showing location & distribution of health facilities
		Container analysis	Number of people in each district	Maps showing the number of population in each district
		Container analysis	Number of households in each ward	Map showing total number of households per Ward
		Closest facility analysis	Distance to nearest facility in meters	Maps showing distance from residential areas to nearest health facility within the Municipality
Usefulness	Efficiency	Interpretation task	- Identifying location and distribution of facilities by types within the Municipality - Interpretation of population distribution within districts - Interpretation of households distribution within wards - Interpretation of distance between location of health facilities and residential areas	Time taken by participants to complete task (in minutes)
	Effectiveness	Interpretation task	Success or error scores obtained by participants	Number of correct interpretation scores obtained by participants
	Appropriateness	Qualitative (interview)	- Which features are easy to identify - Which features are difficult to identify	% of respondents stating difficult or easy to identify features in the maps

1.9. Thesis Structure

This thesis consists of six chapters, reference list and appendix section.

Chapter One: Introduction

This chapter provides the general introduction to the study. It includes the justification for the study, research problem and research gap. The main objective of this study is also stated with specific objectives and their related research questions. This chapter also described the conceptual framework for this case study.

Chapter Two: Literature Review

Chapter two discusses literature on geovisualization in relation to the conceptual framework of this study. It begins with review on GIS based accessibility analysis. Methods of displaying data in 3D are discussed and advantages and disadvantages of 2D and 3D visualizations were also stated as found from previous studies. This chapter ends with a review on the usefulness assessment of the 3D visualization.

Chapter Three: Research Methodology

This chapter described the research methods applied. It gives an overview of the study area, the type of data used, type of accessibility analysis applied to produce the geovisualization models and the data collection methods.

Chapter Four: Results and Analysis

In this chapter the results obtained from the methods applied were presented and analyzed. The presentation and analyses of the results follow the sequence of the three sub-objectives of this study. This include the types of visualization models produced, the main challenges limiting the experts in applying GIS based methods in their practice and the efficiency, effectiveness and appropriateness of the models.

Chapter five: Discussion

Chapter five discusses the main findings presented in chapter four in relation to the findings from other studies. The discussions also follow the sequence of the three sub-objectives of this study.

Chapter Six: Conclusion and Recommendations

This chapter gives a summary on the key research findings and provides suggestions for further research endeavors.

This report ends with a reference list and appendix section.

2. LITERATURE REVIEW

2.1. Introduction

This chapter discusses relevant literature on geovisualization and some of the methods of 3D representation of information. The advantages and disadvantages of 2D and 3D visualizations are discussed. Various GIS based accessibility analysis methods are briefly identified with a view to determine a relevant method that can be applied to analyze and visualize accessibility to health facilities in Kanifing (Study area). The chapter also discusses the literature on the assessment of 'usefulness' of 2D and 3D visualizations, in this regard their efficiency, effectiveness and appropriateness.

2.2. GIS Accessibility Analysis

Accessibility is the ease to reach spatially distributed activities. The concept of accessibility has been related to two main elements; opportunity and travel medium (Suzuki & Suzuki, 2015). Accessibility to geographically or spatially distributed resources (opportunities or activities) can be considered in relation to several factors including, time and travel distance to their location and service level to the targeted population. Accessibility has been broadly defined by Liu and Zhu (2004, p.105) as "the ease with which activities at one place may be reached from another via a particular travel [mode]". In other words the activities are opportunities or destinations distributed spatially within a geographic space. The ease of access to spatially distributed opportunities is affected by travel distance, transportation mode and economic status or characteristic of individuals.

The concept of accessibility is important in urban planning. The analysis of accessibility to spatially distributed activities particularly in metropolitan areas helps to answer questions such as how travel pattern or behavior is affected by their distribution (Handy, 1993). It also helps in understanding the pattern of distribution of the activities, for example showing areas with high or less concentration in relation to the population.

Accessibility analysis has been applied using GIS methods to analyze how ease of access to spatially distributed infrastructures is affected (Comber, Brunsdon, & Green, 2008; Amer & Ottens, 2007; Geurs & van Wee, 2004).

Vector based data models have been used to conduct 3D accessibility analysis of built structures with, for example, 3DCityNet application (Thill, Dao, & Zhou, 2011). 3D models generated through procedural methods using Esri CityEngine application were used evaluate to their perceived usefulness in visualizing urban design for slum upgrading in South Africa (Rautenbach, Coetzee, & Çöltekin, 2016). Other authors have combined 2D and 3D visualization in studies relating to urban environment such as qualitative assessment of urban designs (Pullar & Tidey, 2001b).

Table 2 summarizes various perspectives on accessibility and components described in Geurs and van Wee (2004). The table shows various accessibility measures based on the object of analysis such as infrastructure, location, person and utility. The infrastructure-based measures evaluates the capacity of the road network in terms of travel speed which is affected by congestion and peak hour periods. Location-based measures consider travel time and distance as cost to spatially distributed activities. It is important for network analysis and especially useful for regional scale accessibility analysis (Van Wee, Hagoort, & Annema, 2001). Person-based accessibility measure evaluates an individual's ability to access or reach spatially distributed opportunities in space and time based on the individual's daily activities. According the table below the utility measures on the other hand also evaluate cost between location of activities in terms of the amount and spatial distribution based on different temporal scales at the level of individual or homogenous population group.

Table 2: Various accessibility measures and components

Perspectives on accessibility and components

Measure	Component			
	Transport component	Land-use component	Temporal component	Individual component
Infrastructure-based measures	Travelling speed; vehicle-hours lost in congestion		Peak-hour period; 24-h period	Trip-based stratification, e.g. home-to-work, business
Location-based measures	Travel time and or costs between locations of activities	Amount and spatial distribution of the demand for and/or supply of opportunities	Travel time and costs may differ, e.g. between hours of the day, between days of the week, or seasons	Stratification of the population (e.g. by income, educational level)
Person-based measures	Travel time between locations of activities	Amount and spatial distribution of supplied opportunities	Temporal constraints for activities and time available for activities	Accessibility is analysed at individual level
Utility-based measures	Travel costs between locations of activities	Amount and spatial distribution of supplied opportunities	Travel time and costs may differ, e.g. between hours of the day, between days of the week, or seasons	Utility is derived at the individual or homogeneous population group level

(Geurs & van Wee, 2004)

2.3. Geovisualization

"Geovisualization is a loosely bounded domain that addresses the visual exploration, analysis, synthesis, and presentation of geospatial data by integrating approaches from various disciplines including cartography with those from scientific visualization, image analysis, information visualization, exploratory data analysis, visual analytics, and GI Science"(Kraak, 2005, p.468). This illustrate that geovisualization combines various techniques and information for the graphical display or representation of physical features and abstract phenomena with spatial reference. Bleisch (2012b, p.129) stated that, "3D geovisualization is quite a generic term that is used for a range of 3D visualization types representing the real world, parts of the real world or other data with spatial reference". For example census or survey data about population distribution within a specific geographic boundary such as a city can be visualize along with physical objects like buildings, public infrastructure like roads, parks, hospitals using cartographic and GIS methods. Example, Koua et al. (2004) combined demographic and health survey data to analyze the relationship between variables or indicators using maps and other graphic methods and display the result of their analysis.

2.4. 3D Visualization of Data

Various types of 3D visualization methods have been identified depending on the phenomena or data used. Bleisch (2012) described three main categories of 3D visualization of data which include: (i) the representation of the real world; (ii) representation abstract data and (iii) the combination of both abstract data and the real world. As stated by Bleisch, real world objects such as buildings, water bodies, forests etc can be visualized in 3D in a realistic or generalized way of display in x, y and z coordinates. On the other hand the x, y, and z coordinates are often used to display abstract data such as statistical information in 3D. Abstract information such as population density, air or noise pollution levels can be displayed in 3D based on the values of these variables by extrusion in ArcGIS software. In this study both abstract and real world phenomena are visualized in 2D and 3D models and produced in static hard copy and digital format. The static format is the printed hardcopy of the accessibility analysis models or maps in the form of posters to be used for the task performance while the digital form refers to the same output as soft copy.

Dynamic methods of graphic displays are also possible in 3D visualization and have been widely applied. Dynamic method can simply mean graphic representation of data or information beyond static form but instead by applying animations, interactivity or changing with time (as in real time). Such methods have been used in studies to analyze and visualize real world objects such as buildings with a high level of details (Koeva, 2016). Town plans, cadastral maps, city models and virtual globe like Google Earth are some of the common geographic phenomena represented in static and digital methods of 2D and 3D visualizations. Semmo, Trapp, Kyprianidis, and Döllner (2012), have described different presentation styles of virtual city models in 3D visualization and their potential application methods.

Other methods of 3D visualization have been applied by integrating or combining 3D visualization with 2D GIS in several studies about urban environments (Ahmed & Sekar, 2015; Pullar & Tidey, 2001; Rautenbach, Coetzee, & Çöltekin, 2016; Xu & Coors, 2012). Methods of 3D visualization using 2D GIS data include extrusion of point, line and polygons in 2D data including building footprints to visualize spatial attributes and built features.

In presenting a method for analyzing built environment, Ahmed and Sekar (2015) used the ArcScene™ software package to produce a 3D model from a database with integrated land use, building use, and height with a floor space index, water distribution network, and wastewater network. According Pullar and Tidey (2001, p.30) "3D built environment can be can be generated from 2D features in a GIS using appropriate parameters". Thill, Dao, and Zhou (2011), have demonstrated the effectiveness and practicality of 3D network analysis of built environments by conducting case studies of route finding, accessibility assessment and facility location planning.

Procedural or manual methods are some of approaches involved in generating or developing 3D visualization models. However, manual methods can be time consuming. "Procedural modeling is an umbrella term for a number of techniques in computer graphics to create 3D models from sets of rules" (Ganster & Klein, 2007). Gatzidis, Liarokapis, and Brujic-Okretic (2007) have applied procedural methods to develop 3D virtual city models for mobile navigation. Modeling software, such as Trimble's SketchUp or Autodesk's Revit can be used to generate 3D models (Rautenbach et al.,2016).

3D visualization models are often used to visualize information particularly the real world such as urban environment at different scales (Mao, 2010). The scale of features or objects to be represented in 3D can determine the level of detail (LoD) of the information that need to be graphically displayed. LoD refers to the coarseness of the objects or features visualized in 3D where, for example, LoD0 is coarsest compared to LoD4 (Kolbe, Gröger, & Plümer, 2005).

To visualize a large geographic area such as a region, Municipality or even large areas of the urban environment like a neighborhood, in static or printed form the graphic presentation is displayed in Lower LoD. With advancement in technology it is possible to digitally visualized large geographic areas with high LoD in specific software such as Google Earth. However, this appears to be more enhanced or possible interactively through zooming.

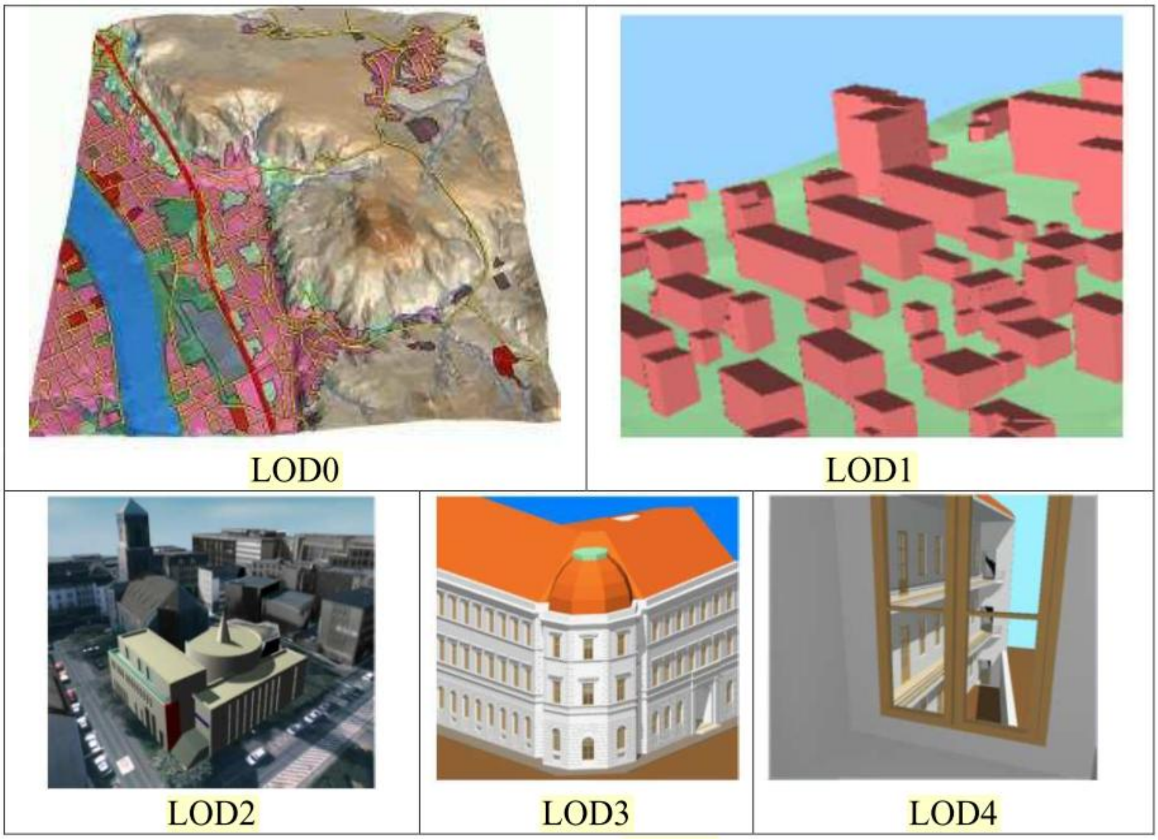

Figure 2: Various levels of detail (LoD) used in developing 3D visualization models in CityGML

Source: (IGG University of Bonn, quoted in Mao, 2010)

Figure 2 shows five LoDs that can be supported in CityGML application as presented in Mao (2010). As shown in the figure (from left to right) large area of terrain is displayed at LoD0, for example a 2.5 Digital Terrain Model (DTM) draped with an image or map. A section of building blocks is displayed at LoD1. However, at LoD1 for instance roof structures and textures of buildings are not featured as compared to LoD2, instead it just depict a block model of the building (Kolbe et al., 2005). It has been shown in figure 2 that the smaller the scale of the area or object visualized the higher the level of detail revealed as shown in LoD2, LoD3 and LoD4 respectively. At LoD3 details about the structure of the building such as, walls, roof, windows etc can be seen. LoD4 further reveal more detail but the scale or area of the building visualized is reduced to only the window.

2.5. Advantages and disadvantages of 2D and 3D visualization

Both 2D and 3D visualizations have advantages and disadvantages depending on the field of application or the type of phenomena displayed. In medical science, particularly in echocardiography (viewing and studying of heart structures using sound waves), 3D visualization was found to be useful by allowing viewing of organs from almost every desired perspective in contrast to 2D which allows viewing from one perspective ("Comparison between 2D and 3D," nd).

The advantages and disadvantages of 2D and 3D visualizations have also been related to both perceptions on the display of the graphics and techniques involved (Dubel, Rohlig, Schumann, & Trapp, 2015). The authors related the merits and demerits of the visualizations to techniques and viewer perceptions like scale, occlusion, or distortions. Swanson (1996) argued that when 3D display of elevation or contour are applied it stimulate spatial reality and enhance quicker understanding in contrast to 2D contour map of the same area.

It has been agreed by some scholars that it is suitable to visualize complex objects in 3D in a relatively more realistic view and with height of the objects represented (Koeva, 2004; Zhou, Dao, Thill, & Delmelle, 2015). Maktav et al. (2005) argued that viewer appreciation is higher for 3D display of planning scenarios than 2D.

In conducting user experiments with 2D and 3D separately, and a combination of both Tory, Kirkpatrick, Atkins and Moller (2006), showed that 2D visualization methods were more effective than 3D in accurate measurements and interpretation task, while 3D models were better for navigation task. However, 3D data acquisition and rendering techniques are considered to be difficult than 2D (Swanson, 1996), and require expert skill ("Comparison between 2D and 3D," nd)

Table 3: Comparing the strengths and weaknesses of 2D and 3D geovisualizations

Advantage	2D	3D	Source
Visualization found to be most favored for depiction of reality	-	+	(Schobesberger & Patterson, 2008)
Visualization found to be most accurate for identifying location on the landscape	-	+	
Better understanding in teaching complex topics among students particularly in the medical science	-	+	(Prinz, Bolz, & Findl, 2005)
Judging vertical distances in air traffic control	-	+	(Baier & Zimmer, 2014)
Judging horizontal distances in air traffic control	+	-	
Accuracy in precise measurement of distances	+	-	(Melanie Tory, Kirkpatrick, Atkins, & Möller, 2006)
Performing of navigation task	-	+	

Table 3 gives a summary of the advantages and disadvantages of both 2D and 3D visualization methods as discovered in different researches. The advantages are compared between the 2D and 3D methods and for each of the two a minus (-) sign indicate a disadvantage while a plus (+) denote an advantage over the other.

2.6. Assessing Usefulness of 3D visualization

In assessing the perceived usefulness or added value of 3D visualization the first step requires developing a model to represent a particular phenomenon. Many studies have developed visualization models or maps to assess how the graphical display or presentation of features in 3D is perceived to be useful or effective to understand compared to 2D methods (Kourouni, 2014; St John, Cowen, Smallman, & Oonk, 2001; Kjellin et al., 2010). For example, developing and assessing visualization models on planning practices such as urban design, zoning, or land use patterns. Other studies have developed 3D visualization techniques to apply in analyzing complex issues such as traffic management, navigation within the urban environment or disaster management (Thill et al., 2011; Kemec, Duzgun, Zlatanova, Dilmen, & Yalciner, 2010).

A widely used approach in the assessment of the 3D visualization considers two aspects: usability and usefulness (Bleisch, 2012). According to authors such as Mackinlay and van Wijk (quoted in Bleisch, 2012) usability is evaluated based on efficiency and effectiveness. The perceived usefulness is simply defined as "the degree to which a person believe using a particular system would enhance his or her job performance" (Davis, 1989, p.320). Usefulness evaluation of 3D visualization involve task performance; for example to test its effectiveness and efficiency in navigation and interpretation exercises or appropriateness of the perspectives displayed (Bleisch, 2012). The author further elaborate that such assessment considers or measure the efficiency and effectiveness of the 3D visualization by comparing with, for example, 2D visualization model of similar phenomena. Schobesberger and Patterson (2008) have compared 2D and 3D visualizations maps of Zion National Park, Utah, to evaluate the effectiveness of presenting cartographic information with hikers. Their findings revealed that both methods have their weaknesses and strengths.

2.7. Efficiency, Effectiveness and Appropriateness

This study seeks to assess the usefulness of 2D and 3D geovisualizations with regard to their effectiveness, efficiency and appropriateness in an interpretation task based on models developed from analysis of accessibility to health facilities within an urban region. While evaluating the 2D and 3D geovisualizations for basic spatial assessment by conducting experiment through task performance, Seipel (2013) relates efficiency to time. Seipel (2013, p. 847), has defined efficiency as "the average time needed [taken] to solve a number of trials". In the discussions of a few literatures on effectiveness of 2D and 3D geovisualizations, success or error score obtained in task activities has been regarded to as common measures for their effectiveness evaluations (S. Bleisch, 2012a; Melanie Tory et al., 2006; Chen & Yu, 2000). This means that effectiveness of the 2D and 3D graphical display or representation of analysis of data such as spatially referenced information can be determined by the level correct score achieved from task activity designed to evaluate the visualization methods. There is little theory on the appropriateness evaluation of 3D geovisualization. "Questions such as what are appropriate 3D geovisualizations, how can different types of data be suitably represented in a single virtual environment or what are the merits of realistic or abstract representation styles are less often asked or even answered"(Bleisch, 2012a, p.129). In another study, in an effort to measure appropriateness of 2D and 3D visualizations produced using different datasets, Bleisch and Dykes (2015), designed and implemented an experimental approach. They analyzed the appropriateness of the two methods based on the time taken to complete, the complexity of the task, plausibility and confidence of participants and concluded that it could not easily determine when to use 2D or 3D based on this method. In this study appropriateness is define as the complexity (difficulty or easiness) in identifying the features represented in the 2D and 3D maps.

2.8. Conclusion

This chapter reviews the literature on the key concepts of this study which include geovisualization and usefulness (in terms of efficiency, effectiveness and appropriateness) assessment of 2D and 3D geovisualizations. It discusses GIS based accessibility analysis, the advantages and disadvantages of 2D and 3D geovisualizations. Some of the methods of displaying data in 3D format were also discussed.

3. RESEARCH METHOD

3.1. Introduction

This chapter describes the research methods applied. Literature review and survey methods, through interviews, group discussions and task performance during field data collection, were applied. The methods were design to address the formulated research questions and related specific objective. This is because the study seeks to capture both quantitative and qualitative information for analysis. Perception studies requires the use of mixed methods (Land, Michalos, & Sirgy, 2012), in order to collect both quantitative and qualitative information. The qualitative information can be quantified using Likert Scale to assign values during analysis (Herbert & Chen, 2015a). For example the percentage of respondents who perceived the 3D or 2D to be 'not useful', 'useful' or 'very useful'.

Structurally, after the introduction, this chapter begins with a description about the case study area. A description on the data used for the GIS accessibility analysis to produce the 2D & 3D models for assessing them follow suit. The methodology framework is presented in section 3.3. This follows a description on the type of accessibility analysis applied before discussion on the data collection methods used for this study.

3.2. Study Area

The Gambia is the smallest country in mainland Africa. It is one of the sixteen member states of the Economic Community of West African States (ECOWAS). Perhaps because of its small size it need introduction herself before the study area concerned. As such the description of the study area for this research will deliberately start with a few lines of facts about the country as summarized by table 4 below.

Table 4: Summary of country attributes, The Gambia

Land area	11,000 square miles approximately.
Population	1, 882, 450 (GBoS, 2013)
Administrative regions	8 (including two municipalities and 7 regions) (GBoS, 2013)
Main economic activity (by order of importance)	Farming, Service & Trading
Resources	Human (no major natural resource)

The study area for this research is Kanifing Municipality. It is one of the eight administrative regions and the larger of the only two Municipalities in The Gambia. The Municipality is divided into five districts and seventeen wards (see figure 3). The smallest administrative unit in The Gambia is a Ward. According to Gambia Bureau Statistics 2013 preliminary census report the Municipality has a total population of 382,096 and a population density of 5057.5 per km^2. The Municipality is 100% urban and the most densely populated among all the regions. The census report stated that Kanifing has on average a population growth rate of 1.7% between 2003 and 2013 inter-census period. With average household size of 5.6 persons, the Municipality is also home to 20.3% of the total population of the country (GBoS, 2013). Yet the main economic activity in this region is service and trading.

A household, as defined by the Gambia Bureau of Statistics consists of a person or group of persons who live together in the same house or compound, share the same house-keeping arrangements and are catered for as one. (GBoS, 2011). It is further noted that members of a household may not necessarily be related (by blood or marriage) as for instance, maid-servants may form part of a household.

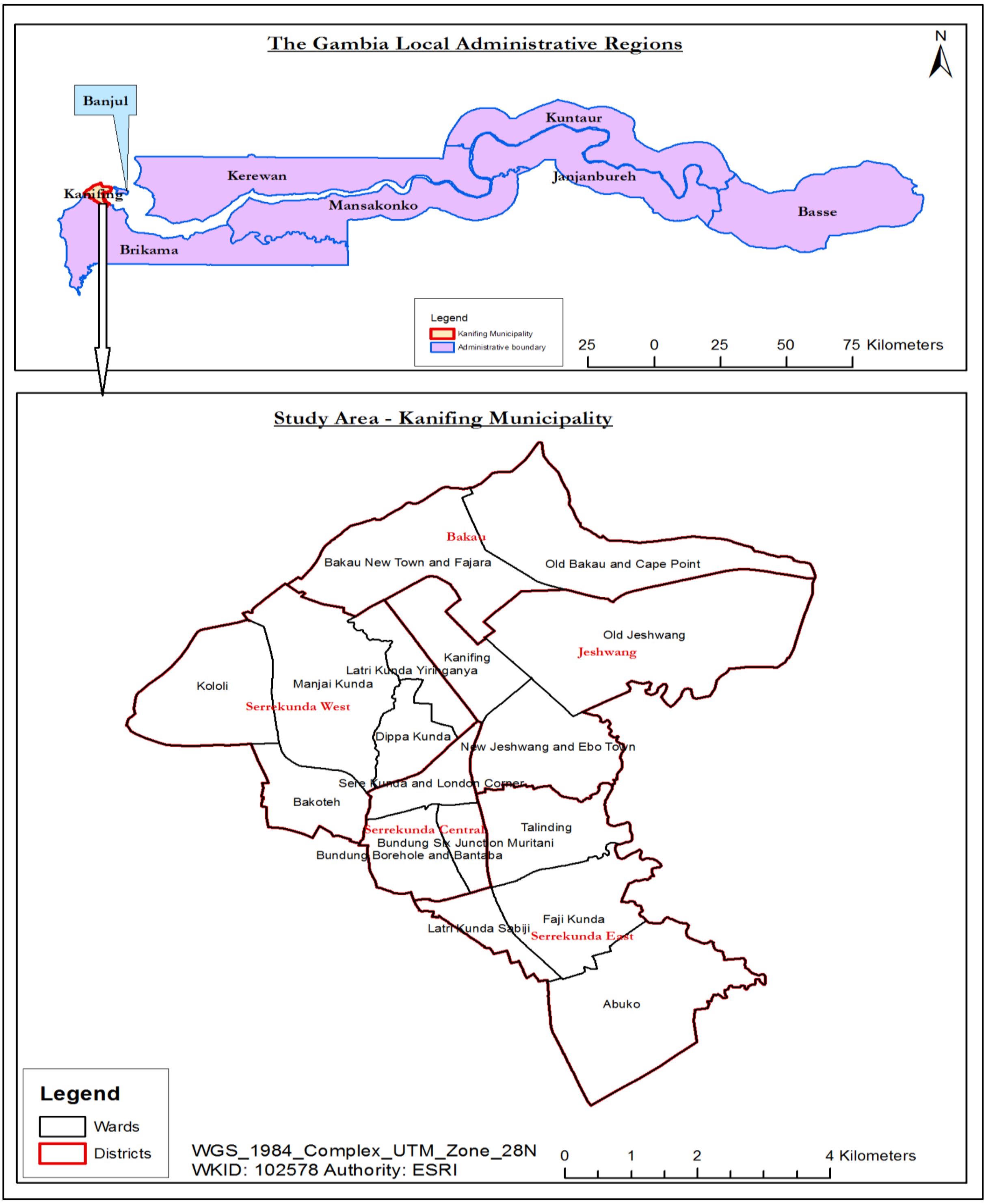

Figure 3: The five districts and seventeen wards of the study area

3.3. Data Used for Accessibility Analysis

The data used for the accessibility analysis was obtained from the Gambia Bureau of Statistics (GBoS). It consists of spatial datasets of the study area (Kanifing Municipality) in vector format. The datasets were produced during the 2013 population and housing census mapping exercise. It included administrative boundaries of Kanifing Municipality at district and ward level. This spatial data contain population statistics in the attribute table. The population statistics indicate the number of people within each of the five districts and seventeen wards based on the 2013 census. Spatial data for the location of residential areas available in GIS shapefiles showing parcel boundaries of residential units is also used.

The data used for the health facilities shows the spatial distribution of the facilities within the Municipality. The attribute data of this spatial dataset contain information about the type of health facility such as hospital or clinic and whether it is public or private ownership. According to the dataset there are 18 health facilities in total. Majority of these (10 in total) were clinics. Information on the number of staff and the patient served by each facility was not available.

The spatial datasets have been used to analyze and visualize accessibility to health facilities. For example, closest facility analysis was carried out using the road network, residential parcel, health facility and administrative boundary datasets. This was performed by analyzing distance ranges or intervals from the health facilities to the residential parcels. Through this method it was possible to visualize the residential areas with distant or close proximity to the facilities. The location and distribution of the types of health facilities was visualized using the health facility and administrative datasets. On the other hand the district and ward administrative datasets with total number of population and household were used to showcase population and household distribution within the municipality respectively.

Primary data was collected through interviews, group discussion and task performance. These three activities focused on the visualization outputs of the GIS based accessibility analysis to health facilities in the study area. The outputs were produced in 2D and 3D models or maps printed as posters and also digital (soft copy) format to collect primary data. The visualization models display spatial distribution of the facilities and their relative distance to the location of the population within a Municipality region. The primary data collected concerned the usefulness of the visualizations by assessing the efficiency, effectiveness and appropriateness of the two methods (2D and 3D). Details on how the primary data was collected is further discussed in section 3.6 of this chapter under the heading 'data collection'.

Table 5 shows the description of the type of spatial datasets used for the accessibility analysis. The coordinate system used for these secondary spatial datasets is also included.

Table 5: Spatial Datasets used for the GIS accessibility analysis to produce the models

Geographic Coordinate System: GCS_WGS_1984 (applies to all datasets)		
Type of spatial dataset	Format	Description
Kanifing district boundary	Vector (polygon)	Administrative boundary of the 5 districts in the study area with 2013 population statistics by district
Kanifing ward boundary	Vector (polygon)	Administrative boundary of the of the 17 wards in the study area with 2013 population statistics by district
Health facilities location	Vector (point)	Types of health facilities by: Size (hospitals, major health centers, minor health centers, clinics and community health post) and Ownership (private and public)
Kanifing Residential Parcels	Vector (polygon)	Plot boundary for the residential properties
Kanifing road network	Vector(line)	Paved and unpaved roads all merged in one dataset

Source*: Gambia Bureau of Statistics; 2013 Population and Housing Census GIS Datasets*

3.4. Methodology framework

This study focused on the measure of the usefulness of 2D and 3D visualizations of GIS based accessibility analysis to health facilities as perceived by experts. The methodology framework developed for this study is represented by figure 4 below. Spatial data and statistical data with spatial reference were used to develop 2D and 3D visualization models or maps based on accessibility analysis to health facilities using ArcGIS 10.3.1 software. The spatial datasets include; types of health facilities, road network and residential locations (parcels). On the other hand the statistical information consists of the population for each district and number of households in each ward. Different analyses were applied and thus different outputs. The assessment was based on the usefulness aspect of the 2D and 3D visualization methods of the analysis in terms of their efficiency, effectiveness and appropriateness using various data collection methods such as discussions, task performance and interviews. The challenges limiting the experts in applying GIS based methods were identified during group discussions.

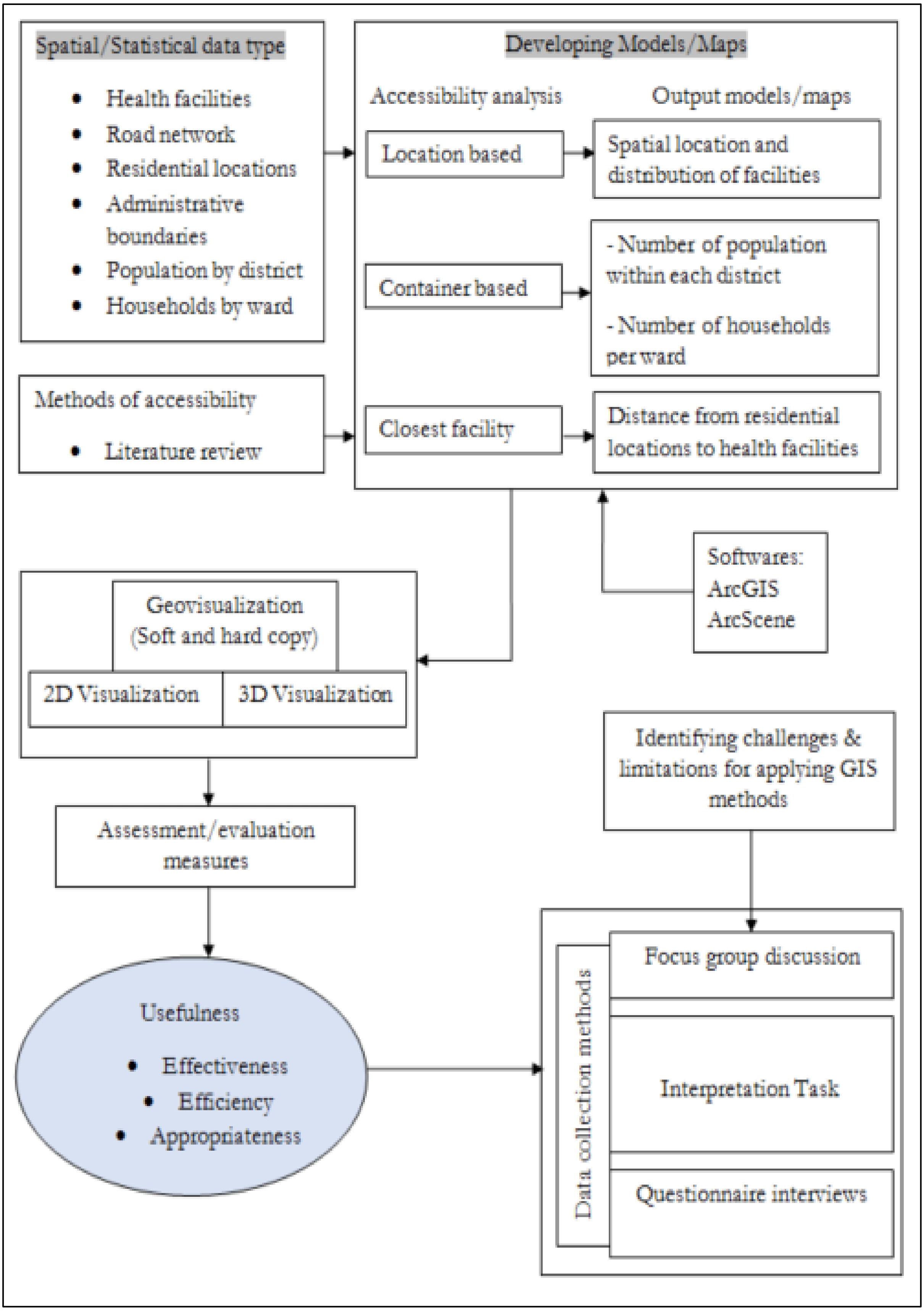

Figure 4: Research methodology framework

3.5. Accessibility Analysis Performed

The study attempt to answer questions 1 and 2, formulated to achieve the first objective, through literature review. This is to identify a method of GIS accessibility analysis to apply. Different types of analysis were applied including location based; container method; and network analysis. These methods are considered since they are simple to apply and are typically applied in large scale urban planning and geographic studies (Geurs & van Wee, 2004; Suzuki & Suzuki, 2015). The location analysis showcased the spatial location and distribution of the types of health facilities within the Municipality. The container method allows for visualization of the analysis to showcase the distribution of the population and households within the administrative units (5 districts and 17 wards) of the study area. On the other hand the network analysis showcased distance between the location of the health facilities and residential areas along the road network within the Municipality.

The GIS accessibility analysis is performed using the ESRI ArcGIS 10.3.1 software. The datasets were prepared and cleaned to suit the purpose of the analysis and display desired. The first step involved creating a network dataset using the health facility, residential location and road network datasets for the study area. The distance analysis model was produced using closest facility tool of the network analyst in ArcMap. The *Closest Facility* network analyst tool in ArcGIS software package determines cost of travel between the closest facilities (in this study - health facilities) from incident location (residential parcels) along a road network[1].

The outputs of the accessibility analysis were developed into 2D and 3D maps in ArcMap 10.3.1 to be used for the interpretation task performance. The 2D shapefiles were then loaded into ArcScene software to produce 3D maps by applying the extrusion function (see figure 6). The extrusion in ArcScene was based on the values in the attribute field with information required to be visualized, example population, household or average distance.

The maps are labeled, for examples 2D-SI-A and 3D-SI-A, to identify the 2D and 3D maps respectively. The letters SI, SII and SIII refer to sections in the task questionnaire. While the letters simply A, B, C and D refers to the numbering or sequence of the maps.

This study acknowledged the importance of travel time in location-based accessibility analysis. However, travel time was not analyzed. This was for a number of reasons. First is to limit the number of visualization outputs for effective task performance due to time constraint since the focus of the study is to assess the usefulness of the 2D and 3D visualizations. Second, policy priority for accessibility to social infrastructure, at least in the health sector, considered availability and proximity of health facilities to the population (MoH & SW, 2014). This can be confirmed with absence of standard travel time data for the study area concerned which might have to be compensated by adopting standards elsewhere. Therefore, for this study it was considered sufficient to visualize the distribution of the facilities within the administrative units, travel distance between the population and the facilities.

The rationale for applying the container method is to show a comparative analysis on a large scale, in this case between districts and wards within an urban region. This was necessary to focus the discussions of the models based on planning perspectives. For example through this

[1] ESRI ArcGIS 10.3.1 help

method it was possible to visualized distribution of health facilities and population in each of the five districts. Pacione, (2009) describes that resource distribution is a planning issue since inequitable allocation of it is one of the major causes of deprivation in urban regions. This was also considered as not just a simple method but also with the anticipation that the targeted respondents might find it easier to understand the output models. The information displayed graphically in the models or maps and printed as posters was used to comparatively assess the two different outputs (2D and 3D maps). The types of information or output of the analysis visualized are further discussed in section 4.2 of chapter four.

Figure 5 presents the flowchart of steps and processes involved in generating the maps and the methods of primary data collection used. The study methods applied are divided into three main stages which involved: model development; field data collection; and data analysis.

3.6. Field Data collection

Three different activities were designed and conducted to collect data during the fieldwork. These are: (1) Group discussion (2) Interview using questionnaire and (3) Task performance involving map interpretation (see appendix A, B and C respectively). Details for each of these three methods are further discussed in sections 3.6.2, 3.6.3 and 3.6.4 respectively. This mixed method approach was considered in order to capture and analyze the subjective perception of the experts and quantify the level of their appreciation based on their views. The focus group discussions, interviews and tasks performance with the 2D and 3D visualizations seek to evaluate the usefulness of the two methods in terms of efficiency, effectiveness, and appropriateness for representing the accessibility analysis information.

Efficiency is measured considering how much time it took participants to complete the task. That is how quick a task was completed with a particular visualization model (2D or 3D). Effectiveness is interpreted here in terms of how much of the tasks (in percentage) can be correctly performed or completed with a particular visualization method. On the other hand appropriateness should be understood as the suitability of representing features analyzed or information displayed in the models or maps such as the population, travel distance and health facilities. This is qualitatively assessed with questionnaires based on how the respondents perceived it difficult or easy to identify or interpret the features visualized graphically in the maps.

Each of the activities was designed to achieve a specific study objective and to answer related research question(s). For example the group discussion was designed to identify the challenges limiting the experts in applying GIS based 2D and 3D methods of geovisualizations. On the other hand, interviews were designed to assess the usefulness of the 2D and 3D GIS visualizations as perceived by the experts. The task performance was carried out to assess the effectiveness and efficiency of the models and as well the appropriateness of the representation or display of the features.

Prior to the start of the discussions with the various groups, which is the first activity, a short presentation is done in order to introduce the study objectives. Different methods of 2D and 3D geovisualizations were described and explained how they can be used or applied using examples.

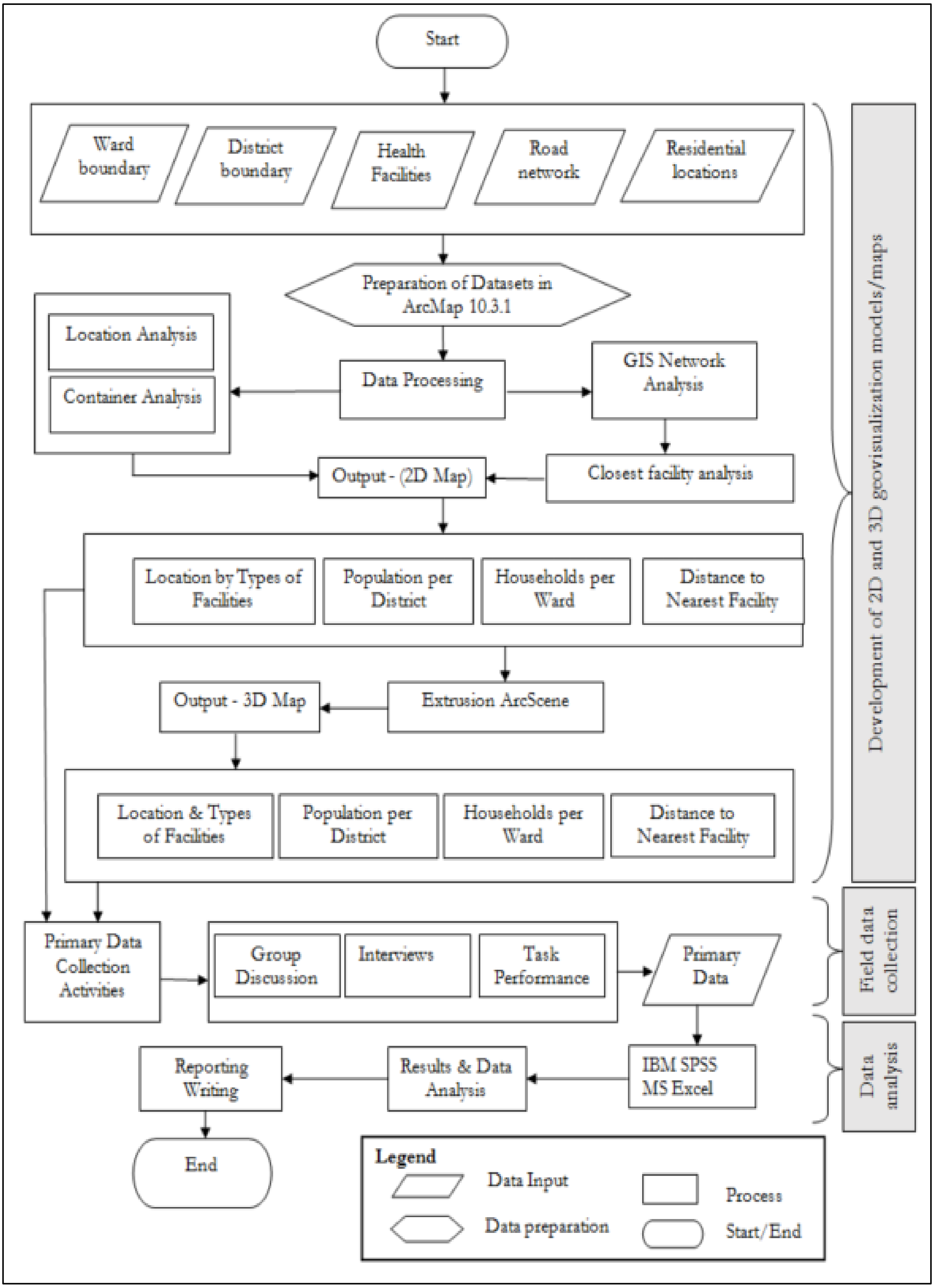

Figure 5: Methodology flowchart

3.6.1. The Participants

Six different organizations or institutions were engaged. These included the following:

1. ***The Gambia Bureau of Statistics (GBoS).***
   GBoS is the national statistical institution and its mandate is to collect process and disseminate official statistics in the country. Four participants from the GIS/Cartography Unit and a principal statistician from the household statistics unit have volunteered to be engaged in the activities.

2. ***Planning and data management unit of Kanifing Municipality.***
   It was recently established by the Municipality to collect and document property information within the Municipality for efficient rate collection. This unit is headed by a senior planning officer. Eight participants including the assistant director were present at the discussions.
3. ***Department of Community Development (DCD).***
   This department coordinates development projects for communities throughout the country, particularly physical infrastructure. The director who is head of the department and seven other development officers participated in the discussions and interviews.

4. ***Department of Lands and Surveys (DLS).***
   DLS is responsible for all land matters including surveying, registration and authentication of land documents. It is under the Ministry of Lands and Local Governments. Three principal surveyors and two international consultants under UNDP Gambia Office had volunteered and participated in the discussions. The two consultants each perform a task using one of the maps.

5. ***Nova Scotia Gambia Association (NSGA).***
   This is a Non Governmental Organization (NGO) with a primary goal of promoting health education in the country. It has regional representatives who coordinate the activities of the organizations in each region of the country. In this discussion six regional coordinators and some staff at the headquarters were present.

6. ***The Department of Planning and Information (DPI)*** of the Ministry of Health and Social Welfare.
   Present for the activities were three participants including the director for Health Information Management Systems (HMIS) and two other senior staff. The HMIS is responsible for gathering health statistics. However, discussions could not be held with this group due to time constraints and hence number of participants was less and. After a short presentation introducing the study objectives the participants were only engaged in interviews and task performance.

3.6.2. Group Discussion

Group discussion have become a popular method for collecting in depth information in many fields of study (Kumar, 2011). Herbert and Chen (2015) have combined group interviews with task performance in assessing the perceived usefulness of 2D and 3D representation of urban planning scenario. In this study group discussions with experts were conducted to identify the main factors or challenges that are limiting the experts in applying GIS based methods and gather information in order to supplement the questionnaire interviews. Discussions were conducted with five different organizations. The discussions sessions last between 25 to 30 minutes. Figure 6 shows discussion sessions with two of the participating groups during field data collection.

The discussions focused on the methods of visualization used by the experts in producing and disseminating the information and the challenges they face. The advantages and disadvantages of the GIS based models were also discussed. With this approach information about the challenges faced by the experts in using innovative visualization methods have been recorded. A discussion checklist (see appendix A) was developed to use as a guide for capturing key information during discussions with the groups.

The checklist included an open-ended question which probe about the challenges and limitations in terms of skills, materials and software. The key questions in the checklist also included:

- Does the experts visualize information using GIS applications [Yes or No]
- Do they have skill in using any GIS software [Yes or No]
- The types of GIS software used by the organization [List]
- The tool or method used to produce and visualize data [Computer, Manual or Both]
- The format of visualizing information [Digital, Static (printed hard copy), None or other]

The discussion checklist also include the following items listed below

- The category of users of the kind of information produced by the experts [the categories are: policy makers local or international; General public or others].
- Whether the users or consumers of their information demand a more enhance way of visualization than they are currently applying and whether they think there is a need for them use enhance method [Yes or No].
- Which method(s) they would consider more enhancing [2D digital; 2D static; 3D digital or other]

Figure 6: Discussion sessions with two of the participating groups

(Pictures taken by author during field data collection)

3.6.3. Interviews

Following the discussions and task performance, self administered questionnaires were issued to collect or capture in-depth primary information. Twenty-seven self administered interviews have been carried out using the questionnaires See appendix C, for details included in the questionnaire. The aim of the interviews is to gauge the perception of the experts about the usefulness of the 2D and 3D GIS visualization methods in relation to their everyday work. The interviews seek to capture the perception of the respondents about following information:

- The method of visualization that best explained the accessibility analysis they displayed
- The most useful of the two methods of visualization for applying in their everyday work
- To rate how useful are the 2D and 3D methods of visualizations
- How easy or difficult they found in understanding the models or maps
- Which features they found difficult or easy to identify in the models or maps
- How would they rate the two methods (2D and 3D) used for visualizing the accessibility analysis

Participation in the interviews and group discussions was voluntary and opens to all staff present. As such the number of participants from each organization is not equal. There was a mixture of participants with regards to their position or rank (see appendix M). The head of the institution or organization, in their capacity as director or manager, also participated in the discussions with a few other senior or junior staff. Figure 7 shows pictures of participants filling in interview questionnaire.

Figure 7: Participants filling self administered questionnaire

(Pictures taken by author during field data collection)

3.6.4. Task Performance

Performing task is one of the methods applied in assessing usefulness of 2D and 3D geovisualization in terms of their efficiency, effectiveness and appropriateness. The task performance involved basic map reading and interpretation of the information about the accessibility analysis that was graphically displayed in the maps by answering specific questions designed for this purpose. Appendix B shows the questions designed for the task performance. Four different types of geovisualization models in 2D and 3D were used for the task activity. The questions drawn for the task performance were group into three sections. A specific section was dedicated to each map to ask questions related to the analysis visualized in the map. In figure 8 below participants can be seen performing the interpretation task using the 2D or 3D models.

Figure 8: Participants performing interpretation tasks with the 2D and 3D models.

(Pictures taken by author during field data collection)

In section one the task question were related to the map displaying the types and distribution of health facilities within the five districts of the Municipality. In this section participants were task to compare the districts in terms of the following:

- The number of the health facilities (opportunities) contained or located in each district
- The types of health facilities available
- The most common type of health facilities

The task questions in section two relates to the maps showing the number of population in each district and households within the seventeen wards. In this section participants were tasked to compare the districts and wards in terms of the population and household distribution in these administrative units.

In section three the task questions relates to distance analysis. The participants were tasked to identify residential areas most accessible to the health facilities in terms of distance.

The maps were labeled (see appendix D to K respectively) according to the section (see appendix C) the participants were to answer the task questions on. In total twenty task questions were designed for the map reading and interpretation task. A maximum of 35 minutes was allocated to complete the task. This timing was based on the average time taken to complete the task during the pre-test. For each organization or institution two volunteers performed the task using one of the two maps (2D or 3D). The same types of questions were asked for the different maps. The tasks performance was aimed to evaluate the effectiveness, efficiency of the 2D and 3D visualizations and appropriateness of their graphical displays.

3.7. Study limitations

Some of the experts that participated in the discussions, task performance and interview activities during the data collection have little or no skills in GIS. To address this, a short introduction in the form of power point presentation was performed prior to discussions to explain and give example of how GIS methods of visualization using maps.

Essential cartographic or map elements such as legend, scale and north arrow were not able to be produced in ArcScene application for the processing of the 3D maps. This was compensated by reloading the 3D maps as picture in the ArcMap to insert the Legend, scale and north arrow.

3.8. Conclusion

This chapter presents the research methods adopted which includes literature review, group discussion, task performance and interview to achieve the specific objectives. It described the study areas, data used and accessibility analysis applied. As part of the specific objectives the study has developed 2D and 3D geovisualization models or maps based on the out puts of the accessibility analysis to be used for assessing the two methods. The models showcased the location and distribution of the health facilities; the population and household distribution within the five districts and seventeen wards respectively; the distance ranges from the residential areas to the health facilities.

4. RESULTS AND ANALYSIS

4.1. Introduction

This chapter presents the analysis of the results obtained from the methods applied. The visualization outputs of the accessibility analysis applied are presented in section 4.2. The result obtained from the discussion is presented in section 4.3 while the results and analysis of the task performance and the interviews are presented in sections 4.4 and 4.5 respectively.

4.2. The 2D and 3D Visualization Outputs of the Accessibility Analysis

The first objective of this study is to develop geovisualization models in 2D and 3D form based on analysis of accessibility to public health facilities at Municipal level and to assess the two methods. The output of the analysis showcased the distribution of health facilities and distance from residential location to the facilities along the road network within five administrative districts in the Municipality of Kanifing, The Gambia. It also graphically displays population and household distribution within the five districts and seventeen wards respectively.

Four different analyses were performed and hence four different models or maps were produced. The outputs of the four different analysis applied were each visualized in 2D and 3D visualization methods. The four types of maps included the following:

1. *Map showing types and spatial distribution of the health facilities within the five districts in Kanifing.*

Figure 9 shows the 2D (A at the top) and 3D (B at the bottom) visualizations of the outputs of the analysis showing the location and distribution of the types of health facilities within the five districts. The cartographic variables for the visualization include title, north arrow, scale bar and legend. A graduated color symbol and labels of the districts and the types of the facilities was also applied. This map is used by the participants to answer the questions in section one of the task performance.

2. Map showing representation of population per district

Figure 10 shows the output maps in 2D (A at the top) and 3D (B at the bottom) .This map visualized the population representation of each of the five districts. This map was developed to be used by participants for the task in section two of the task performance. The district boundary shapefile with attribute information on the statistics of total number of population for each district was used. The main cartographic variables used in the visualization are title, legend, north arrow and scale bar. The population comparison between the districts was shown in a graduated color such that the smaller the population the lighter the color representing the district.

3. Map showing representation of total number of households per ward

This analysis is similar to that of the districts. However, the graphic display showcased the household distribution by ward in 2D and 3D. The wards are the smallest administrative units within each Municipality. This was considered relevant to include because statistical analysis are often limited to district level. Since ward councilors who are the administrative heads are important stakeholders in planning decisions it might be worthwhile to include analysis at ward level. Figure 11 (A at the top) and 3D (B at the bottom) represent the comparison of household information within the seventeen wards.

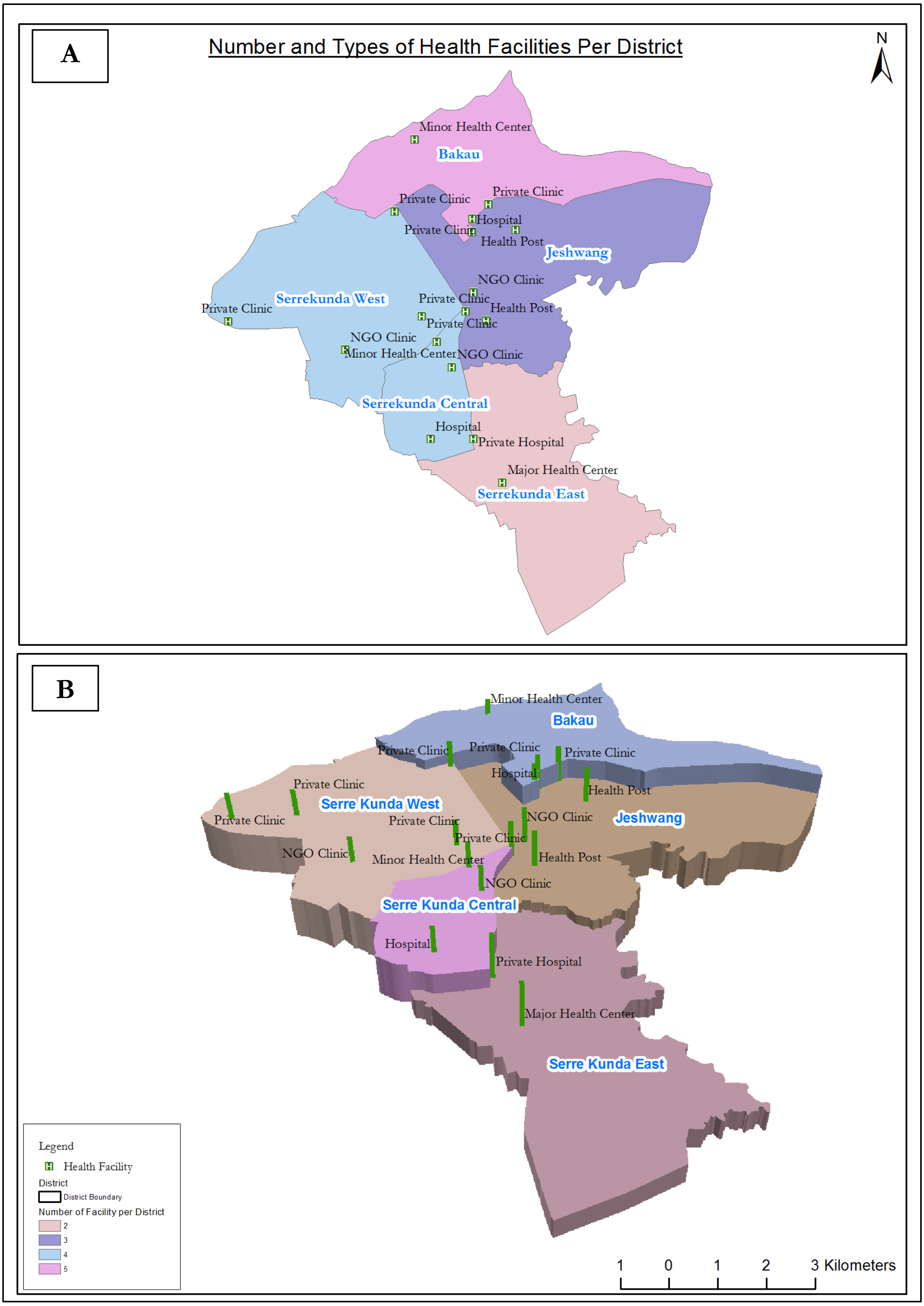

Figure 9: Models showing the location and distribution of the types of health facilities in 2D (A) and 3D (B) visualizations

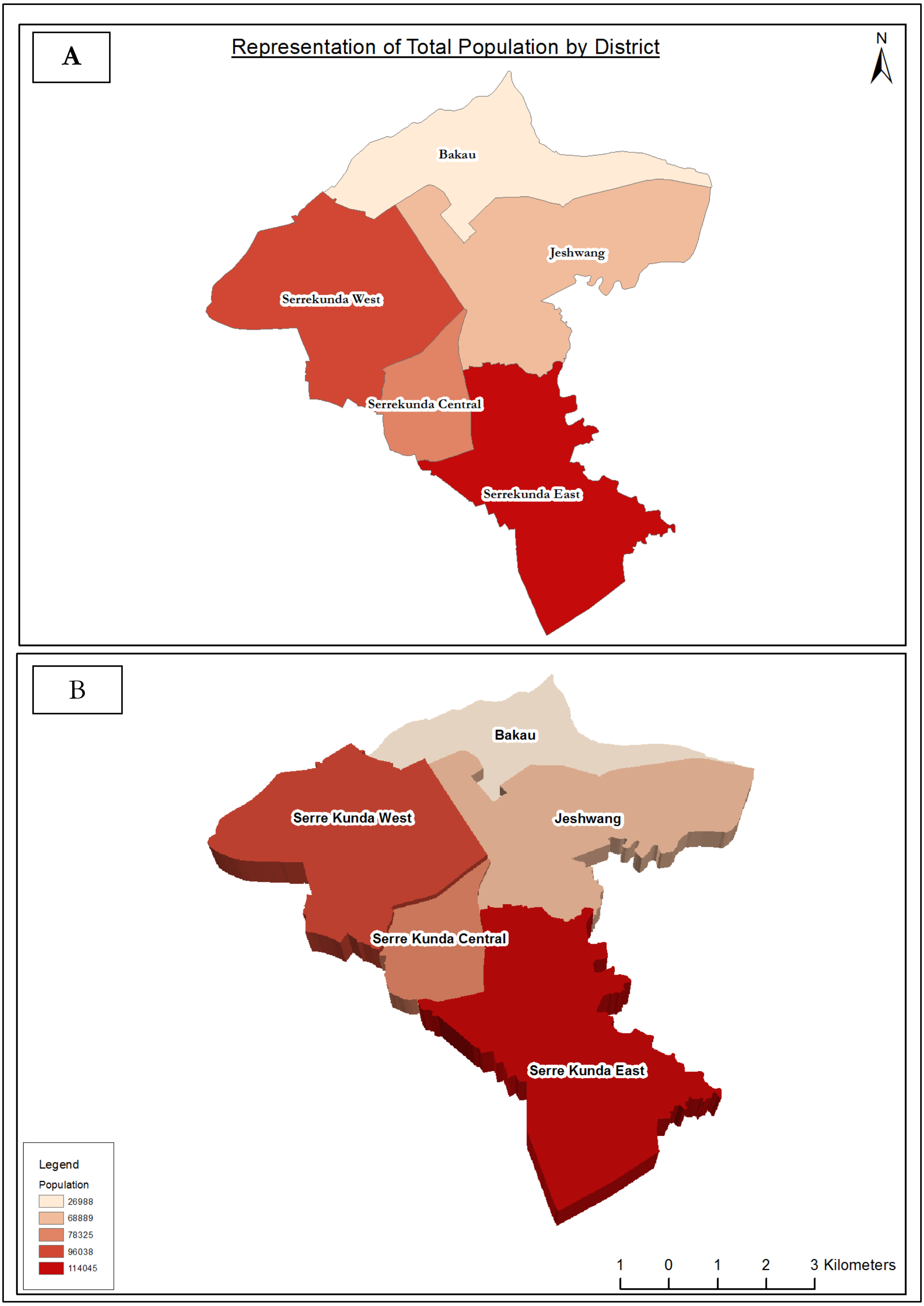

Figure 10: Model representations population by districts in 2D (A) and 3D (B) visualizations

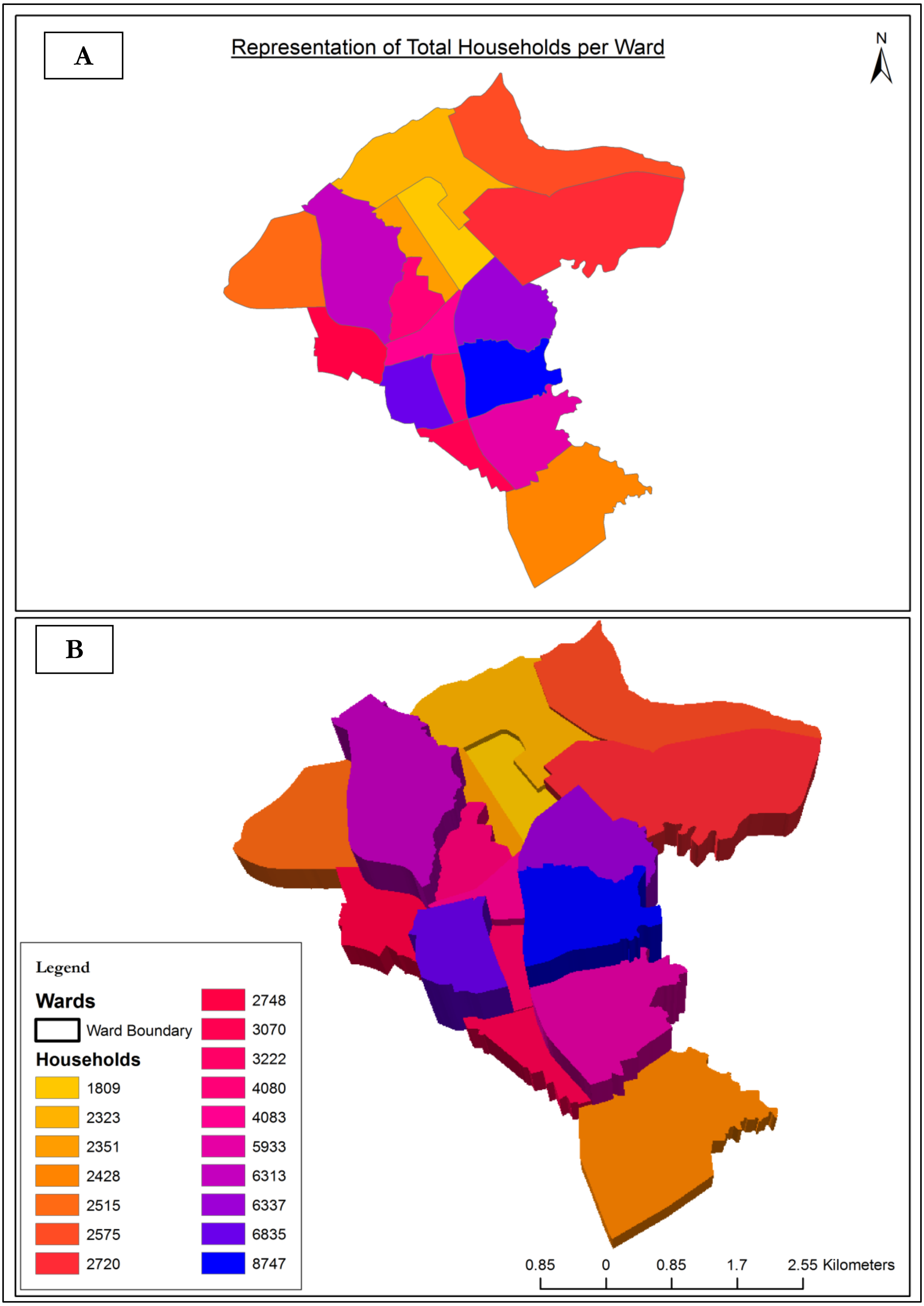

Figure 11: Models comparing the number of households by ward in 2D (A) and 3D (B) visualizations

4. Map showing travel distance from residential locations to the health facilities.

This model or map shows the visualization (in 2D and 3D) of output of the distance analysis from the residential parcels to the nearest health facility. A GIS based analysis was performed using "closest facility" function of the network analyst tool in ArcGIS software. In this analysis the cost considered was the distance between the incident locations (residential areas) and the facilities. Five distant intervals between 0 - 2652 meters were generated around each facility. The closest is 0 - 249 meters interval range from the health facilities and the furthest was 2652. The output generated was a map in graduated color ramp as shown in Figure 12.

To produce similar output in 3D the same shapefile (residential parcels) used to create the 2D map was loaded into ArcScene. The polygons were simply extruded based on the distance field in the attribute table to generate 3D model. Since the residential parcels (polygons) are incident locations travel distance is displayed according to the distance from the parcels to the nearest health facility. The same cartographic elements were applied as used for the 2D output.

The purpose of generating both maps using the same data input and similar cartographic elements is to ensure that they all contain the same information or futures represented in the visualization of the analysis. In other studies it has been shown that the use of different datasets have strong influenced the analysis of the results, see (Bleisch & Dykes, 2015).

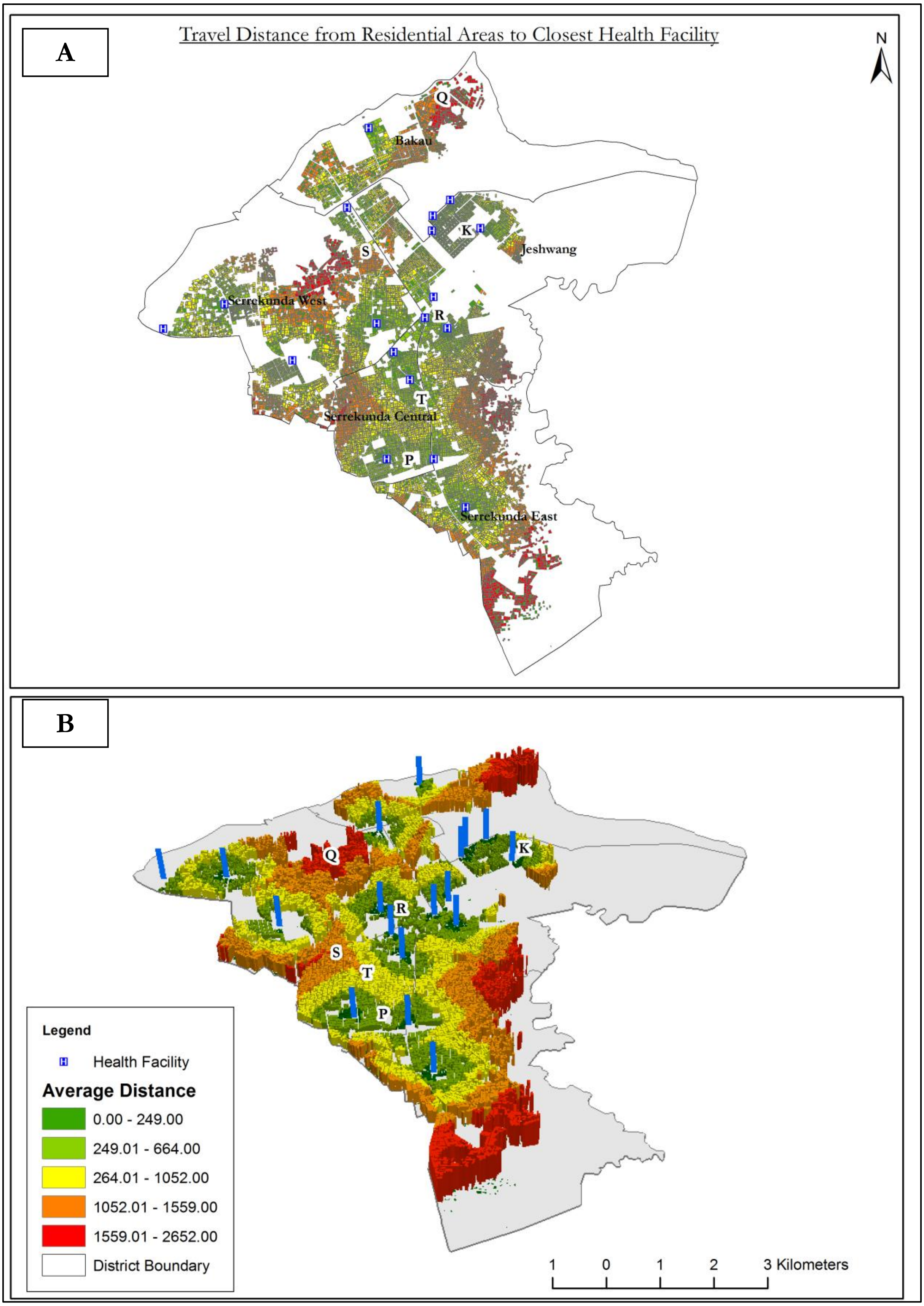

Figure 12: Models displaying travel distance from residential locations to the closest facility in 2D (A) and 3D (B) visualizations

4.3. Challenges Limiting the Experts in Applying GIS Methods

The second objective of this study is to identify the challenges limiting the respondents (experts) in applying GIS based 2D and 3D methods of visualization. Ahmed and Sekar (2015) argued that the complexity of the techniques, cost and lack of skills are limiting factors among urban planners in applying 3D visualization methods in everyday practice.

In this study group discussion was conducted with five of the participating six organizations to discuss the challenges they face in applying GIS based methods of visualization. Due to the engagements of the staff and limited time, discussions could not be done with the Health Management and Information System (HMIS) unit, which is part of the Department of Planning and Information at the Ministry of Health and Social Welfare (MoHSW).

Due to ethical considerations the names of the organizations are presented anonymously. The responses from to the open-ended question are analyzed by categorizing under four main themes to derive a list of the challenges or limitations reported by the experts. These include (1) inadequate skills (2) lack of Software (3) inadequate equipments and (4) budget constraints.

Inadequate skills

The experts from all the five groups indicate having limited skills to apply GIS based methods in their practice. Apart from two of the groups none of the experts in the groups have skills or apply any form of GIS methods. But still members in the two groups (with GIS skills) stated that they need to improve their skills. *"Further training on GIS especially network analysis, GIS server..."* (This was stated by a participant in one of the group). "*We need to know or learn about other tools like SketchUp, Photoshop, etc*", (stated by another participant). The experts from three of the groups (with no skills in GIS based methods) use computers, and also manual methods except one of the groups (which use only computers), to produce and visualize information.

Lack of Softwares

The GIS softwares such as ArcGIS and QGIS are the types mentioned by the experts two of the groups that apply or used GIS methods. However, the experts from one of the groups with GIS skills stated they also used other softwares namely AutoCAD and Revit. A participant in one the groups mentioned that even though they have professional software (licensed ArcGIS) it does not include other applications. "[We] *also do not have a license for certain extensions like 3D Spatial Analyst, Network Analyst and Geostatistical Analyst*". The experts from the other three groups (with no skills in GIS based methods of visualization) do not use any form of GIS based software or application hence they do not produce information using GIS application.

Inadequate equipments

Equipment in this study refers to computers, printers (various types) and scanners required for the processing, storage and production of GIS based data or information. All the experts from the five groups engaged in the discussions mentioned the lack of inadequate equipments at their disposal for use in their work. However, the experts in two of the groups have a lab equipped with equipments such as LaserJet printers including plotter and flatbed scanner which can scan or print on various sizes of papers (up to A0 and custom size). Experts from the other three groups do not have such equipments but still use desktop computers and printers for basic information processing and printing on small page size (A4) in hardcopy or storage in digital format. The basic information processing includes word processing with Microsoft word and Excel.

Until recently the experts in most of the groups use manual methods to produce and visualize information related to their work. Figure 13 shows district and city (Banjul) map with Enumeration Areas (EAs) for census data collection drawn by hand during the 2003 population and housing census.

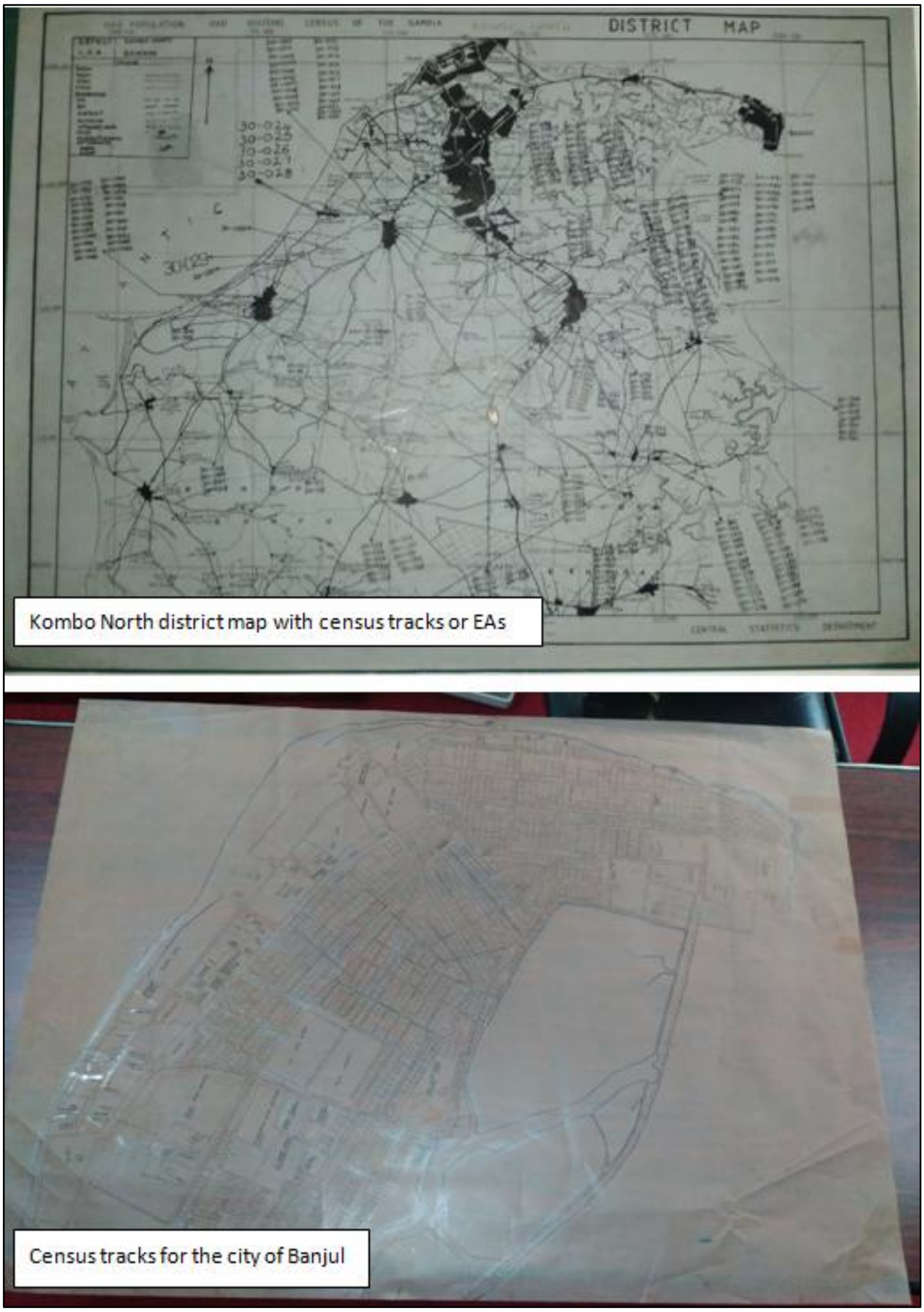

Figure 13: Shows district and city maps with census tracks or Enumeration areas (EAs)

(Pictures taken by author during field data collection)

Budget constraint

Budget or financial constraint is another limitation mentioned by all the groups during the discussions. The experts in one of the groups stated that the cost of the materials is too expensive to afford from their allocated institutional budget despite the need to have such materials. One if the participants stated this: *"The tools are very expensive....we don't even use land-use maps for analysis"*. Despite already having equipments or materials for processing and visualizing GIS based data, the experts in this group indicate that the cost of cartridge and maintenance or repair of the materials has limitation on their production capacity. The experts in two of the groups with some GIS equipments revealed that the materials at their disposal were acquired through international organizations namely UNFPA and UNDP respectively.

All the five groups of experts generate information for use by both local and international policy makers, and the general public. Only the experts in one of the groups stated that they produced information mainly for their own administrative use.

The experts from all the five groups mentioned that the consumers of their information or output of their work demand a more enhance way of visualization than they currently apply. The groups also generally believed that they need more enhanced methods to generate and visualize information related to their work. In light of this the experts from three of the groups considered 2D and 3D methods in hardcopy and digital forms for enhancing the visualization of their work for the users. On the other hand, the experts in the other two groups considered 3D methods in digital form as more enhancing for visualization for the users of their information.

4.4. Efficiency, Effectiveness and Appropriateness Analysis

One of the specific objectives for this study was to comparatively assess the perceive level of appreciation and usefulness of the 2D and 3D geovisualization methods of the accessibility analysis among the experts in terms of their efficiency, effectiveness and appropriateness. To achieve the specific objective two questions were asked:

1. What is the perceived level appreciation for the 3D geovisualization method of the output of the accessibility analysis to the health facilities compared to the 2D among the experts?
2. What is the usefulness in terms of efficiency, effectiveness and appropriateness of the 2D and 3D visualization models as identified with the experts?

In order to answer these questions two activities were designed involving interviews and task performance. The later was a method to comparatively assess the efficiency, effectiveness and appropriateness of the 2D and 3D geovisualization methods. In addition, the interviews seek to provide in-depth information about the perception of the experts on the two methods of visualizations.

4.4.1. Efficiency analysis

Efficiency in this study is considered in relation to time. It refers to how much time was taken to complete the task with a particular visualization method. This means the longer or shorter the time taken to complete the task questions determines how efficient is the method of the visualization. This also implies the lower the average time taken by all the participants to complete the tasks with the 2D or 3D maps the more efficient it is.

Time is considered with respect to completion of the task. Therefore, if a participant could not complete the task with a particular visualization within the 35 minutes allocated it can in turn be interpreted as inefficiency in this study. As stated earlier in 3.6.4 of chapter three this timing was adopted considering the average time recorded for two participants during a pre-test.

The result of the task performance activity shows that on average participants took 28 and 26 minutes to complete for the 2D and 3D visualizations respectively. A maximum time of 35 minutes was allocated to complete the task. The result shows that the quickest time (15 minutes) taken to complete a task was registered by a participant with the 3D map. The quickest time by a participant with the 2D map was 2 minutes more than the quickest time for the 3D. On the other hand the longest time recorded for a participant for the 2D task was 40 minutes compared 36 minutes for the 3D. The results for the time taken by each of the seven participants to complete the task activity with the 2D or 3D maps are compared in table 6 and table 7 respectively. The tables also show the time taken by individual participants to complete the task.

Table 6: Time taken by participants to complete the task with 2D maps

Participant Number	Time Completed (minutes)
2D-1	17.00
2D-2	27.00
2D-3	35.00
2D-4	32.00
2D-5	27.00
2D-6	24.00
2D-7	40.00
Average time	28 minutes

Table 7: Time taken by participants to complete the task with 3D maps

Participant Number.	Time Completed (minutes)
3D-1	15.00
3D-2	20.00
3D-3	28.00
3D-4	36.00
3D-5	33.00
3D-6	35.00
3D-7	21.00
Average time	26 minutes

4.4.2. Effectiveness analysis

In this study effectiveness is determined with regard to the level correct interpretation score obtained by the participants with the 2D or 3D visualizations during the task performance exercise. Therefore, it should be understood from the point of view of this study that effectiveness is defined as the average correct interpretation score obtained by the participants with the 2D or 3D maps. Since the number of participants for the task performance for each type of visualization method is many (seven for each), therefore it is considered sufficient to compare the average scores of the two groups of participants. This takes into account the number of correct scores for each possible answer. This also means questions requiring more than one answer a point is allocated for each correct interpretation.

Table 8 and table 9 respectively show the total points scored by each participant with the 2D and 3D visualization types during the task performance. The average correct points scored out of maximum possible score of 23 points by the seven participants for each visualization map (seven each for 2D and 3D) are 15.7 (for the 2D) and 17.4 (for the 3D). The table also compares the individual performance for each type of visualization. The result shows that there is little difference between individual participants for the 2D and 3D maps in the scores achieved.

Table 8: correct interpretation scores obtained by participants with 2D maps

Participants No.	Total Points Scored
2D-1	19
2D-2	16
2D-3	16
2D-4	17
2D-5	17
2D-6	15
2D-7	10
Average	15.7

Table 9: correct interpretation scores obtained by participants with 3D maps

Participants Number	Total Points Scored
3D-1	19
3D-2	17
3D-3	20
3D-4	15
3D-5	15
3D-6	16
3D-7	20
Average	17.4

The performance by the participants for each section is also compared. This analysis seeks to assess the effectiveness of the visualization of the different types of accessibility analysis graphically displayed in the two different methods (2D and 3D). In figure 14 the average correct points obtained by the participants in each of the three sections for the 2D and 3D visualization are compared in percentage. This is because each section was dedicated to a particular visualization model or map based on the type of analysis displayed.

In section one of the task performance activities; participants used the maps in appendix D (those with 2D) and appendix E (those with 3D), showing the location and distribution of the types of health facilities in 2D and 3D models. In this section participants were tasked to identify the district with more or less health facilities. They were also tasked to identify the most common type of facility within the Municipality. On average participants performed better with 3D visualization in this section with 63% correct score compared to 54% with the 2D.

Section two tasked the participants to interpret the maps visualizing the population and household analysis (see figures in appendices F, G, H and I respectively) in 2D and 3D. In section two participants perform slightly better with the 2D maps with average score of 74% compared to the 3D maps (70%).

In section three the task questions relate to the distance analyzed between residential locations to the health facilities and visualized in 2D and 3D methods (see appendices J and K respectively). As shown in figure 14 the average correct point score by the participants in section three is 91% for the 3D visualization map of the distance analysis while for that of the 2D it is 64%.

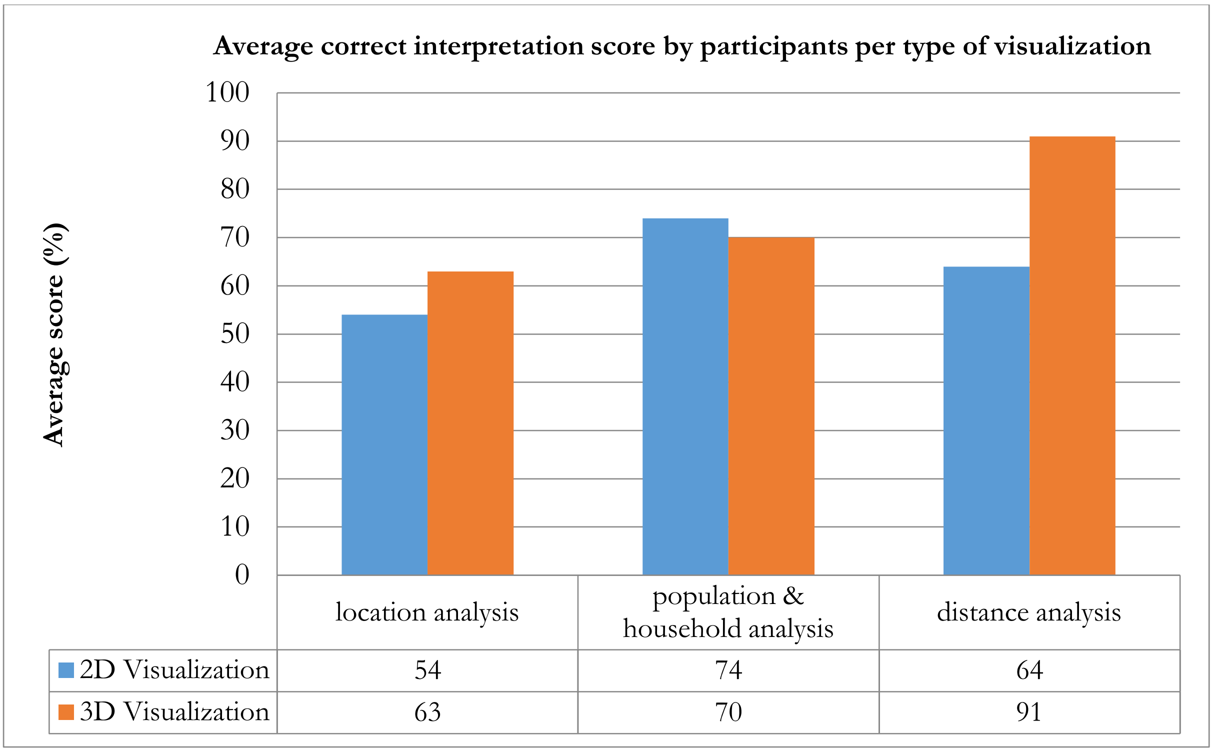

Figure 14: Average score obtained by participants for each section based on the type of analysis visualized in 2D and 3D

4.4.3. Appropriateness Analysis

This section aims to analyze the appropriateness of the graphic display of the analysis visualized in the 2D and 3D methods. Appropriateness is considered here with regard to the suitability of the presentation of the graphic elements in the maps. It is defined as the ease or difficulty to identify or interpret the features represented in the maps. The features refers to the information about the analysis visualized graphically such as population by district, household number by ward, travel distance from residential areas and the location of the health facilities within the Municipality. To assess how appropriate the graphic elements are displayed the participants were asked to list two features each that they found difficult or easy to identify in the 2D or 3D maps they are using to perform the task.

Figure 15 shows the number of participants who stated the difficulty in identifying certain features or information represented in the 2D and 3D models or maps. 3 out of 7 participants for 2D and 4 out of 7 for 3D tasks had stated the display of the distance analysis was difficult to interpret during the task exercise. Likewise 3 out of 7 participants found the household information difficult to interpret in 3D map compared to just 1 out of 7 for the 2D display. On the other hand none of the participants for the 2D maps found the display of the health facilities by type (displayed using cartographic symbology with label) and district boundary to be difficult to interpret.

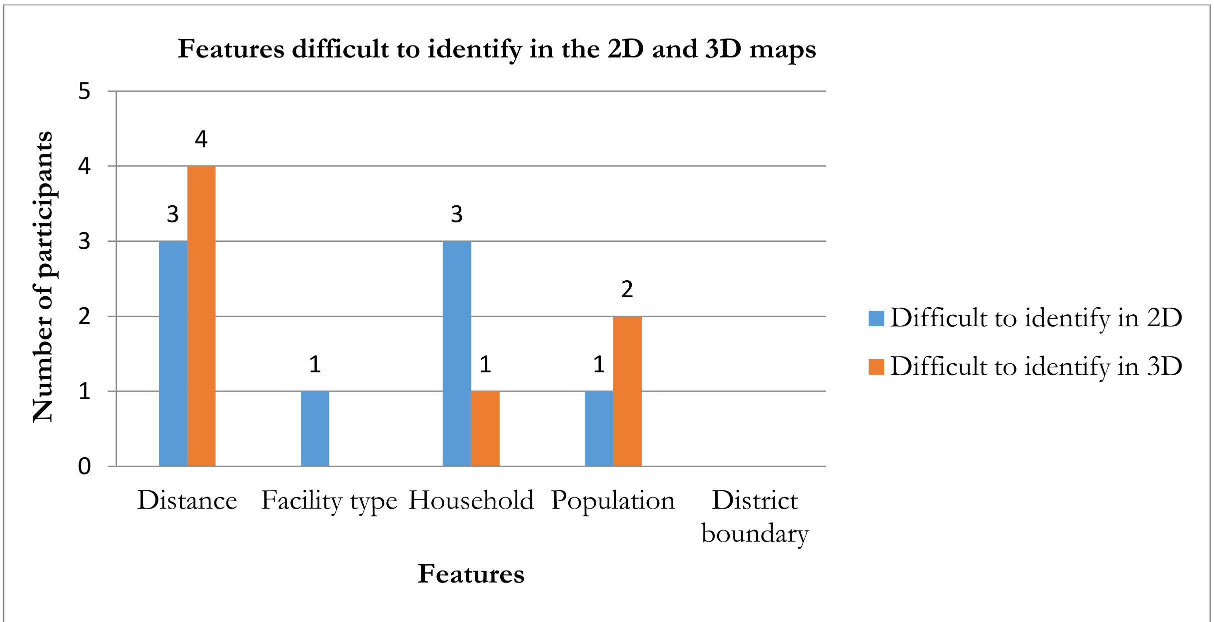

Figure 15: Showing number of participants indicating difficulty in interpreting certain features in the 2D and 3D maps

In figure 16 the reaction of the participants about how easy they found it to identify the features is analyzed and presented. 3 out of the 7 participants found it easy to identify the representation of the health facilities by type in both 2D and 3D visualization methods. The representation of the population information is found to be appropriate with the 2D maps compared to that for the 3D. However, as shown in figure 16 the representation of the distance from the residential areas in 3D was slightly more appropriate than in 2D.

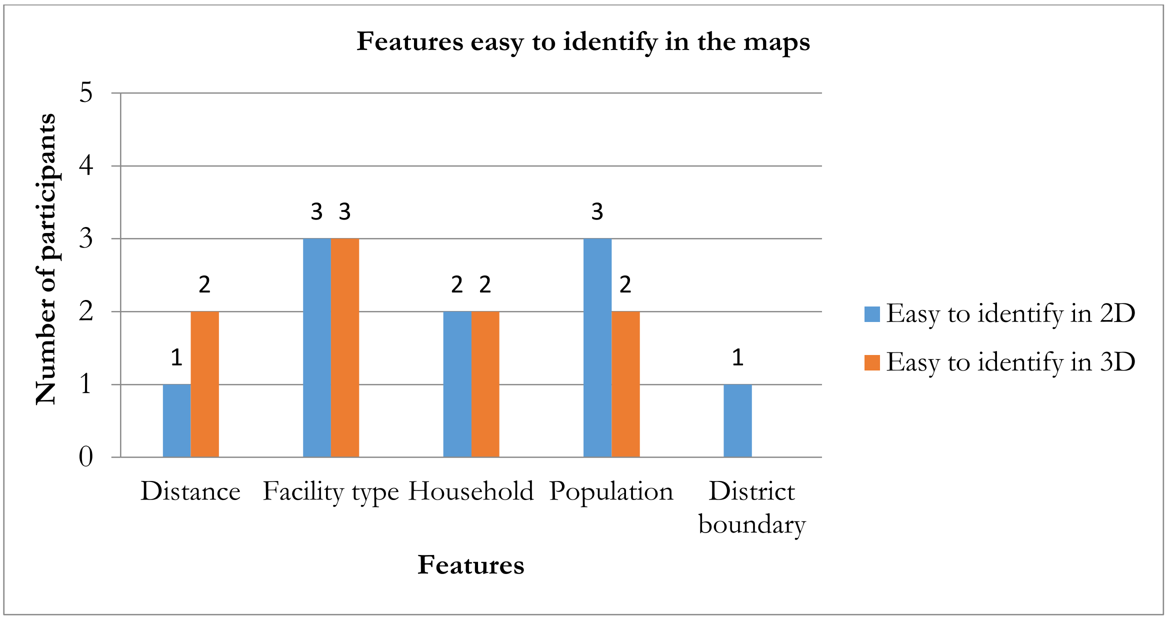

Figure 16: Showing number of participants indicating which features they found easy to identify in the 2D and 3D maps

4.5. Level of Perceived Usefulness Analysis

During the interviews the respondents were asked which of the two visualization methods (2D or 3D) has, generally, better described the accessibility analysis graphically. The respondents have overwhelmingly (85% of them) showed appreciation for the 3D visualization models which they considered to have generally better displayed the accessibility analysis compared to the 2D.

To understand how the respondents also appreciate the GIS methods of analysis and visualization they were asked to rate how good they perceived the 2D and 3D visualizations are for displaying the analysis. Figure 17 shows how the respondents rate the two methods. The figure shows that many respondents rated the two methods as very good (11 for the 2D and 13 for 3D). However, many (10 respondents) considered the 3D method to be excellent compared to that of the 2D (3 respondents). The respondents were also asked whether they think, in general, GIS based models or maps are more enhancing for communicating the type of information they disseminate, in addition to text, tables and graphs. The respondents have the option of indicating 'Yes', 'No' or 'Not sure' (see appendix C). 25 out of 27 respondents stated 'Yes' while one of them stated 'No'.

Seven (7) of the respondents also stated that the 2D and 3D GIS visualizations of the accessibility analysis were very easy to understand while twelve (12) considered the methods to be easy. Five (5) of the respondents stated they are about right while three (3) others indicated they are difficult to understand.

Concerning the cartographic elements that were helpful to the respondents in interpreting the maps, the respondents were asked to select one of the following; legend, title, color scheme and the 3D blocks (height of bars). Most of the respondent (10 in total) mentioned that the legend was more useful compared to title of the maps (only 1), color scheme (5), or bar heights (blocks)

(4) in interpreting the maps. However, as for which of the two methods (2D or 3D) gives more detail for understanding the visualization of the outputs of the accessibility analysis, the majority of respondents (24 out of 27) stated that it is the 3D method.

As to which specific method of visualization is more applicable in their day to day work, the respondents had the option to choose either 2D, 3D, both or none (see appendix C). All the respondents considered one or both methods of visualizations to be applicable in their everyday work. About 30% stated that the 3D is more useful while 11% of them prefer the 2D visualization and 59% stated both methods to be applicable in their day to day work. Figure 18 shows the number and percentage of respondents who stated which type or method of visualization to be more applicable in their everyday work.

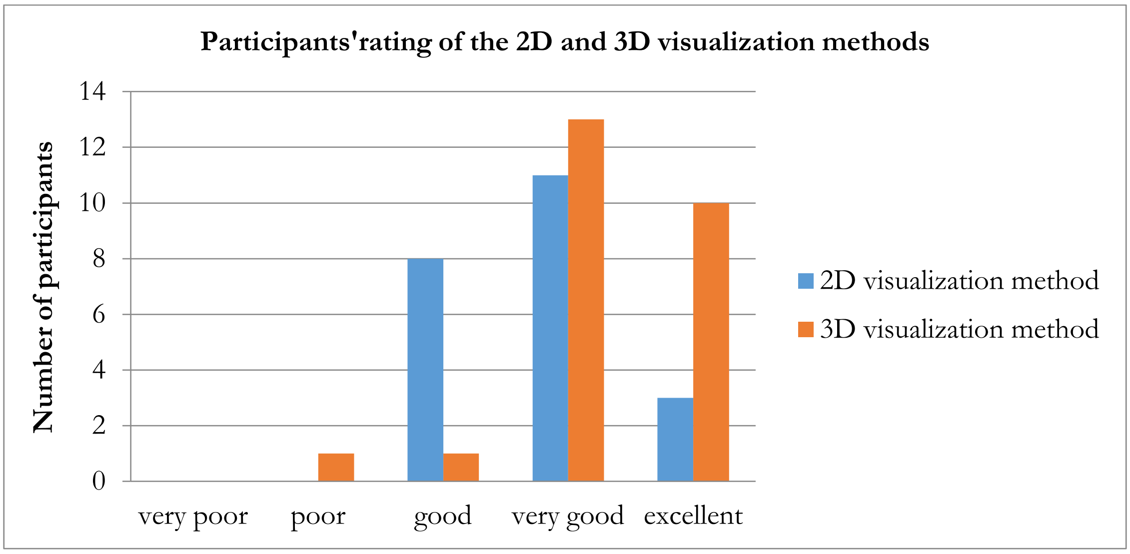

Figure 17: Showing the rating by the respondents for the 2D and 3D methods of visualizing the accessibility analysis

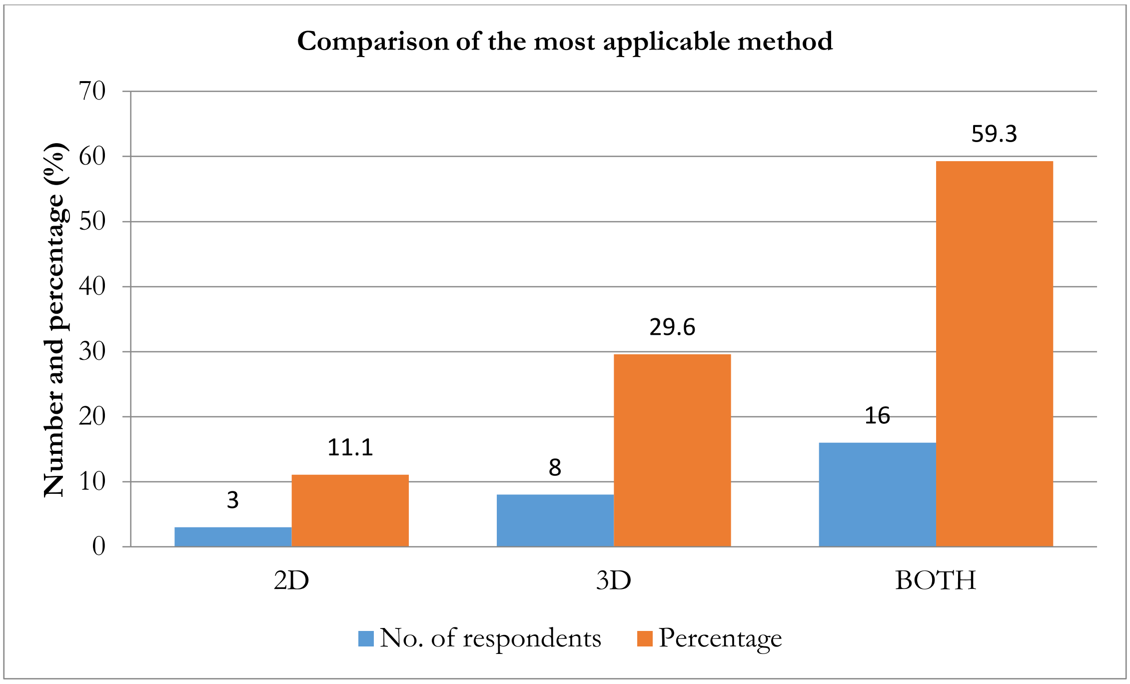

Figure 18: Shows the comparison in terms of the most applicable method of visualization in the day to day work of the experts

Table 10 shows number and percentage of respondents who stated which type or method of visualization can be more applicable in their daily work and how useful they perceived it to be. The level of appreciation or perceived usefulness expressed by the respondents about the method they have stated to be more useful in their day to day work is measured using four point Likert scale ranging from very un-useful to very useful. 14 (about 52%) out of 27 respondents interviewed have perceived both the 2D and 3D methods to be very useful. However, 6 of the respondents (22%) perceived the 3D method to be very useful compared to just 1 (about 4%) for the 2D method. On the other hand, none of the respondent perceived any of the two methods to be very un-useful.

Table 10: Perceived level of usefulness of the methods of the visualizations as stated by respondents in number and percentage (%)

Method of visualization	Very un-useful		Un-useful		Useful		Very useful	
	No.	(%)	No.	(%)	No.	(%)	No.	(%)
2D	0	0	1	3.7	1	3.7	1	3.7
3D	0	0	0	0	2	7.4	6	22.2
Both	0	0	0	0	2	7.4	14	51.9

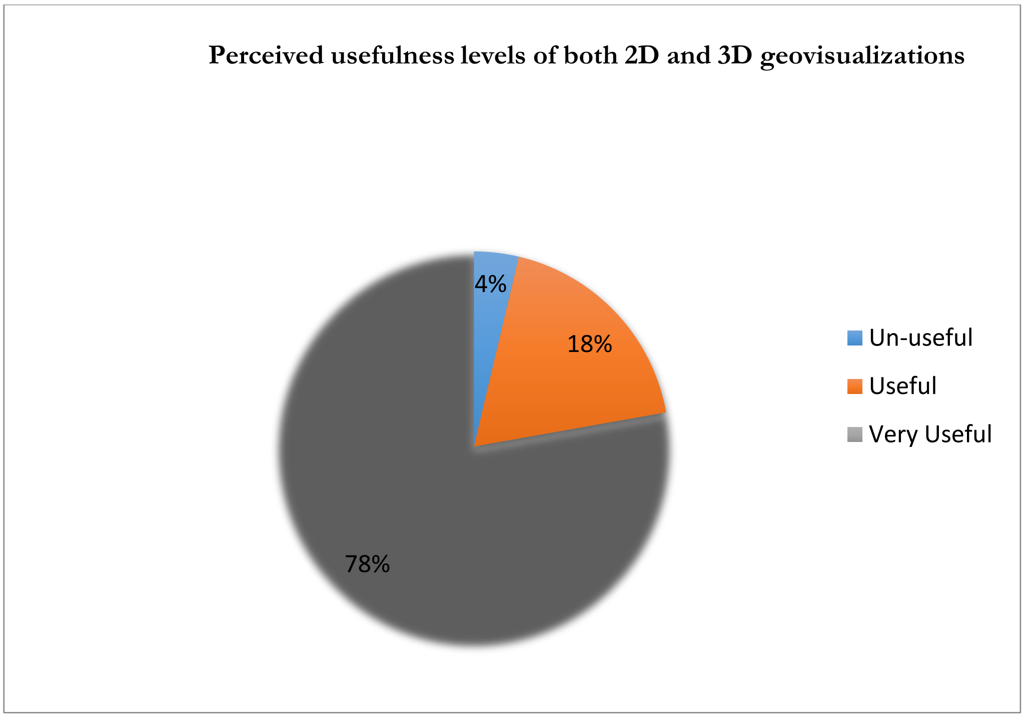

Figure 19: Shows the perceived level of usefulness of both the 2D and 3D visualizations by the respondents in percentage

Figure 19 shows the percentage of respondents which stated the usefulness for one form of the visualizations or both. About 78% of the respondents considered either the 2D or 3D and both methods of the GIS visualization to be very useful for their every day work while 18% of them considered the methods are useful.

4.6. Conclusion

The results and analysis were presented in this chapter. The presentation of the results was based on the specific objectives and the methods of data collection adopted for this study. The types of 2D and 3D visualization models or maps that were developed based on the outputs of the accessibility analysis to achieve the first sub-objective have been presented. The challenges limiting the experts from applying GIS based 2D and 3D visualization methods were also identified as stated in sub-objective 2 of this study. The chapter also presents the results on the level of appreciation of the two visualization methods as perceived the experts and usefulness in terms of their efficiency, effectiveness and appropriateness.

5. DISCUSSION

5.1. Introduction

In the previous chapter the results and analysis of the data obtained from the data collection methods were presented. The analysis follows a sequence with the objectives of this study. In this chapter a discussion is presented on the results obtained and analyzed in chapter 4 in reflection to the methods applied to achieve the study objectives and in reference to the literature reviewed in chapter two. The discussion is organized in three main parts. First the visualization models developed from the analysis of the accessibility to the health facilities in Kanifing Municipality, which is the first sub objective of this study, are discussed in section 5.1. The findings on the challenges limiting the use of GIS based methods by the experts are discussed in section 5.2. In section 5.3 the perceptions on the usefulness of the 2D and 3D geovisualizations in terms of their efficiency, usefulness and appropriateness of the methods are discussed.

5.1. Developing of 2D and 3D Geovisualization Models of the Accessibility Analysis

To assess 3D visualization, the first objective of this study required developing 2D and 3D geovisualization models using accessibility analysis to health facilities on large geographic scale (Municipality). GIS based location and distance analyses were performed using ESRI ArcMap 10.3.1 software. The outputs of the analysis were visualized in 2D and 3D digital (soft copy) and paper based printed (hardcopy) as posters. As explored in literature on assessing 2D and 3D visualizations, various approaches have been to first develop a model on a particular topic or phenomena to evaluate the methods. A similar approach by Kourouni, (2014) was adopted to developed a workflow for comparing different 2D and 3D visualizations of an alpine region to evaluate both methods. Seipel, (2013) has also developed different 2D and 3D visualization maps presentation to assess both methods through basic geospatial task involving distance measurements.

However, scale of the phenomena or objects on which the visualization models are based is rather small. For example, Herbert and Chen (2015b) have selected a study site of about 1 acre (see red square in figure 20) to develop 2D and 3D visualization models of a proposed building and surrounding environ to assess the perceived usefulness of both methods among planning professionals in Queensland, New Zealand. Similarly, Rautenbach et al. (2016); Dubel et al. (2015); Wang (2015); Thill et al. (2011), have developed small scale 3D model representation for their studies.

With background knowledge of the study area and the targeted participants this study has considered producing simple visualization models to ensure effective data collection. This is because the GIS based methods of analysis and visualization have not been anticipated to be an old practice among the experts in the Gambia who are the targeted participants for this investigation. One of the critiques on methods of assessing or evaluation 3D visualization is that it involves complex procedure and required expert skills for both researchers and participants or respondent to develop models and conduct experimental task. Bleisch (2012) asserts that research efforts hardly look into usefulness evaluation of 3D visualization but focused on technology. Therefore it became pertinent to develop simple visualization model based on an analysis of the environment the respondents are familiar with. This is expected to enhance the understanding of the map elements by the participants.

Figure 20: Scale of the study site (in red) use to develop 2D and 3D models by Herbert and Chen

Source (Herbert & Chen, 2015a, p.24)

5.2. Challenges and Limitations

The main challenges limiting the experts in applying GIS based methods in their everyday practice have been identified during group discussions with the different institutions or organizations. The challenges were analyzed and thematically listed as follows: (1) inadequate skills; (2) lack of softwares; (3) inadequate equipments; and (4) budget constraints.

This finding is in consonance with Ahmed and Sekar (2015), who assert that the reason urban planners are not applying 3D visualization methods in every day practice is related to the complexity of the techniques, cost and lack of skills. In this study the focus was not on investigating the ease of applying 2D and 3D GIS based methods. And therefore, the level of complexity of the techniques involved in such methods is not measured among the experts. However, the lack of training or limited skills in applying GIS based methods of 2D and 3D visualizations was commonly stated by all groups during the discussions.

Two of the groups have members with some basic skills in using GIS applications namely QGIS and ArcGIS. These two groups have recently (3-4years ago) received training mainly through short term consultancy projects. One of the participants has undertaken a three months short course at the Faculty of Geoinformation Science & Earth Observation of the University of Twente - ITC. Before this period these two groups (with skills in GIS), like the other three Groups (without skills) also lack basic GIS based skills to apply. In one of the groups, two of the participants were international consultants with a Masters degree in Geodetic survey and Geoinformation Science and Earth Observation. These participants have both volunteered in doing the task performance. Their missions include providing technical assistant for the institutions. Their presence is sign for the need to improve the skills of the local experts.

The study has found out that lack of software for GIS analysis and presentation of data is another challenge faced by the experts. Although two of the participating institutions are equipped with license ArcGIS software package yet it still lacks some useful extensions such as Network analyst, ArcScene and ArcGlobe, as one of the participants has stated. This implies that even the institutions that have acquired some professional GIS software but does not include other relevant applications or extensions might limit the experts in applying GIS methods. The other institutions do not have even free GIS software package like QGIS. Perhaps they could not access to such freely available software because they are not even aware of it or because they do not have skills in GIS to have interest in it.

It has been also established in this study that experts in three out of the five groups representing the institutions in the discussions lack adequate equipments needed to apply GIS methods in their daily work. Equipments such as computers, printers and scanners are essential for the production of GIS based analysis and visualization of information in both 2D and 3D displays. However, at least all the groups use equipments such as laptop, desktop, small printers and scanners for basic information processing and production in Microsoft word or Excel. These equipments are not up to standard for the purpose of 2D and 3D methods of geovisualization since they are not equipped with the necessary software or application. Two among the five groups of experts have at their disposal GIS equipments to capture, store, process, and retrieve geographic information. Such equipments include hand-held GPS receivers, licensed GIS software and server, LaserJet printers, flatbed scanners and plotters.

Insufficient budget is another major limitation stated by all the expert groups. Finance is needed to acquire the necessary software and equipments required to operate and perform the daily activities of the experts. It is also needed to secure the service of consultants or pay for training and capacity building of the staff of the institutions in order to improve their skills. It was confirmed by the participants that institutional budget is not sufficient to achieve this. This can have limitations on the performance of the experts in their daily work. Although as to how much negative impact the lack of sufficient budget will have on the performance of the experts cannot be established by this study. For example they may not be able to acquire professional softwares, equipments and their maintenance.

5.3. The Perceived level of appreciation and Usefulness of the 2D and 3D Geovisualization Methods

Task performance is one of the primary data collection methods design to achieve the objectives of this study. This activity is designed to comparatively assess the usefulness of the 2D and 3D visualization models or maps produced from the accessibility analysis in terms of their efficiency, effectiveness and appropriateness. In addition, structured and open-ended questions were included in the interviews and task questions to gauge the perception level of the respondents.

Efficiency measure as mentioned earlier in section 2.7 of chapter two has been determined by the time of completion for the task performance for both methods. Average time of completion of a number of trials was used as measure for efficiency of 2D and 3D geovisualizations through task performance, see (Seipel, (2013). In total fourteen participants carry out the task performance, with seven participants each for the 2D and 3D visualization maps. The results shows that the average time of completion of the task by participants with the 2D visualization of the accessibility output was 2 minutes more than those with the 3D. This did not show a very significant difference between the two types of visualizations. A similar finding by Seipel (2013) who investigated efficiency of 2D and 3D geovisualizations through task performance, did not show a statistically significant difference.

The number of correct interpretations by participants with a 2D or 3D visualization of the output of the accessibility analysis was considered in this study as a measure for effectiveness of the two methods. The overall effectiveness of the two methods for displaying the accessibility analysis as analyzed in section 4.4.2 by comparing the average score of the seven participants for each method did not also indicate a big difference. There was a margin of only 1.7 points difference between the participants for the two methods. However, when analyzed by section (based on the type of analysis visualized) there has been significant difference in terms of level of average correct score obtained by the two groups. In section three of the task activity participants with the 2D visualization, which showcased the travel distance from the residential areas to the health facilities, scored an average point of 64% compared 91% for those with the 3D. This result suggested otherwise to previous findings by Baier and Zimmer (2014) who stated that 2D visualizations are more advantageous for identifying horizontal distances. Although the task for the participants in section three did not require for direct or accurate measurement of distance between the residential areas and the health facilities, however, they were tasked to use the distance thresholds to identify the furthest areas from the health facilities. But as the results indicate the 3D visualization method was more effective than the 2D and this fail to confirm the finding of Melanie Tory et al. (2006) who reported that 2D visualization is more advantageous than 3D for accuracy in precise measurement of distances.

The 2D visualization of the output represented in figure10 and figure 11 was a little more effective than that of the 3D for section two. In this section the maps showcased the population and household analysis for each district and ward respectively. This finding suggests that abstract or statistical data, in this case population and household information, is effectively displayed in 2D than 3D. There is little difference in the effectiveness of the 2D and 3D methods for representation of the spatial distribution and location of the health facilities with which participants were tasked in section one. The average score by participants in section one for the 2D map is 4 points lower than those with the 3D maps showing the location and distribution of the health facilities by type within the five districts (see figure 9).

The appropriateness measure has been determined based on qualitative responses from the participants during the task performance. This was designed to compare the advantages and disadvantages of the two methods of visualization in representing or displaying the accessibility analysis information. It has been determined by how difficult or easy (complexity) the participants have found in interpreting or understanding the display of the information represented in the maps. The responses from the participants revealed how difficult or easy to identify or understand five features represented in the maps; district boundary, household, population, facility type and distance.

The results for these five features which were compared for both the 2D and 3D maps shows that more than half of the participants (4 out of 7) found it difficult to identify or interpret travel distance information displayed in 3D than in 2D (3 out of 7). This suggests that the travel distance information is less appropriately displayed in 3D than in 2D. However, the display of the household information was found to be more difficult to identify in 2D than in 3D. Three out of the seven participants for the 2D task stated the household feature or information was difficult to identify compared just one out of seven participants for the 3D maps. Few participants (less than 3) regarded or stated the representation of district boundary, population and health facility by type as difficult.

On the other hand, the finding shows that less than half of the respondents, three out of the seven participants found it easy to identify the health facilities by type and population features in 2D representation. Compared with the 3D, the representation of the health facilities by type and population information were found to be easily identified by three out of seven participants and two out of seven respectively. Moreover, even fever participants (less than 3) stated it was easy to identify that of the district boundaries, household and distance.

The findings did not provide a clear-cut conclusion as to whether the 2D or 3D displays of the features (administrative boundary, population, household or distance) represented in the maps were more or less appropriate. This is because for each of the features (except for the distance in 3D display) less than half of the respondents for each type have stated it to be either difficult or easy to identify in both the 2D and 3D visualizations. However, the finding might suggest some advantages and disadvantages for the 2D and 3D visualization methods. For example, the result indicating more participants stating it is difficult to identify the distance feature in 3D maps than those with the 2D suggests that the 2D visualization is more advantageous for representing distance. For this reason it can be asserted that this support the finding by Melanie Tory et al., (2006) who found out that 2D visualization is has more advantage over 3D for accurate measurement of distance.

The perceived level of appreciation of the 2D and 3D visualizations among the experts has been assessed using interview methods. The majority of the respondents (85% out of an interview population of 27) perceived the 3D display of the accessibility analysis to be generally more appreciative than the 2D method. This finding has affirmed previous argument by Maktav et al. (2005) that viewer appreciation is higher for 3D display of urban scenario compared to that of 2D. This can be even noticed during the group discussions prior to the interviews when the participants were introduced to various methods of applying 2D and 3D geovisualizations.

However, when asked to rate the GIS method of displaying the analysis in 2D and 3D on a five point Likert's scale from very poor to excellent, the response was not the same. A good number of the respondents (11 out 27) rated the 2D geovisualization as very good even though this was slightly less than those who (13 out of 27) rated 3D method as the same (very good). This shows that both methods were highly rated by the respondents as very good. On the other hand many respondents (10 out of 27) even rated the 3D method as excellent compared to just few (3 out 27) for the 2D method.

As for which of the two visualizations is more preferable or applicable in everyday work of the experts, it is shown that over 59% of the respondents considered both 2D and 3D GIS methods to be useful. The greater percentage of the respondents considering both methods to be more applicable could be attributed to the fact that it can enhance the communication of the type of information they produce and disseminate. Since overwhelming majority (25 out of 27) of the respondents considered GIS based methods of visualization to be more enhancing in communicating the type of the information they produce. But comparing the two methods, over 29% of the respondents thought the 3D method is more applicable compared 11% who stated that the 2D method is more applicable for their daily work.

5.4. Conclusion

In this chapter the analysis of the results presented in chapter 4 have been discussed. The challenges limiting the experts in applying GIS methods of 2D and 3D visualizations in their practice includes inadequate skills, lack of softwares, inadequate materials (computers, printers and scanners) and budget constraints.

Also discussed based on the results presented in chapter 4 above, as the main objective of this study, was the level of perceived appreciation of the 3D visualization compared to that of the 2D display of the accessibility analysis presented in the result section. The experts have shown more preference for the 3D visualization compared to that of 2D. However, majority of the experts believed both 2D and 3D GIS methods are applicable to their everyday practice and useful for enhancing the visualization of the type of information they produce.

6. CONCLUSION AND RECOMMENDATION

The main objective of this study is to assess the usefulness of 3D geovisualization compared to 2D as perceived by experts using models based on accessibility analysis of health facilities within Kanifing Municipality in The Gambia. In this chapter conclusions are drawn based on the specific objectives set to achieve the main objective of this study.

Objective 1: To develop geovisualization models in 2D and 3D form that show accessibility to health facilities at Municipality level for assessing the two methods.

It has been gathered from literature review that to comparatively assess the perceived usefulness of 2D and 3D geovisualizations the initial step require developing models based on a specific topic or phenomenon. Most studies have developed models based on small areas or even objects such as buildings to assess the usefulness of 3D visualization. In this study 2D and 3D geovisualization models or maps have been developed from analysis of accessibility to health facilities within the Municipality of Kanifing covering a land area of 75.55km^2. Four different outputs of the analysis were visualized in 2D and 3D graphic displays and printed as posters on A1 paper size. The outputs of the accessibility analysis showcased the location and distribution of the health facilities within the five districts of the Municipality. The number of population and households within the five districts and seventeen wards respectively was also visualized. The distance from the residential parcels to the health facilities is also displayed.

Objective 2: To investigate the challenges limiting the experts in applying GIS based 2D and 3D geovisualization methods in their everyday practice.

The challenges limiting the use of GIS based methods of geovisualization by the experts include; inadequate skills, lack of GIS softwares, inadequate materials (in the form of computers, printers and scanners) and budget constraints. The experts in all the institutions indicated having limited skills to perform GIS based analysis in relation to their everyday practice. The experts in three out of the five institutions do not have training in GIS applications and therefore do not even use such methods in their expertise.

Only two out of the five organizations or institutions engaged in this study have professional licensed GIS software (ESRI ArcGIS). However, the license package did not include some essential features or extensions such Network Analyst tool, Spatial Analyst, 3D Analyst, CityEngine and ArcScene which are all useful in their work.

None of the five organizations or institutions has adequate equipments in the form of computers, printers and scanners, required to carry out GIS based analysis and visualization in 2D and 3D methods. Although two among the institutions have computers equipped with GIS software, printers and scanners for paper sizes from A4 up to A0 or custom size paper, yet they lack production materials like large size papers

Institutional budget constraints is another limitation faced by the experts in applying GIS based methods of analysis in 2D and 3D visualizations. The experts stated that the limited budget for their organizations or institutions cannot afford the softwares, computers, printers, scanners and their maintenance. The only two institutions with a professional licensed GIS and large scale printers and scanners such as plotter and flatbed scanners have acquired these through funding from international organizations in particular UNDP and UNFPA.

Objective 3: To comparatively assess the perceived level of appreciation and usefulness of the 2D and 3D geovisualization methods among the experts in relation to their efficiency, effectiveness and appropriateness.

This study attempts to assess the perceived level of appreciation and usefulness of 3D visualization over 2D among the experts through discussions, interviews and task performance, using the outputs of the accessibility analysis.

The experts in two of the five participating groups whose practice is related to public sensitization and city administration, considered 3D visualization to be enhancing for their work. The experts from the other three groups considered both 2D and 3D to be useful in their every day practice. The work background of the experts in the three of the groups include; statistics, physical planning and property management.

The usefulness of the 3D visualization of the accessibility analysis has been compared with that of the 2D, through task performance. The result of the task performance does not show a great difference in terms of their efficiency, effectiveness and appropriateness. The results of the efficiency measure shows that participants with the 3D visualization maps completed their task on average 2 minutes earlier than those with the 2D maps. The effectiveness of the 2D and 3D methods of visualization, which was measured based on the correct interpretation score by the participants for the task performance, was also compared. The result shows that participants with the 3D maps scored an average point of 17.4 while those with the 2D maps scored 15.7 points. The appropriateness measure for the two methods, which considers the ease or difficulty in identifying the information represented in the models such as population, household, administrative boundaries and distance features, did not yield a big difference between them. Overall, less than half of the participants with either the 2D or 3D models indicated the features to be easy to identify. Likewise, less than half of participants thought the features were difficult to interpret, except for the representation of the distance feature in 3D for which four of participants considered it difficult to identify.

General Conclusions

The main objective of this study is to assess the usefulness of 3D geovisualization compared to 2D as perceived by experts using models based on accessibility analysis of health facilities within Kanifing Municipality in The Gambia. The findings revealed that the experts appreciate GIS based methods of the analysis and visualization in both 2D and 3D. 59% of the experts perceived the 2D and 3D visualizations to be useful as both methods are applicable to their everyday practice. However, compared to 2D the experts appreciate the 3D visualization more (11% and 29% respectively). The results of the task performance designed to evaluate the efficiency, effectiveness and appropriateness of the 2D and 3D models or maps did not yield a major difference between the two. It is difficult, therefore, to conclude the efficiency, effectiveness and appropriateness of the 3D method over that of the 2D base on the results.

The study findings suggest that most of the experts are not applying GIS based methods in their everyday practice. The main reason for not applying the GIS based methods of 2D and 3D visualization by the experts in Kanifing can be related similar findings in Ahmed and Sekar (2015). In this case study the challenges or limitations include; inadequate skills, lack of GIS softwares or applications, inadequate materials (such as computers, printers and scanners) and inadequate institutional budget.

Recommendations for Further Research Endeavors

The following recommendations are suggested for future research:

- Since there is little research into the perceived usefulness of 3D visualization study attempts could further investigate the perceived appreciation of experts on the techniques involved in the preparation or production of 3D geovisualizations compared to 2D methods.
- Future research endeavors to compare the perceived usefulness of 2D and 3D geovisualizations may not only be based on the outputs or models on a small scale but also on a large geographic scale with physical and human features represented.
- Future research effort can be directed to measuring the level of appreciation of 2D and 3D methods of visualization from the point of view the public or users of visualization produce by experts from various backgrounds such as urban planners, architects, or statisticians.

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APPENDICES:

Appendix A: Discussion checklist Task

University of Twente Faculty of Geoinformation Science & Earth Observation - ITC
MSc Thesis Research. October, 2016
Topic: Assessing 2D and 3D Geovisualizations Using Accessibility Analysis to Health Facilities. Case Study in The Gambia

Introduction

My name is Ebrima Wally Manneh, a student at the University of Twente Faculty of Geo-Information Science and Earth Observation - ITC, and student number s6025714. In reference to the letter of support attached, I would like to conduct some activities with you as part of fieldwork for my MSc research.

First we will have a discussion, which is one of the three activities I wish to conduct with you. The other activities will include task performance and interviews. The discussions will be centered on the current methods and tools you applied in information or data analysis and visualization in your work. We will also discuss about the various challenges or limitations you may have in applying enhance visualization methods such as skills and software required. If you agree as a group or individually the discussion will be recorded to allow for thorough analysis.

A task will be performed to assess the two visualization methods (2D and 3D) showcasing accessibility analysis of the health facilities in Kanifing Municipality. This will be timed for a maximum of 35 minutes. Interviews with self administered questionnaires will follow the task.

Your contribution is highly solicited as it will be useful in achieving my study objectives. Therefore information you give will be treated confidentially with ethical considerations and will be only used for the purpose of this study.

1. Does your organization perform analysis and visualization of information or data using Geographic Information Systems (GIS) applications, example: QGIS, ArcGIS or others?
   A) Yes [……] B) No […...]
2. Do you have skills in using any GIS software? A) Yes [....] B) No [....] if (No) skip to question → 4
3. If [Yes] list the type of softwares and how many among the group can use it in every day practice.
4. Which of the following tools do you use to visualize data?
   A) Computer [.....] B) Manual [.....] C) Both [.....]
5. Do you visualize your work in any of the following formats of visualization? (you can tick as many as may be applied)
   A) 2D digital GIS (computer-base) [.....] B) 2D static (printed hard copy) [.....]
   C) 3D digital (computer-base) [.....] D) None [.....]
   E) Other [.....] (Please specify)...
6. Which category below are the main users of your data or work output? (tick as many as may apply)
   A) Policy and decision makers (local) [....] B) Policy and decision makers (local) [....]
   C) General public [....] D) other [....] (please specify...
7. Do the users of your data or information demand a more enhance way of visualization than you are currently applying?
   A) Yes [.....] B) No [.....]
8. Do you think you need a more enhance method of visualization to generate and communicate your information than you are currently using?
   A) Yes [....] B) No [.....]
   If (No) s kip directly to question→ 10
9. Which of the following would you consider to enhance the visualization of your information to the users (multiple choice)
   A) 2D Digital (computer-based) [.....] B) 2D static (printed hard copy) [.....]
   C) 3D digital (computer-based) [.....]
   D) Other [.....] (Please specify)...
10. What are challenges and limitations in terms of skills, materials and softwares:

Appendix B: Task Questions

Write the name of your organization, date and code	
Organization/Institution/Department…………………………………………………………………………………………… Date of the task……./………/…………… Participant number or code [.................................]	
For use by the monitor (please skip this part)	
Type of visualization map used	Outcome
2D [.............] 3D [..............]	Section I [...........] Section II [.........] Section III [..........]
Time taken to complete:.........................minutes	

<u>Section I:</u> Visualization of the location and types of health facilities within KMC

Instruction: Use the map with number **(<u>2D-SI-A</u>)** or (**<u>3D-SI-A</u>**) given to you to answer the questions for part one.

1. Write down the name of the district which has the highest number of health facilities
   ....
2. Write down the name of the district with the smallest number of health facilities
   ....
3. Which district has more clinics than other types of health facilities
   ....
4. How many types of health facilities can you identify from the map? ....
5. Which type of health facility is more common? ....

<u>Section II:</u> Visualization of analysis of population and household accessibility to health facilities

Instruction: Use the maps with numbers (**<u>2D-SII-B</u>)** and (**<u>2D-SII-C)</u>** or (**<u>3D-SII-B</u>**) and (**<u>3D-SII-C</u>**) to answer the questions for section two.

6. Which district is more populated? ....
7. Write down the name of the district with the highest number of population served by its health facility (ies)? ....
8. Write down the name of the district that has the lowest number of population
   ....
9. How many people are there in the district with the lowest number of population?
   ....

10. List down the names of the first two wards with the highest number of households compared the rest of the wards.
    (i).. (ii)...
11. List any two wards with a total household of between **2515 and 5933**
    (i)... (ii)..
12. Carefully observe the maps and identify the two wards with the most similar number of households.
    (i).. (ii)..

<u>Section III</u>: Visualization of analysis of accessibility by travel distance to health facilities.

Instruction: Use the map with number (**<u>2D-SIII-D)</u>** or (**<u>3D-SIII-D</u>**) to answer the questions for section three. The letters in the map can be used to answer either questions 13, 14, 15, 16 or 17.

13. Which letter represents the area in the map that has the closest accessibility in terms of distance to hospitals? ....
14. Which letter represents the area in the map that has the closest accessibility by distance to clinics? ....
15. Write down **t**hree letters that represent areas with the highest accessibility to a health facility of any type in the map
    i)....................................... ii).............................. iii).............................
16. Which two letters represent areas in the map that are more than **1100 to over 2600** meters away from any health facility? i)......................... ii)...........................
17. Identify with the letters one area which within **700 to 1000** meters away from a hospital.
    i)......................... ii).......................
18. List any two features (example population, travel distance, household number etc.) represented in the maps that you find it difficult to identify in the maps given to you.
    ....: write the map label.............................
    ....: write the map label..............................
19. List any two features (example population, travel distance, household number etc.) represented in the maps that you find it easy to identify in the maps given to you.
    ....: write the map label...............................
    ....: write the map label...............................
20. Can you comment on the level of ease or difficulty of the task? (Tick in one box)?
    Very difficult: ...☐ Difficult: ...☐ About right: ...☐ Easy: ...☐ Very easy: ...☐

Appendix C: Interview Questionnaire

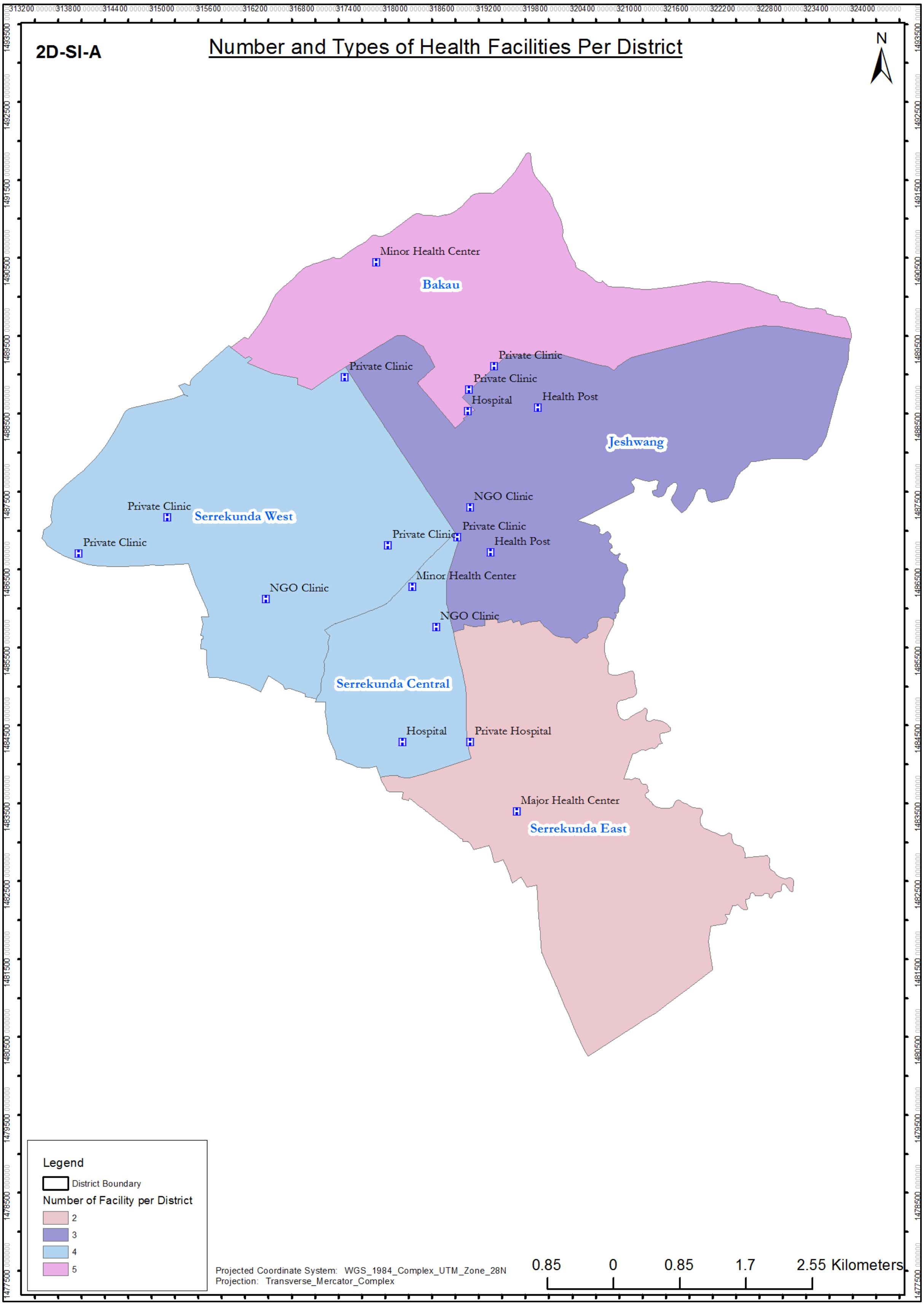
Activity 3: Interview on Perception
Name of the organization/Department: …………………………………………………………...
Age…………………years Place... Date of Interview….…/………/2016

Please fill-in the following questions by writing or making a check mark ☑ in the boxes in front of the options. Where necessary you may tick more than one box for some questions. Please ask question to clarify anything you don't understand.

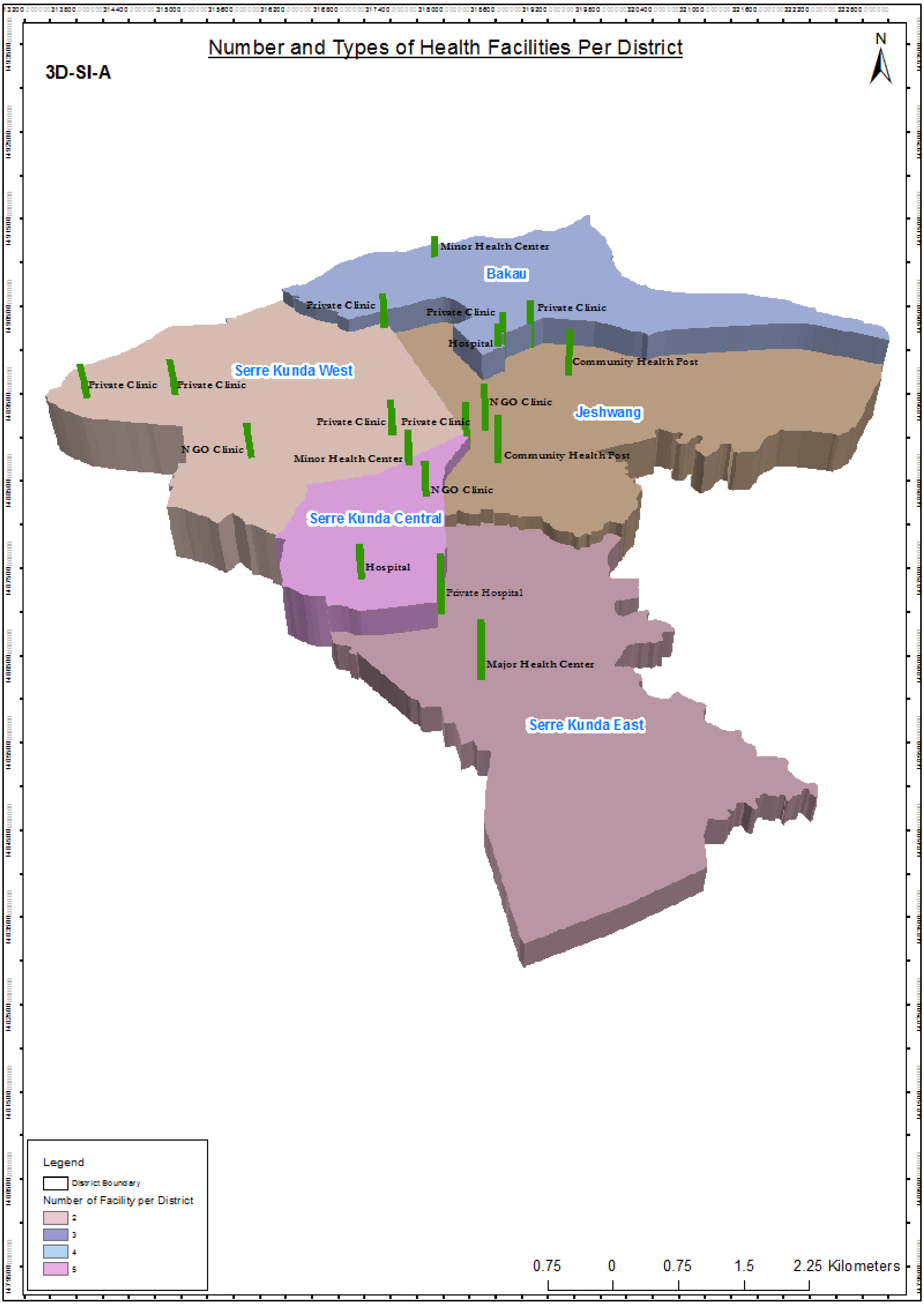
Number	Questions
1	What is the title of your job? ....
2	How long have you been in this job? Less than 5 years...☐ 5 - 10 years... ☐ 11 - 15 years... ☐ More than 15 years... ☐
3	A) In general which of the two visualization models (maps) do you think better explained or described the accessibility analysis to you? 2D...☐ 3D... ☐ B) Any reason why you think this is so? ....
4	A) Which of the visualization methods can be more useful for applying in your everyday work? (tick in one box only) 2D visualization...☐ 3D visualization...☐ Both...☐ None...☐ (if None skip directly to question→ 6) B) Briefly state why: ....
5	How useful can be this method of visualization you chose in question (4A) for data or information visualization to present your everyday work to the users? Very un-useful...☐ Un-useful...☐ Useful...☐ Very useful...☐
6	A) How do you find it easy or difficult to understand the visualization of the analysis of accessibility to health facilities in the maps presented to you? Very difficult...☐ Difficult...☐ About right...☐ Easy...☐ Very easy...☐
7	Which of the following map elements helps you more to answer the questions during the task (Tick one) Legend... Title... Color... Height of the bars...

8	In addition to texts, table and graphs do you think including GIS maps in 2D or 3D is more enhancing for communication and understanding of the type of information generated by your organization? (tick in one box) Yes... ☐ No... ☐ Not sure.. ☐
9	In your view which of the two maps gives you high level of detail for easily understanding the information they represent? 2D... ☐ 3D... ☐ Not sure... ☐
10	How would you rate the two methods (2D and 3D) used for the visualization of the analysis to the health facilities? (please tick one box for each) A) 2D: Very poor... ☐ Poor.. ☐ Good... ☐ Very Good... ☐ Excellent.. ☐ B) 3D: Very poor... ☐ Poor... ☐ Good... ☐ Very Good.... ☐ Excellent.. ☐

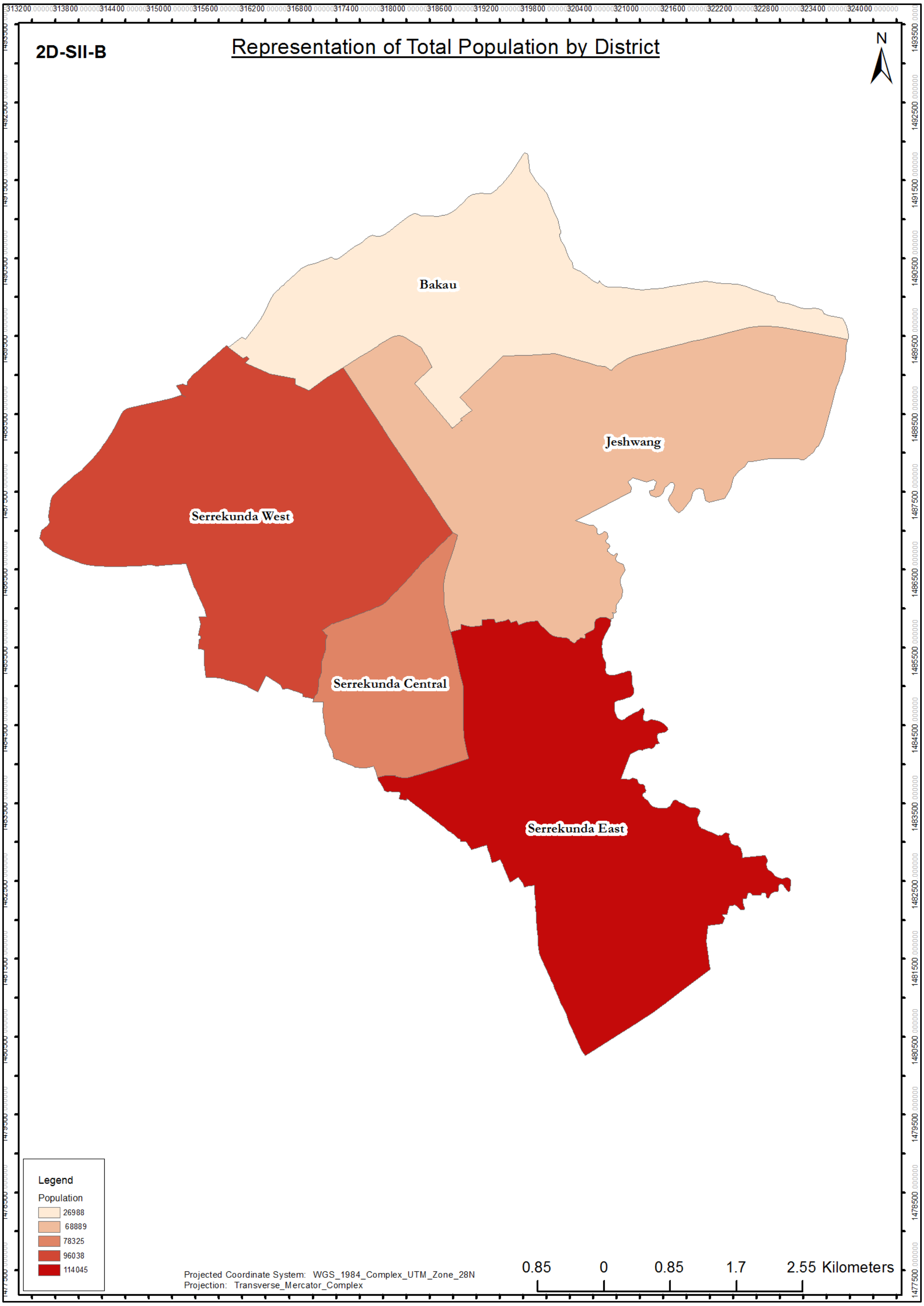
Appendix D: 2D Map of the location and distribution of the health facilities in Kanifing Municipality



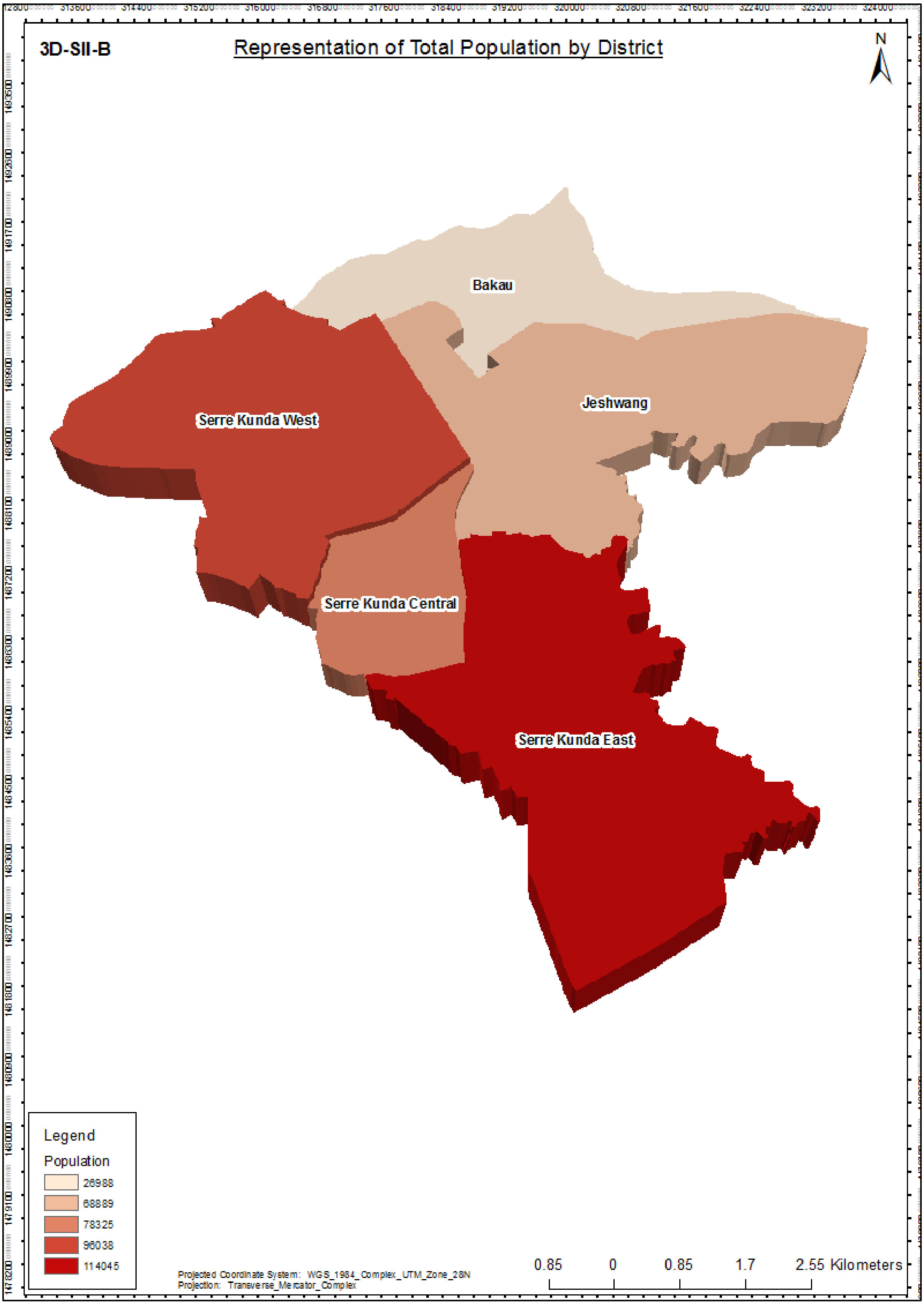
Appendix E: 3D Map of the location and distribution of the health facilities in Kanifing Municipality



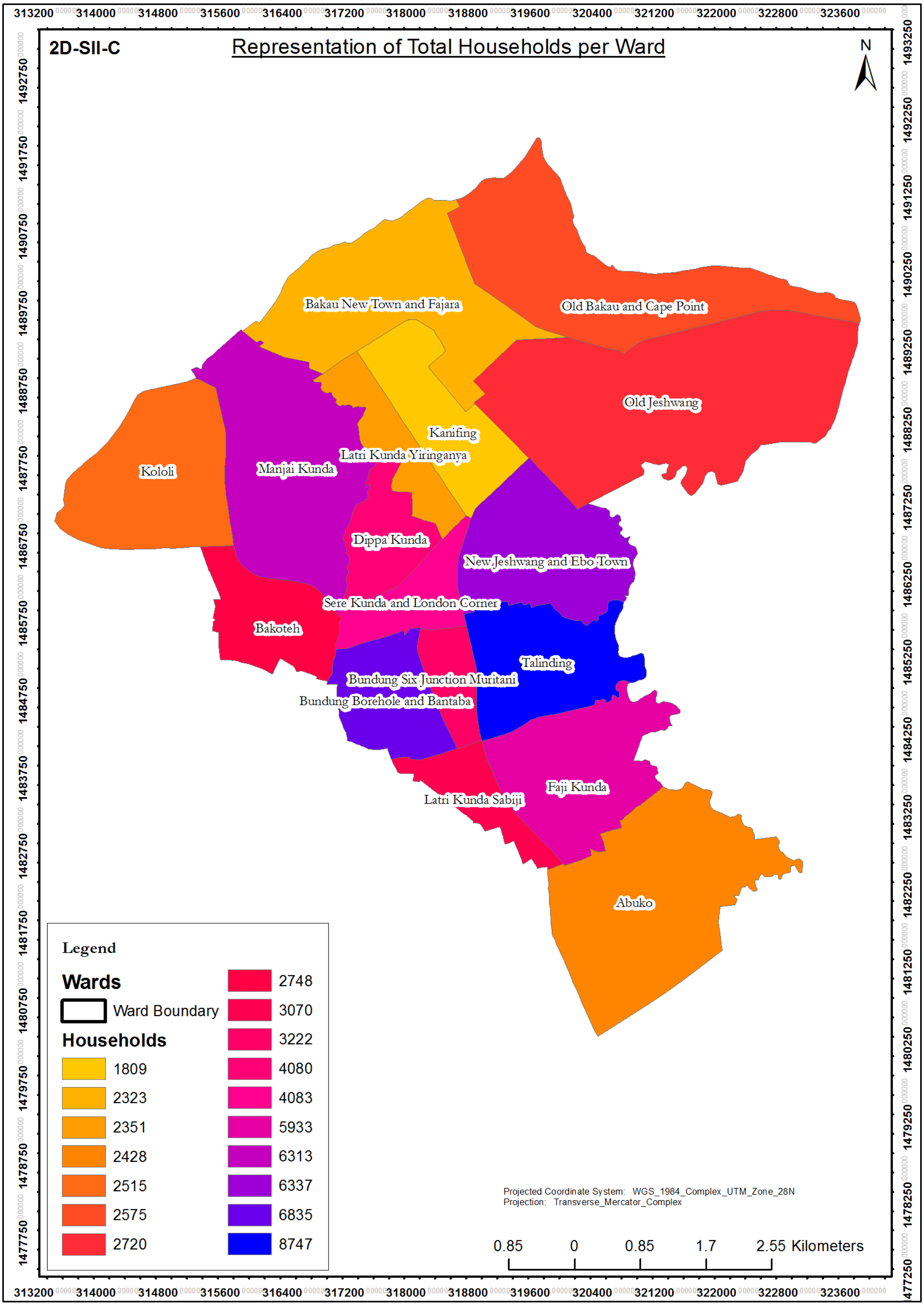
Appendix F: 2D map representation of population for each of the five districts in Kanifing Municipality



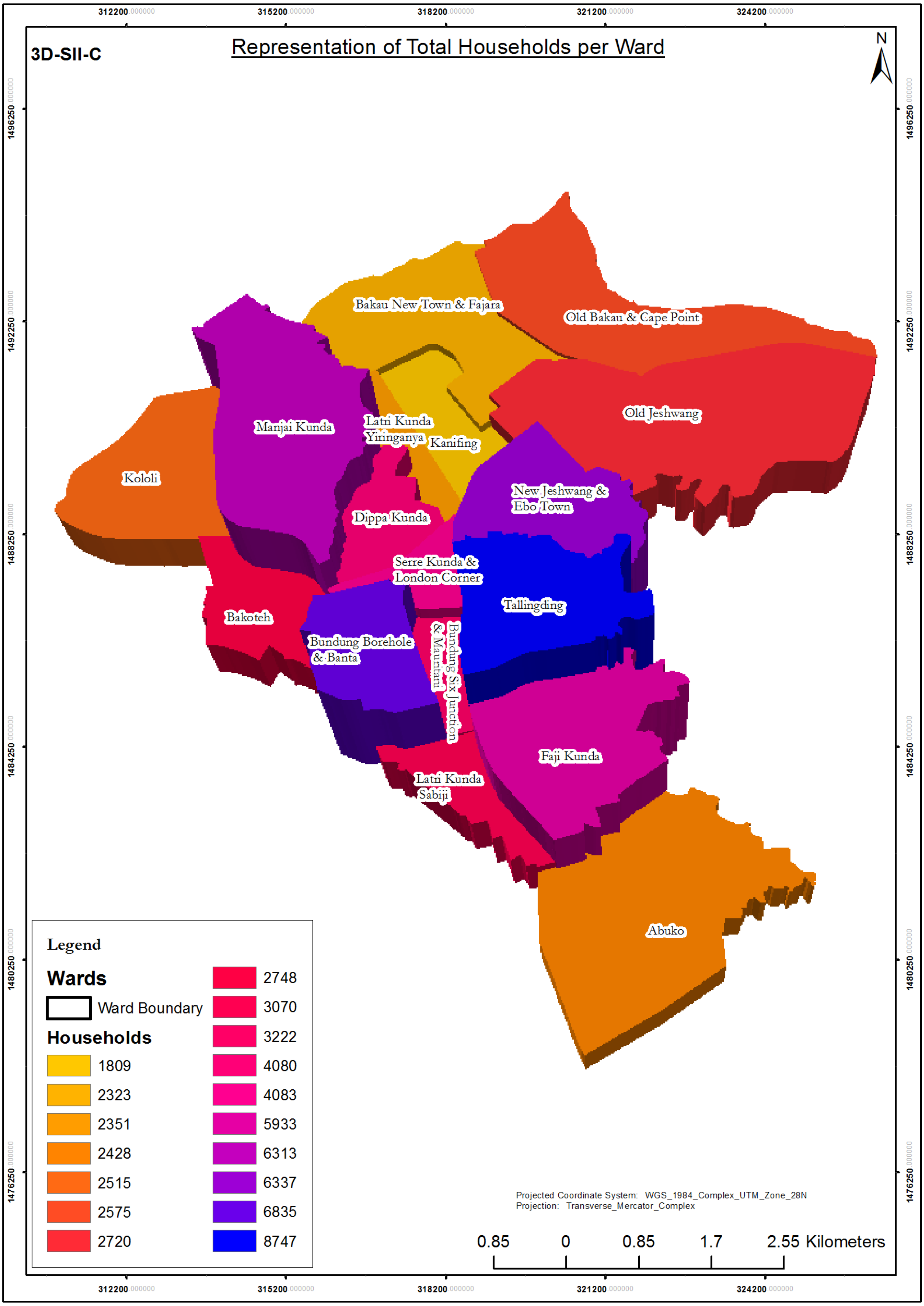
Appendix G: 3D map representation of population for each of the five districts in Kanifing Municipality



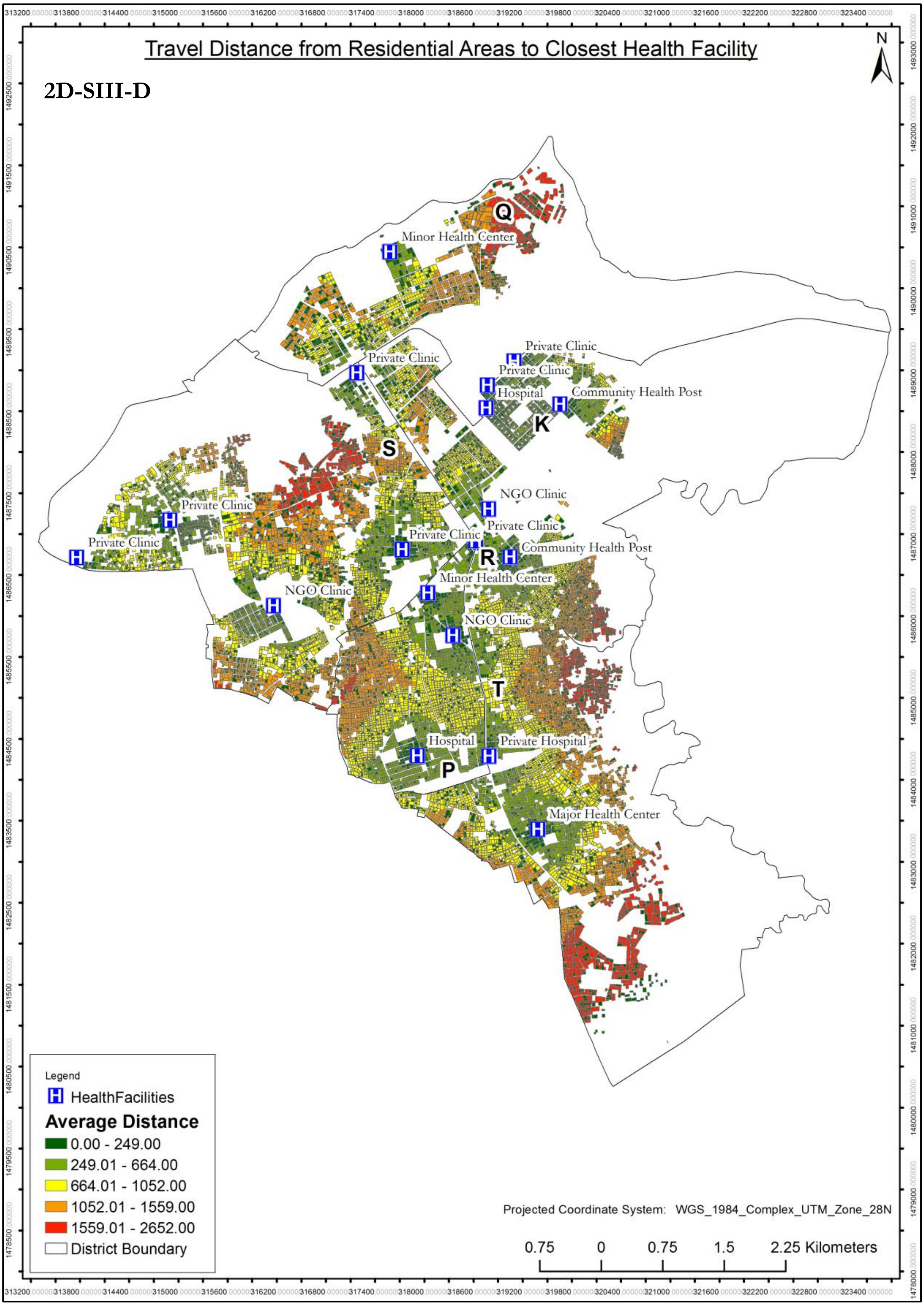
Appendix H: 2D map representation of number of household for each of the seventeen Wards in Kanifing Municipality



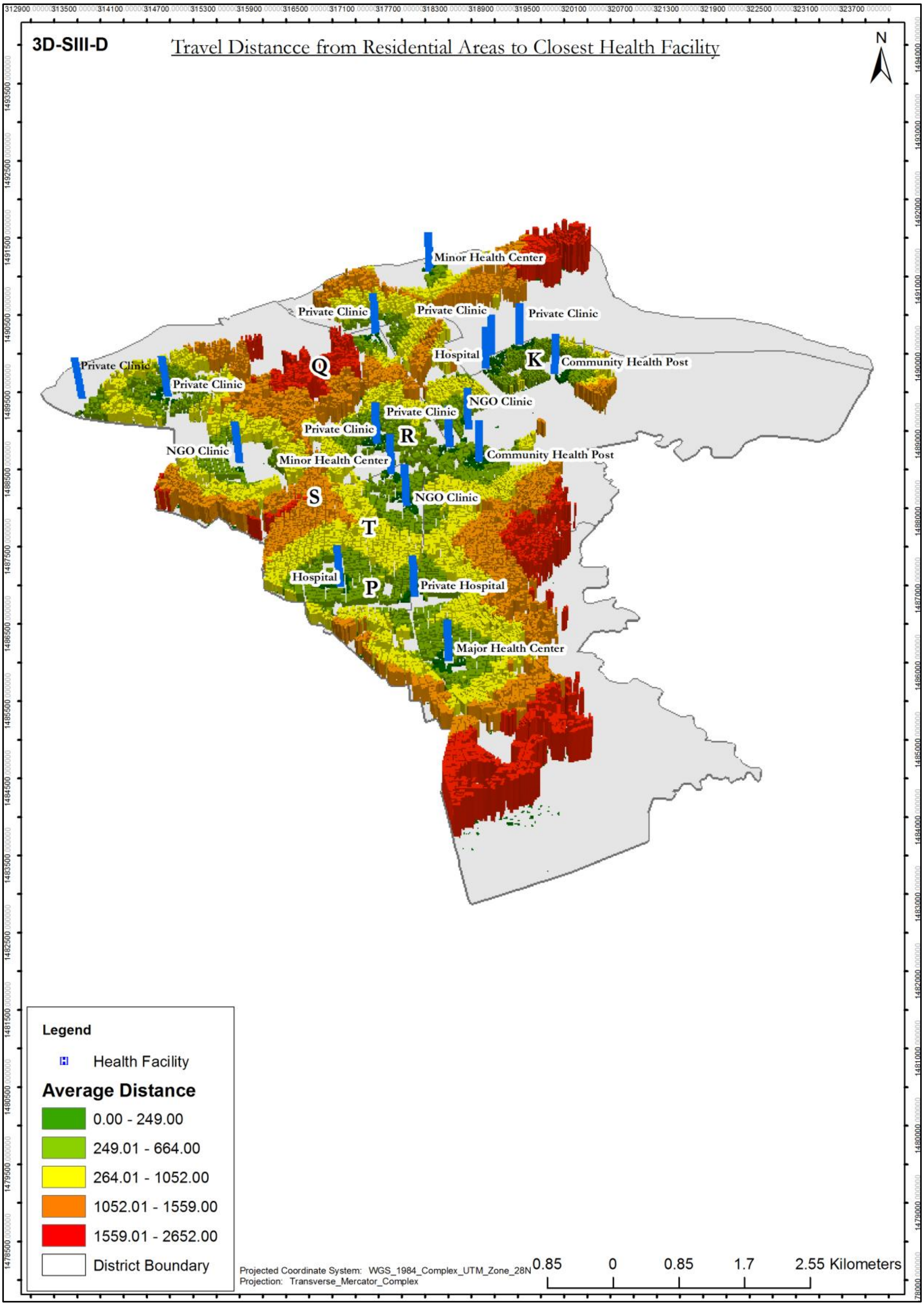
Appendix I: 3D map representation of number of household for each of the seventeen wards in Kanifing Municipality



Appendix J: 2D map showing average travel distance from residential areas to the closest health facility in Kanifing Municipality



Appendix K: 3D map showing average travel distance from residential areas to the closest health facility in Kanifing Municipality



Appendix L: Timing and Score of participants for each of the three sections of the task performance

Timing and scores for participants with 2D visualization

Participant Number	Section 1 Score (out of 5)	Section 2 Score(out of 10)	Section 3 Score(out of 8)	Total Score (out of Max. 23)	Timing (Minutes)
2D-01	4	7	8	19	17.00
2D-02	3	7	6	16	27.00
2D-03	2	6	8	16	35.00
2D-04	2	8	7	17	32.00
2D-05	4	8	2	17	27.00
2D-06	3	9	3	15	24.00
2D-07	1	7	2	10	40.00

Timing and scores for participants with 3D visualization

Participant Number	Section 1 Score (out of 5)	Section 2 Score(out of 10)	Section 3 Score(out of 8)	Total Score (out of Max. 23)	Timing (Minutes)
3D-01	4	8	7	19	15.00
3D-02	2	9	6	17	20.00
3D-03	4	8	8	20	28.00
3D-04	2	5	8	15	36.00
3D-05	3	4	8	15	33.00
3D-06	3	7	6	16	35.00
3D-07	4	8	8	20	21.00

Appendix M: name of organization/institution and position of the experts interviewed

Number	Organization/Institution Name	Position
1	Gambia Bureau of Statistics	Statistician
2	Gambia Bureau of Statistics	Senior GIS Officer
3	Gambia Bureau of Statistics	Cartographer
4	Kanifing Municipality	Planning and development officer
5	Kanifing Municipality	Data Officer
6	Kanifing Municipality	Data Officer
7	Kanifing Municipality	Data Manager
8	Kanifing Municipality	Data Officer
9	Kanifing Municipality	Data Manager
10	Department of Community Development	Development Officer
11	Department of Community Development	Development Officer
12	Department of Community Development	Assistant Director
13	Department of Community Development	Planning & Monitoring Officer
14	Department of Community Development	Principal Development Officer
15	Department of Community Development	Senior Development Officer
16	Department of Community Development	Programme Supervisor
17	Lands & Survey/Physical Planning	Surveyor & GIS Specialist
18	Lands & Survey/Physical Planning	Cartographer
19	Lands & Survey/Physical Planning	Cartographer
20	Nova Scotia Gambia	Monitoring & Evaluation Officer
21	Nova Scotia Gambia	Regional Coordinator
22	Nova Scotia Gambia	Health & Education Promotion
23	Nova Scotia Gambia	Regional Coordinator
24	Nova Scotia Gambia	Regional Coordinator
25	Nova Scotia Gambia	Accountant
26	Nova Scotia Gambia	Manager
27	Health Management & Information Systems	Data Manager