IMPROVING SPATIAL ACCESSIBILITY TO AGRICULTURAL MARKETS IN THE AFRAM PLAINS, GHANA.

by

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A dissertation submitted to the Graduate Council of
Texas State University in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
with a Major in Geographic Information Science
May, 2017

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DEDICATION

To the people of Afram Plains for your resilience and commitment to food production amidst all the strenuous conditions and for the warm reception and remarkable support you gave me during my visit to the area.

ACKNOWLEDGEMENTS

All Glory to God Almighty for His mercies, grace, and blessings towards me in making this dissertation a possibility. I am forever grateful.

I am also deeply indebted to several people who contributed immensely in diverse ways to help me complete this dissertation and my studies at Texas State University successfully. I first say thanks to my advisor, Dr. T. Edwin Chow, for his outstanding guidance, patience, encouragement and inspiration throughout my entire life at Texas State University. Dr. Chow, I just cannot thank you enough.

My next appreciation goes to my dissertation committee: Dr. Benjamin F. Zhan, who provided essential feedback and suggestions that significantly improved my dissertation; Dr. Denise Blanchard-Boehm, for her sustained encouragement, thoughtful insights and constructive comments throughout my research, and Dr. Taewon Suh, who particularly helped me frame the economic and marketing aspects of the dissertation.

My profound gratitude also goes to the West Africa Research Association and Center (WARA and WARC) for awarding me the WARC Travel Grant that enabled me to conduct field studies and gather data from my study area in Ghana. To Dr. Jennifer Yanco, the Director of WARA, thanks for your great assistance in processing my grant.

Again, I am grateful to the faculty and staff at the Geography Department at Texas State University especially Dr. Philip Suckling, Dr. Alberto Giordano, Dr. Ronald Hagelman, Ms. Allison Glass-Smith, Ms. Angelika Wahl, Ms. Pat Hell-Jones and Mr.

Charles Robinson for their priceless administrative support offered me during my entire doctoral program. In addition, I say thank you to Dr. Andrea Golato (Dean of the Graduate College), Dr. Eric Paulson (Associate Dean), Dr. Sandy Rao (Assistant Dean), Ms. Sylvia Mobley and all the staff at the Graduate College for their morale support.

I would also like to thank my wife Ohenewaa for her love, patience, advice, suggestions and unflinching support throughout my doctoral studies. Ohenewaa, thank you for everything; I could not have done it without you. To my parents, Mr. and Mrs. L.K. Dede-Bamfo for providing me with the precious gift of education; my brothers Frank, Isaac, Ebenezer, and Stephen and my uncle, Uncle Kwabena for their prayers and encouragement. I will forever be grateful to you all.

A special thank you goes to Mr. Guixing Wei, a PhD student at Texas State University for helping me code parts of my work in python and Mr. Isaac Mensah, an Agricultural Extension Officer in Afram Plains for his insights and expert knowledge that helped frame parts of the modelling procedures. Again, I say thank you to the following people: Ms. Victoria Tsibu, Mr. Frank Siaw (my field assistant), Mr. Ansong, Interviewees and all respondents in the Afram Plains, Mr. George Owusu, Mr. Evans Afful and Mr. Saban Parimah (all in Accra- Ghana) for their invaluable support during the data collection stage of this research.

Further thanks go to the following persons: Mr. and Mrs. Robert Sessions (Binghamton, New York), Prof. E. L. Tettey-Fio (Binghamton University, New York), Mr. Richard Skinner and friends of Chi Alpha Christian Fellowship (Texas State

University), Pastor Ken Volkert and members of New Life Christian Center (San Marcos, Texas), Mr. Doug Stovall and members of Christians at Texas State (San Marcos) for their morale support and encouragement during my doctoral program.

Finally, to my school mates: Kumudan Grubh, Dr. Adam Mathews, Dr. Khila Dahal, Dr. Naizhou Zhou, Dr. Yan Lin, Ryan Schuermann, Monica Medel, Tom Shelton, and Chunhong Zhao, I am grateful for your insightful contributions and humorous conversations.

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ABSTRACT

Poor spatial accessibility has been known as one of the main factors responsible for the poor development of Afram Plains in Ghana. Spatial accessibility here refers to the capacity to reach one location from another. Due to poor conditions of transport infrastructure in the Afram Plains, many farmers have limited access to local markets. This research, therefore, focused on assessing the current nature of spatial accessibility in the area and explored effective ways to improve the situation.

A mixed method approach was adopted to fulfill this objective. It included an innovative spatial accessibility model that considered a multi-mode transportation system. Also, this research explored the combining effects of developing new road networks and new facilities simultaneously on spatial accessibility. Geocomputation techniques such as multi-criteria evaluation was used in modelling the new road networks and locating the new markets. These methods were aimed at improving spatial accessibility but ultimately, economic development in the area.

The results indicated that a large part of the area has very low spatial access to market. This finding was corroborated by results from the survey; over half of the respondents acknowledged their travel experience to market as extremely difficult. In addition, the south-eastern peninsula and a pocket of areas in the north-east showed up as having the greatest need. Regarding the best way of improving spatial accessibility in the area, the results showed, a combination of new roads, road improvement and new markets to be the best solution to the problem.

1. INTRODUCTION

1.1 Rural Development and Spatial Accessibility in Developing Countries

1.1.1 Rural Development

According to the United Nations (UN, 2013), about 3.3 billion people, approximating 48 percent of the world's population, lived in rural areas in 2011. Among them, about 91 percent lived in developing countries alone. In the developing world, rural residents accounted for about 54 percent of the entire population (UN, 2013). Unfortunately, most rural areas are characterized by the incidence of poverty, lack of physical and social infrastructures, physical isolation and poor spatial accessibility (Guimarfies and Uhl, 1997; Porter, 2002(a); 2002(b)). Such conditions essentially deny most residents of basic life opportunities. Therefore, every step towards enhancing rural development is a necessity rather than an option in the developing world.

Even though the idea of rural development is generally understood, there is no formal definition as all perceived definitions are subject to evolving objectives over time (Anríquez and Stamoulis, 2007). For instance, in the 1960s, the general idea was simply a shift from agriculture to a structurally transformed and diversified economy (Anríquez and Stamoulis, 2007). However, with time, the focus settled on the change in the well-being (e.g. provision of social services) of the rural poor (Anríquez and Stamoulis, 2007). Formally, rural development in recent times, is defined as a type of "development that benefits rural populations; where development is understood as the sustained improvement of the population's standard of living or welfare" (Anríquez and Stamoulis, 2007, pp. 2). In this research, the term "rural development" is defined as the sustained improvement in the general living standard or welfare of a group of people living in a rural community.

From the above, rural development like any type of development, elicits change or transformation. In this case, it is a change in the economic living conditions of people. According to Olsson (2009), it is “a structural shift, where a new social and technical environment or a new set of economic opportunities emerge, and the pattern of relationships between the environment and social actors change” (pp. 477). A key to such structural shift though, is the capacity for people or activities to congregate in an area (Kilkenny, 1998). Rodrigue et al. (2013) described it as spatial interaction: the “realized movement of people, freight or information between an origin and a destination”. Apparently, the ability for people to spatially interact is considered as a necessary condition for regional growth and development (Niebuhr, 2000). Such clustering or interaction oftentimes occur if there exist some attraction or factors such as economies of scale, market and product diversity (Kilkenny, 1998).

Moreover, people and activities can only cluster or spatially interact unless there exist some infrastructure linking them to the destination (Rodrigue et al., 2013). In other words, they must have the ability to spatially access the destination. Where transport infrastructure is in short supply, unreliable and poor, the cost of movement tends to be high which in turn significantly constrains people’s tendency to move or interact (Olsson, J. 2009; Rodrigue et al., 2013). Consequently, people or activities cannot concentrate to stimulate economic growth and development (Roehner, 1996; Kilkenny, 1998). And this is one main reason why many rural areas remain undeveloped (Guimarfies and Uhl, 1997).

1.1.2 Spatial Accessibility in the Developing World

As noted already, most rural areas, particularly in the developing world, suffer from poor spatial accessibility to social amenities. Spatial accessibility in this context refers to the ease by which a location can be reached from another location (Ahlström et al., 2011). Poor spatial accessibility in rural areas is considered as the major obstacle to economic development in the developing world (Guimarfies and Uhl, 1997; Porter, 2002 (b); Nutley, 2003; Olsson, 2009). In Sub-Saharan Africa (SSA) for example, the lack of reliable transport infrastructure is responsible for persistent poor agricultural productivity (World Food Program, 2009; Gwilliam, 2011) and minimal trading opportunities (Hoyle and Knowles, 1998; Lamport, 2009).

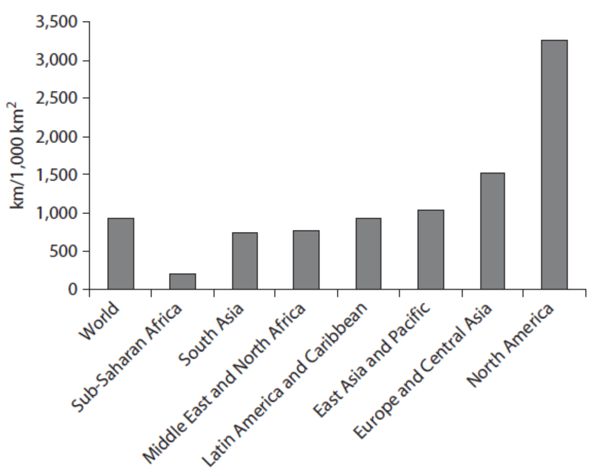

Figure 1.1: Global spatial density of road networks
Source: Gwilliam (2011)

The SSA region is actually considered as the worst accessible region in the world (Buys et al., 2006; Gwilliam, 2011) (Figure 1.1). The dominant transportation system is roads networks (Gwilliam, 2011). SSA has a total road network of 3.4 kilometers per 1,000 people, compared with a world average of 7.1 km (Gwilliam, 2011). Motorable roads form a small portion (about 34 percent) of rural road network but almost half are in deplorable conditions (African Development Bank (ADB), 2010) (Figure 1.2). The remainder include tracks or paths that link communities to farms and market centers (Riverson et al., 1991) (Figure 1.3).

Figure 1.2: A major road in bad condition
Source: Lamport (2009)

Figure 1.3: A farm track - Afram Plains

1.1.3 Importance of Spatial Accessibility in Agriculture

Agriculture remains the major source of revenue in many SSA countries (Abatena, 2009). It accounts for about one-third of the region's GDP and 40 percent of its export revenues (Gwilliam, 2011). It is the largest employment sector in the region (World Bank, 2008). In fact, the proportion of labor force in agriculture in the SSA is comparatively higher than that of the developed world (World Bank, 2008). Yet, agricultural productivity in the former remains the lowest in the world (Grigg, 1995; World Bank, 2008).

Even though factors like unfavorable climatic conditions, poor state protection for farmers and the lack of agricultural research (Grigg, 1995) are noted as partly responsible for low agricultural productivity in SSA, poor spatial accessibility is considered as the most crucial problem (Mission 2014, n.d.(b); Buys et al., 2006; World Food Program, 2009). The following sections discuss the importance of transport infrastructure and periodic market in improving spatial accessibility in agriculture; a critical factor for rural development in the region (Wanmali and Islam, 1997; Abatena, 2009).

1.1.3.1 Transportation Infrastructure

Riverson et al. (1991) observed that an improvement in rural transport infrastructure enhances local farmers' access to better and profitable market. In turn, it serves as an incentive for farmers to increase their production. Similarly, Porter (2002b) and Olsson (2009) noted how rural transportation improvement directly led to reduction in travel time and cost of production, business expansion, attraction of investors and employment opportunities in their research. Among the direct effects, reduction in both travel time and cost of production is the most reported (Mwase, 1989; Roehner, 1996; Kilkenny, 1998; Peters, 2003; Olsson, 2009). Olsson (2009) for instance, in a study in the Philippines observed that an improvement in local roads led to reduced journey time and forced local transport operators to lower freight charges as competition surged. Consequently, cost of production dropped drastically.

The reduction in cost of transportation and production also induce competition among producers; a condition that "theoretically benefits the entire society through lower trade costs and consumer prices" (Olsson, 2009, pp. 477). Similarly, lower transport cost regulates incidences of price volatility (Roehner, 1996). Roehner (1996) indicated that, high production cost due to inadequate transport infrastructures resulted in frequent price volatility and food crises in most of Europe in the 19th and early 20th Century.

Moreover, improvement in transport infrastructure generates other benefits such as enhanced access to capital, farm implements, and labor markets which are all essential for local production (Leinbach, 1995; Hoyle and Knowles, 1998; Olsson, J. 2009). It also stimulates interaction and trade relations among distant communities (Roehner, 1996). Such economic interactions encourage concentration of people and activities thus provide the stimulus for economic growth (Kilkenny, 1998). The impact of transport infrastructure and spatial accessibility is summarized as in Figure 1.4 below.

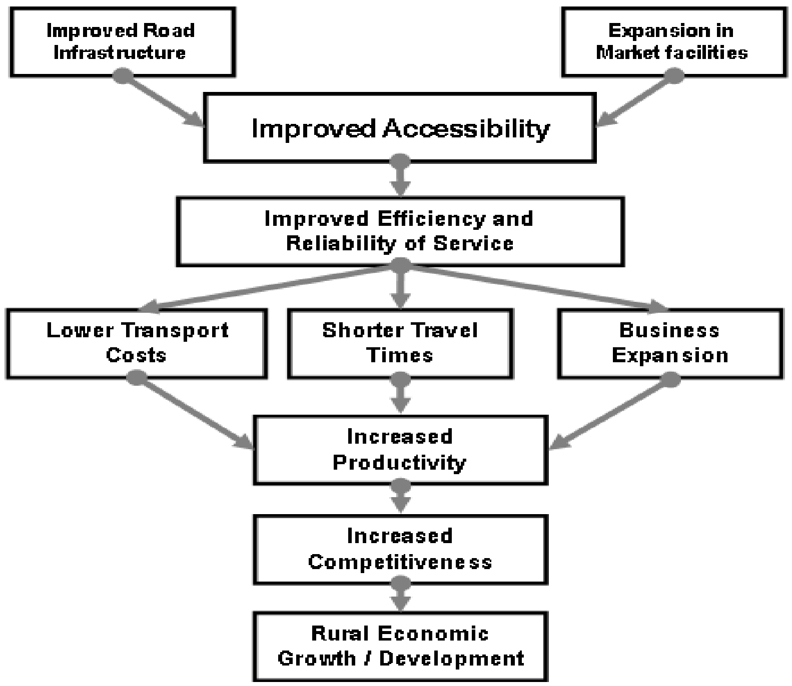

Figure 1.4: The effects of improved spatial accessibility
Source: Adapted from Rodrigue et al. (2013)

The above discussion clearly highlights the importance of transport networks in improving spatial accessibility. It, however, takes a lot of careful planning to develop new transport networks. One, is to determine the network model fit for the area. Two notable models used are the *extensive* and *intensive* transport models (Guimarfies and Uhl, 1997; Herzog, n.d.(b); Herzog, 2013.). Generally, the intensive model is preferred over the extensive model but that is subject to local conditions. Owning to the level of uncertainty involved in choosing the right model, optimization techniques involving a geocomputational approach are often used (Abrahart and Openshaw, 2000; Qishi and Shan, 2000; Kumar et al., 2009)

1.1.3.2 Periodic Marketing

Besides transport infrastructure, the availability and distribution of markets also play an important role in the growth and development of human economies through the exchange of goods and services (Berry et al., 1988). A market simply represents the relationship between supply and demand (Rodrigue, et al., 2013). The interaction between supply and demand ultimately determines the price for economic products; the equilibrium charge (Isard, 1956). Hence, theoretically, a market does not assume a location. Yet, in reality, consumers and suppliers tend to move and meet at a designated location to exchange goods and services (Rodrigue, et al., 2013). Thus, a market in real sense assumes a spatial dimension (Isard, 1956; Rodrigue, et al., 2013).

In line with that, an agreed price in any market includes the equilibrium charge as well as the transportation cost; cost of moving products from a source location to a market center. These factors play a role in distinguishing markets. In the developing world, due to factors like high transport cost and low aggregate demand, markets tend to be periodic rather than permanent. The low aggregate demand is due to low spatial concentration of consumer demand caused by low population density and low per capita income. In periodic markets, buyers and sellers only meet on set scheduled days often known as market week. (Bromley, 1971; Berry et al., 1988). According to Berry et al. (1988), periodicity of markets helps patrons to manage cost of operation, which is essential for the sustenance of rural economies especially in the developing world. The cost of operation includes the fixed cost of setting up a trade, the production cost and the cost of shipment to a market center (Berry et al., 1988). Rationally, trading is unlikely to occur where permanent cost exceeds trade returns. Periodicity, however, provides a means of offsetting cost of operation through actions like diversification of economic activities, diversification of trading stock, and becoming mobile or an itinerant trader (Berry et al., 1988). Periodic markets therefore have three categories of traders: *part time* traders (those who diversify their activities in an attempt to be profitable), *multi-stock* traders (those who deal in different products) and *itinerant* or *mobile* traders (those who visit different markets in a market week to take advantage of available lucrative sales).

1.2 Statement of Problem: Spatial Accessibility in Afram Plains, Ghana

1.2.1 Background

The above discussions on the relationship between spatial accessibility, agriculture, periodic markets and rural development may best be illustrated by the conditions in the Afram Plains of Ghana– the focus of this research (Figure 1.5). The Afram Plains is located in the Eastern Region of Ghana, an area largely regarded as the food basket of the country (Ghana District News, 2013). Yet, it is one of the poorly developed areas in Ghana (ADB, 2006; Daily Graphic, 2006). There is virtually no access road connecting the district to the rest of the country as it is almost completely cut off by Lake Volta and Obosom River. Currently, the main gateway to the area is by water transportation through a ferry service (Figure 1.6).

According to Afram Plains Catholic Apostolic Prefecture (APCAP, 2010(c)), geographic isolation is the root cause of many of the problems in the area. Besides, the existing transport networks are inadequate within the district itself, and hence cutting off several communities from major towns with social services (MOFA, 2013).

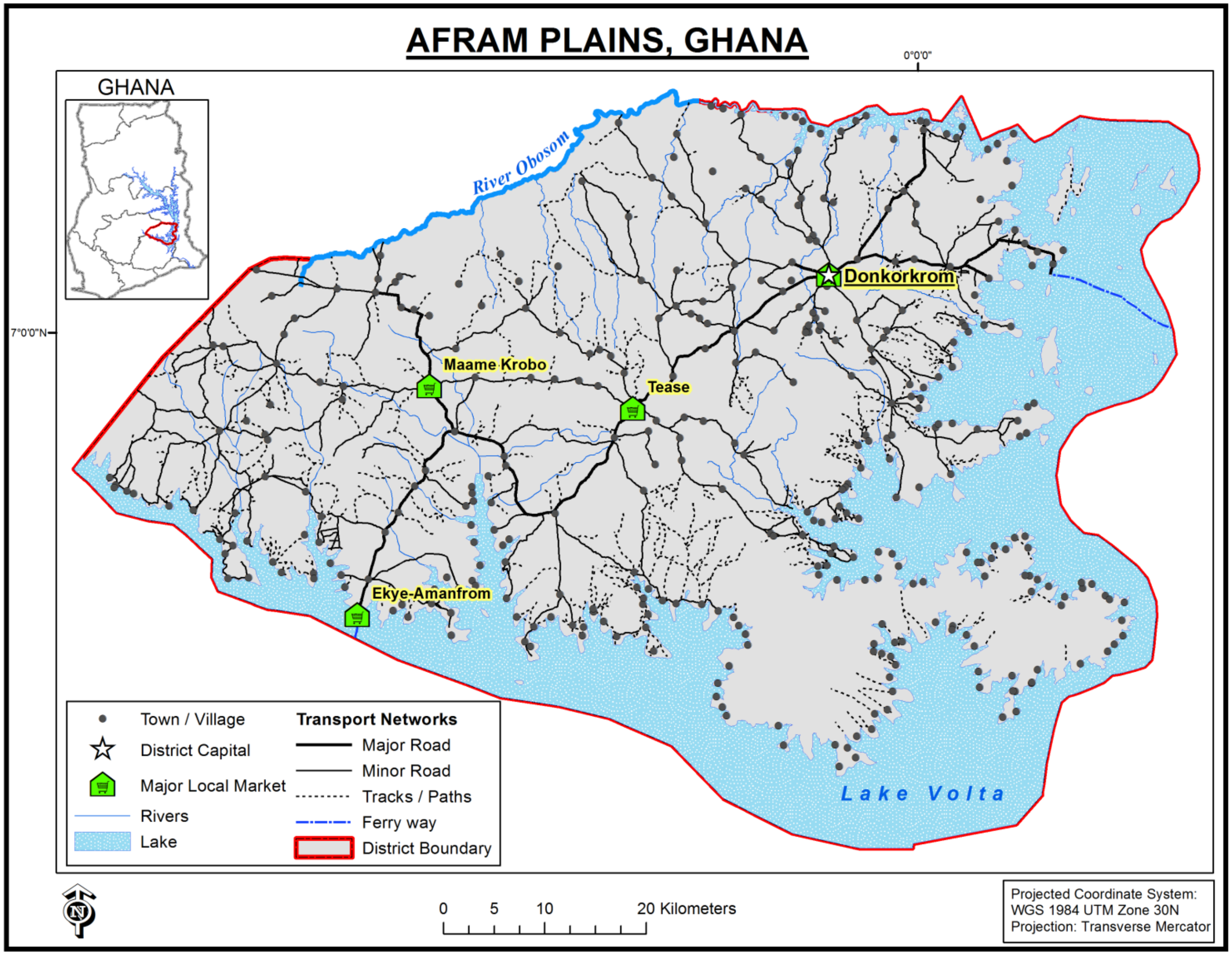

Figure 1.5: Afram Plains area

Figure 1.6: Ferry service

Figure 1.7: Poor roads in Sene
Source: Baidoo and Danso (2013)

Even among the few privileged areas with tangible road networks, a substantial number of the roads are in deplorable conditions (APCAP, 2010(b)) (Figure 1.7). The situation even worsens during the rainy or wet farming season, which is characterized by torrential rains and flash floods that render many agricultural areas practically inaccessible. Such conditions limit access to local social facilities like markets, health centers, schools and credit facilities (ADB, 2006; MOFA, 2013). Besides, they induce high cost of transportation. Local transport operators commonly charge more than the normal fares due to transport shortage and lack of competition (APCAP, 2010(b)).

Moreover, existing market facilities in the area are few and quite far from many of the villages meaning the residents who are mostly farmers need to pay more in hauling their produce to market to sell. This results in high cost of production. It is therefore not surprising that markets in the area are all periodic as it allows residents to offset their operating cost (Berry et al., 1988). Part time and itinerant trading is common in the area. In addition, high cost of production in the area discourages investors from visiting the area to engage in business (Ghana District News, 2013). In short, poor spatial accessibility to market has been acknowledged as the primary factor for the delayed growth and development of the Afram Plains (ADB, 2006; Ghana District News, 2013).

1.2.2 Causal Factors

Previous studies in Ghana have revealed the following as some key factors responsible for the prevailing situation: late development, low population density, low income levels, poor road planning and maintenance capabilities and lack of community involvement. First, Porter (2002b) indicated that, the late development of transport infrastructure in the country (just as in many SSA countries) is partly responsible for the current problem. Earlier developments which occurred during the colonial era were concentrated mainly in selected resource-rich areas. The large part of the country was left undeveloped hence contributing to the current low spatial density of transport networks in many countries (Gwilliam, 2011).

Second, the situation reflects the low population densities of many areas of SSA (Gwilliam, 2011). Unlike other regions like South Asia, population in rural SSA is sparsely distributed. Sparse population coupled with low productivity and low per capita income make the rural areas less economically attractive to governments and investors hence the continual neglect and marginalization of these areas (Deichmann et al., 2006).

Third, the lack of effective road planning and regular maintenance has been proven as drawbacks to infrastructural development in SSA (Riverson et al., 1991; Buys et al., 2006). Riverson et al. (1991) noted that many governments lack quality and reliable data on production and transport activities as well as the know-how and maintenance capabilities. As a result, they are unable to track changes in travel and haulage activities to effectively forestall the deterioration of the few existing infrastructures. Besides, some scholars also think that, the sheer neglect of periodic maintenance works by some local government authorities and exclusion of local communities in infrastructural development and maintenance programs engender the situation (Riverson and Carapetis, 1991; Porter, 2002(b)). Oftentimes, new developments and maintenance are biased towards areas that support the government. Such decisions are purely partisan and rarely have any backing from empirical research (Oppong, 1997).

Community involvement has been identified as key in most successful rural road planning programs. Riverson et al. (1991) observed in their study that, a "multi-tiered planning and programming system based on locally acceptable criteria allowing participation of local communities" proved efficient for local planning programs. Upon this observation, they concluded that, any rural program must reflect the community's priorities and demands (may include: economic, social and cultural services and technical information on terrain and hydrology).

1.2.3 Past Interventions and Present Needs

The realization of the overarching influence of poor spatial accessibility on rural development in the Afram Plain has led to the introduction of various projects in the past. One of them was the Afram Plains District Agricultural Development Project (APDADP) which ended in 2012 (MOFA, 2013). The main goal of the project was poverty reduction by ways of increasing agricultural output and improving existing feeder (dirt) roads (MOFA, 2013; KNDA, 2013). Besides APDADP, there was also the Millennium Challenge Account which focused on three main areas: agricultural commercialization, transport infrastructural development and rural development. Under the transportation segment, the key objectives were to enhance access to international air and sea ports, improve trunk road networks as well as ferry services (ADB, 2006; Ghana District News, 2010; KNDA, 2013).

Despite some substantial achievements made through the above projects, there remains acute need for improvement in residents' overall spatial accessibility to amenities in the area (MOFA, 2013). There are still many communities that are inaccessible within the area, especially during the wet or rainy season. The two major drainage systems in the area, the Afram and Volta basins, containing several rivers, streams, and a lake, experience seasonal flooding that affect road transportation, disrupt economic activities, and contribute to significant post-harvest losses (APCAP, 2010(b)) (Figure 1.8).

Moreover, it has also been reported that newly constructed or rehabilitated feeder roads in the area tend to deteriorate within a relatively shorter period (APCAP, 2010(b)). The reason is that, feeder roads are susceptible to water erosion, a common phenomenon in Afram Plains. However, the situation of road deterioration could be contained if proper road planning, periodic maintenances and community involvement are carried out or ensured (APCAP, 2010(b)).

Figure 1.8: Truck containing farm produce immobile in mud
Source: Baidoo and Danso (2013)

Furthermore, the means of entry into the area also remains a major challenge for the area. As described earlier, the current major means of entry is by water transport. Even though this means of transportation is comparatively cheaper, it is unreliable, short in supply and inconvenient (APCAP, 2010(b)). Thus, it frustrates trading and business in the area forcing many traders and investors turn to other alternative locations in the country for business. In light of that, APCAP (2010(b)) asserted that, until a reliable, convenient and readily available means of transportation is developed, much of the efforts being made currently in the area will be of little effect towards improving the situation. To APCAP (2010(b)), a road network will provide the solution. Considering the above, this research originally aimed at exploring how access to and within the Afram Plains area could be improved. But, due to resource constraints, the focus settled on the latter. Regardless, the author anticipated that, with improvement in local roads, trading among the communities will improve which then, will ultimately attract external traders into the area.

1.3 Research Objective / Questions

This study evaluated the spatial accessibility to local market centers in the Afram Plains based on a multi-mode transportation system using geocomputational techniques. The ultimate goal was to improve spatial accessibility of residents to agricultural markets within the Afram Plains of Ghana by modelling new road networks and locating new market centers. Specifically, the author sought ways to improve overall spatial accessibility within the area by minimizing the total sum of travel time from towns/villages to markets. To achieve the above goal, this research sought answers for the following questions:

1. *What is the spatial accessibility of the inhabitants to market centers based on a multi-mode transportation system?*
    a. *Is there any geographic disparity of spatial accessibility to market centers in the area among the agricultural zones?*
    b. *Is there any significant difference in the spatial accessibility to market centers by various modes of transportation across the agricultural zones?*
2. *Based on the level of spatial accessibility and economic potential, where are the areas of greatest need (i.e. poor access but high economic potential)?*
3. *How best can spatial accessibility be improved?*
    a. *If new roads are to be developed, which network model (intensive or extensive) is suitable and where should the roads be constructed to better improve spatial accessibility within the area?*
    b. *If new markets are to be developed, where should they be located?*
    c. *If the above interventions (i.e. roads and/or markets) produce any changes in spatial accessibility:*
        i. *Is there any significant difference between them after their implementation?*
        ii. *How is spatial accessibility affected when both are applied together?*

1.4 Organization of the Research

This dissertation is organized into eight chapters. Chapter one introduces general issues about rural development, rural accessibility and transportation in developing countries with emphasis on SSA. The chapter goes on to state the problem under investigation: spatial accessibility in Afram Plains of Ghana. It further outlines the research objective and questions, and concludes with the organization of the research.

In chapter two, the author establishes the research context and provides a review of relevant literature that forms the basis of this research. The review focuses on: the concepts of spatial accessibility and location allocation as they relate to transportation planning and decision making, spatial disparity in service provision, measures of economic potential and GIS applications related to transportation planning and location allocation.

Chapter three provides a description of the study area as well as research methods. The description of the study area comprises the precincts and general geography, socioeconomic indicators, current state of transportation, and spatial accessibility to social facilities in the area. Following the discussion of the study area is a detailed description of the data and methods for implementing the objectives and research questions outlined in this research.

The results are presented in Chapters four, five, six and seven. Chapter four presents the results for the multi-mode spatial accessibility model. Chapters five and six present the results for the interventions while chapter seven provides an evaluation of the interventions.

In Chapter eight, the author provides a summary of the main findings in this research, discusses some limitations, and then concludes with some recommendations for both policy makers and for future research directions. Other peripheral materials are presented in the appendices and list of all referenced materials are listed in the bibliography.

2. LITERATURE REVIEW

This chapter reviewed relevant past studies that investigated the relationship between road transportation, spatial accessibility and rural development. The chapter is organized into three main sections; each corresponds to reviewing fundamental concepts and existing knowledge in answering the research questions. The first section discusses the concept of spatial accessibility, modes of transportation and access to markets as well as notable measures for estimating accessibility. The second section explores the means of modelling "level of need" based on spatial accessibility and economic conditions. The third section identifies popular models/algorithms employed in improving spatial accessibility.

2.1 Spatial Accessibility in a Rural Setting

2.1.1 Defining Spatial Accessibility

The concept of accessibility, due to its usage in diverse fields, has lent itself to various definitions (Geurs and van Wee, 2004). A specific definition is usually associated with the objectives of a project at hand or a particular condition an analyst is measuring. Thus, accessibility definitions may be broadly categorized as following:

- Location-based measures – evaluate the "ease by which a location may be reached from another location" (Ahlström et al., 2011) or the spatial distribution and number of opportunities within a specified area (Theriault et al., 2005). For example, the number of local markets within an area that might be reached in 30 minutes from an origin.

- Individual-based measures – concern the restrictions experienced by an individual in his/her attempt to patronize activities within their immediate surroundings. The restrictions may come in the form of time budgets, speed limits and other socio-economic limitations (Geurs and van Wee, 2004; Salze et al., 2011).
- Infrastructure-based measures – assess the efficiency of existing transport infrastructure in terms of supply and reliability based on factors like traffic congestion and mean travel speed (Geurs and van Wee, 2004; Ahlström et al., 2011).
- Utility-based measures – analyze the benefits derived by the population from patronizing spatially distributed activities (Geurs and van Wee, 2004; Salze et al., 2011).

Each of the above measures evaluates a very important aspect of accessibility and thus, it is impractical to value one measure over the other (Handy and Niemeier, 1997). Practically, none of the measures can completely account for all the aspects of accessibility. Therefore, an analyst must select the most appropriate measure that suits the purpose of his analysis (Lovett et al., 2002; Geurs and van Wee, 2004). In choosing a suitable measure, Geurs and van Wee (2004) suggested subjecting a measure to these four criteria: theoretical foundation (ability to account for prevailing land-use, transport infrastructure, time and individual elements such as needs, preferences and abilities), operationalization (the ease in modelling it), interpretability and communicability (the ease in understanding and explaining the results), and usability (the ability to use for addressing socio-economic problems).

Besides the above classification of accessibility measures, Luo and Wang, (2003) also broadly categorized accessibility as either potential or realized accessibility. They defined the former as the capacity to reach a destination and the latter as the actual usage of a facility or service by people. Between the two approaches, realized accessibility is considered as cumbersome to model since it requires the collection of empirical data based on people's actual experiences. Often times, due to resource constraints and sampling limitation, it is almost impossible to model realized accessibility (Haynes et al., 2003; Luo and Wang, 2003; Wang, 2006). Potential accessibility on the other hand, is considered as more manageable due to its tolerance of secondary data. Potential accessibility is often classified under location-based measures (Geurs and van Wee, 2004). Further details about it are discussed under the sub section for location-based measures.

2.1.2 Geographic Disparity in Access to Market

Like many social facilities in rural SSA, spatial access to periodic market centers is very limited (Riverson et al., 1991; Porter, 2002(b)). The inadequate number of these facilities coupled with the scattered and sparse nature of the communities limit the utilization of periodic markets (Naude et al., 1999). The situation is exacerbated by the lack of adequate and reliable transport infrastructure (Hoyle and Knowles, 1998; Lamport, 2009). Very few areas enjoy considerable access to social facilities due to proximity and/or relatively better transport services (World Food Program, 2009; Mission, 2014a). This geographic disparity in market distribution engenders inequality and poverty (Apparicio and Seguin, 2005).

According to Tighe (2008), markets are generally the primary destination for residents in the rural area. Even though they are primarily centers of commerce, markets also serve as information centers where residents seek advice and useful information about their farming activities like produce prices, pest control and credit facilities. They also provide avenues for other social activities such as marriage arrangements, loan payments, theatrical performances and renewal of friendships (Berry et al., 1988). In view of this, a limited access to a market does not only affect residents economically, it entrenches their social isolation (Tighe, 2008).

One test of efficiency of a local service delivery system is its guarantee of social equity (Sanders, 2007; Chang, 2009). Spatial equity describes a situation whereby social services are located or provided such that all underprivileged populations have some fair access to them (Apparicio and Seguin, 2005; Omer, 2006). To help ensure spatial equity, there is a need to understand existing geographic distribution and nature of local supply and demand (Porter, 2002(a); 2002(b); Ahlström et al., 2011). In addition, Church and Murray (2009) recommend that available facilities must be fairly divided among local demand. According to Apparicio and Seguin (2005), ensuring spatial equity is necessary for two reasons: it helps improve the wellbeing of the poor and weak in society, and also helps maximize their chances of getting out of poverty.

2.1.3 Impact of Geographic Disparity on Periodic Markets

An efficient distribution of market facilities is essential in a periodic market system (Stine, 1962). According to Von Thünen's (1826) theory, for a market to remain functional and profitable, its range must exceed its threshold. The market range refers to the maximum distance a demand unit is willing to travel to a good or service or the maximum distance a product can be shipped to a customer (Rodrigue et al., 2013). It is a function of transport cost, time or convenience in relation to intervening opportunities. On the other hand, the threshold is the minimum demand vital for the sustenance of an economic activity (Rodrigue et al., 2013). A poor distribution of markets therefore essentially undermines market profitability and access to potential patrons

According to McKim (1972), the relative location of periodic market centers in space and time is crucial for local patrons as each market's function is directly or indirectly linked to others. Fagerlund and Smith (1970) noted that, periodicity often substitutes spatial competition with temporal differences. Two hypotheses attempt to explain this space-time synchronization of periodic markets. The first is the *consumer hypothesis*; it claims that there is an inverse relationship between the temporal and locational position of periodic markets: the closer in space, the farther in time of meeting (Berry et al., 1988). The second is the *trader hypothesis*. It posits that the temporal sequence chosen by patrons in utilizing markets is influenced by cost. Hence, an itinerant trader follows a sequence that minimizes his total travel to all market centers on his schedule. In this case, markets are likely to be both close in space and time (Berry et al., 1988). Ghosh (1982), however, critiqued the two hypotheses as failing in adequately explaining real situations faced by consumers and traders in periodic market systems. He argued that it is more reasonable to admit that a trader will choose an itinerary that maximizes profit than one that just reduces cost.

Though the above propositions are yet to be proven conclusively (Berry et al., 1988), they underscore the importance of adequacy and efficient distribution of markets in an area. A shortage or disproportionate supply is likely to affect local patrons, especially itinerant traders. The reason is that, they will likely not be able to cover all their overhead cost which includes fixed cost of trading and cost of movement to other market centers to trade. As a result, making efficient plans for improving the distribution of local markets are necessary for effective functioning of a local periodic market system thereby enhancing rural development.

2.1.4 Mode of Transportation for Agricultural Products

From the preceding sections, food production has been established as the major source of income for many rural residents in SSA. Yet, for this economic activity to yield expected returns, the products must reach the market at a reasonable cost and sold profitably; implying the need for a reliable and adequate transport system (Tighe, 2008). Unfortunately, most rural areas in SSA lack reliable transport system (Mwase, 1989; Riverson and Carapetis, 1991). In fact, poor transport infrastructure in the region is known to be one of the major reasons responsible for high cost of travel, haulage and agricultural production in the area (Buys et al., 2006). In 2010, the African Development Bank observed that, poor infrastructure alone accounted for 60 percent of transport costs in landlocked countries and 40 percent in coastal countries (ADB, 2010).

According to Tighe (2008), haulage of agro-products oftentimes follows a step-wise sequence: from farm to the household or village then on to the local market. And, if weather and network conditions permit, some farmers carry their products directly from farm to market. This sequence is characterized by different grades of road networks that form a hierarchy of networks. Table 2.1 identifies these networks, their characteristics and popular form of usage.

From Table 2.1, one may realize improvement in the networks and increase in traffic as they progress towards the market center and district capital. Tighe (2008) observed that, most rural road systems, however, comprise the first three levels with the market center being the top destination in the hierarchy. Though the lower levels may be considered as less efficient, they play a vital role in the rural transport and food marketing system (Tighe, 2008).

Table 2.1: Rural transport infrastructure in SSA

Level	Transport Infrastructure	Characteristics	Popular usage
1 (Basic)	Paths	Narrow; 1-5 km.	Headloading or walking, biking. Connects farms to households. Inaccessible during wet season.
2	Tracks	Small width; 1-10 km; very low traffic: 0-5 Vehicles Per Day (VPD).	Limited vehicular access; mostly tractors, animal drawn carts. Connects large farms to villages but usually link households to village facilities.
3	Earth (feeder) roads	Medium width; 5-20 km; Paved with no surface coating; low traffic: 5-50 VPD.	Mostly village to market centers; tractors, trucks and limited cars.
4	Gravel Road	Wider across, 10-50 km; surface improved with gravels; medium traffic: 20-200 VPD.	Connects villages/towns to market centers and sometimes district capital; vans, motor bikes and cars.
5 (Highest)	Surface Coated Road	1-2 lanes. 20-100 km; surface improved with bitumen; high traffic: >100 VPD.	Usually connects towns/market centers to the district capital; very limited. All forms of vehicles.

Source: Adapted from Tighe (2008).

Regardless of the nature of the various transport activities, profit maximization forms the core objective of all patrons. Since prices normally increase with increase in demand (buyers), the value of farm produce often appreciates from the farm to the highest market level. Yet, inadequate transport system tends to limit the profitability of patrons. Reacting inversely, transport cost appreciates as one moves from the market center towards the produce source or farm. This is due todepreciation of the networks along with such direction of movement. It gets worse in the rainy season as transport operators, anticipating possible breakdowns, compensate by doubling their charges. In some cases, the transport owners decide not to travel at all. This eventually affects prices of goods in rural areas leading to dire consequences for rural communities.

Moreover, poor transport networks discourage investment in the transport sector and hence, limit economic competition (Lamport, 2009). As a result, the transport sector is characterized by a few small-scale operators, limited vehicular supply and unreliable operations (Porter, 2007). These conditions create a local scarcity leading to increasing transportation cost (Lamport, 2009; Gwilliam, 2011). Consequently, high cost of transportation, coupled with pervasive high poverty levels in the area, compel the majority of locals, particularly women, to resort to headloading/walking and other forms of transportation collectively referred to as Intermediate Means of Transport (IMT) for their transportation needs (Mwase, 1989; Riverson and Carapetis, 1991; Porter, 2002(a); 2002(b)). IMTs are cheaper forms of transportation that are adapted to the needs of a rural clientele (Tighe, 2008). Though rural SSA is generally characterized by low vehicular traffic, Riverson and Carapetis (1991) indicate that they experience a lot of movements than many other areas. This suggests that majority of movements are carried out via non-motorized systems. Table 2.2 identifies some of the common modes of transportation used in SSA.Table 2.2 clearly shows that the majority of modes of transportation are non-motorized. With regards to load capacity and speed, the non-motorized modes are the least efficient. Riverson and Carapetis (1991) observed in their study in Ghana that, on average, a rural household of about 12 people spent 4,830 hours per year transporting about 216 ton-kilometers of farm produce and household needs, representing about 73 percent of total time and ton-kilometers spent on transport. They noted that, this was a major constraint to agricultural production and other economic activities in the rural areas as very little time remained for possible expansion of business or attend to other ventures. Nevertheless, these non-motorized systems remain the most utilized mode of transportation in SSA.

Table 2.2: Common modes of transportation in SSA

Vehicle	**Max. load capacity (kg)**	**Max. Speed (kph)**	**Max. Range (km)**	**Terrain/Route Requirements**
Head load / Walking	40% of body weight: Men - 30, Women - 20	1.5-3.0	3	---
Wheelbarrow	100	5	10	Flat, narrow path
Bicycle	75 - 150	20	20	Flat, narrow path
Bicycle with trailer	200	10 to 15	15-20	Flat, wide track
Pack Animal	100-250	5	15-20	Hilly, narrow path
Animal-drawn cart (oxen)	500-1500	5	15-20	Flat, wide track
Motorcycle	100	40-90	100	Motorable path
Motorcycle and cart	250	30-60	60	Unsuitable for steep hills
Single-axle tractor and trailer	1500	15-20	40	Unsuitable for steep hills
Asian Utility Vehicle	1000	60	60	Motorable road or track

Source: Adapted from Riverson and Carapetis (1991)

Among them, headloading/walking is by far the most popular mode of transport in the rural areas. This is due to the fact that, it is readily available, low cost and more adaptable to local conditions than their motorized counterparts (Mwase, 1989; Riverson and Carapetis, 1991; Tighe, 2008). The motorized systems on the other hand, are by far more efficient especially in terms of speed. However, they tend to be costly for most rural residents (Mwase, 1989; Guimarfies and Uhl, 1997).

Furthermore, the scattered nature of most rural settlements coupled with inadequate market facilities means residents must travel long distances between farms and villages and nearby markets to sell their farm produce. It is estimated that only 25 percent of rural residents have access to market within two hours (World Food Programme, 2009). Such long travels over deplorable roads attract a high cost which many residents cannot afford (Buys et al., 2006). This setback contributes to mass post-harvest losses during major farming seasons in SSA (Mission 2014, n.d.(a); World Food Program, 2009). Figures 2.1 to 2.4 show some of the modes of transportation.

Figure 2.1: Head loading
Source: Cycle Your Heart Out (CYHO; 2014)

Figure 2.2: A motorcycle and cart

Figure 2.3: An Asian utility truck

Figure 2.4: A farm tractor

As acknowledged above, the poor state of transport infrastructure and accessibility in SSA undoubtedly prohibits spatial interaction, trading (Lamport, 2009), and food security (SOW-VU, 2011). Improving spatial accessibility can help alleviate these problems (Mission 2014, n.d.(a)). It however requires a clear understanding of the prevailing problem, meticulous planning, and application of appropriate techniques. The next section discusses techniques for measuring spatial accessibility.

2.2 Measuring Spatial Accessibility

In section 2.1.1, it was noted that, the choice of measure for estimating spatial accessibility is primarily dependent on the objectives or requirements of the analysis. As this research concerns the capacity to overcome the space between two locations with either providing demand or supply (Naude et al., 1999), this research used a location-based measure to model spatial accessibility. The subsections below discuss various location-based measurements, including basic measures (like distance and isochrones), potential measures and spatial interaction models (Zhang et al., 2011).

2.2.1 Basic Location-based Measures

Distance measures are sometimes referred as connectivity measures (Geurs and van Wee, 2004), minimum distance (Omer, 2006; Zhang et al., 2011), proximity (Ahlström et al., 2011) and relative accessibility (Ingram, 1971). Distance, in fact, is deemed as the simplest measure of accessibility (Geurs and van Wee, 2004; Zhang et al., 2011). Distance measures simply measure the minimum travel distance (or travel time or cost) from a point of origin to the nearest destination (Wang, 2006; Ahlström et al., 2011; Zhang et al., 2011). It is mathematically formulated as:

$$D_i = \min_j d_{ij}$$

(Equation 2.1)

where D_i is the minimum distance between origin *i* and the nearest opportunity *j*, within a specified geographic unit.

There are various types of distance applied in quantifying spatial accessibility. They include Euclidean, Manhattan (i.e. network), terrain, time or cost distances (Apparicio and Seguin, 2005; Wang, 2006). The Euclidean distance which is a straight-line distance between two points or locations (Esri, 2011(a)) is considered the most popular and simplest approach (Tanser et al., 2006; Wong et al., 2012). It assumes the landscape as isotropic, hence the range of distance is the same from a point of origin irrespective of direction.

In the context of spatial accessibility, Zhang et al. (2011) suggested that Euclidean distance is useful when dealing with an urban area with a dense street network. However, Euclidean distance tends to underestimate actual travel distance especially in a rural setting where road density is far low (Omer, 2006; Wong et al., 2012; Zhang et al., 2011). Again, many scholars argue that in most real situations, geographic spaces are not isotropic as assumed by Euclidean distance; rather, they are heterogeneous due to varying physical and social factors (Gibson et al., 2010; Ahlström et al., 2011). Thus, to overcome the shortcomings of Euclidean distance, network distance is recommended.

Network distance describes the minimum travel distance allowed within a given street network connecting between an origin and a destination (Theriault et al., 2005; Zhang et al., 2011). Comparatively, a network distance is considered as a more accurate approximation of actual travel distance because of its capacity in accounting for real conditions such as length of roads, speed limits, road quality and topography; factors which essentially control how easy or difficult one may overcome an intervening space (Ahlström et al., 2011; Tanser et al., 2006). Based on these factors, one may estimate other conditions such as travel time and travel cost, which would yield more credible results than Euclidean distance (Tanser et al., 2006; Salze et al., 2011).

In situations involving more than two destinations, *contours* or *isochrones*, are commonly used (Geurs and van Wee, 2004; Omer, 2006). Contour measures sometimes assume these names: cumulative opportunities (Kwan, 1998; Theriault et al., 2005); proximity count or daily accessibility (Geurs and van Wee, 2004), "Floating Catchment Method" (FCM) (Luo, 2004) and integral accessibility (Ingram, 1971). Essentially, contour measures assess all the possible "opportunities which can be reached within a given travel time, distance or cost (fixed costs)" (Geurs and van Wee, 2004, pp. 135). In other words, they summarize all opportunities within a specified geographic unit (Salze et al., 2011; Zhang et al., 2011). The geographic unit may be defined based on the basic spatial unit under consideration in a study, such as census tract, zip code, or a local neighborhood unit, and is often defined as an area within a certain walking distance or travel time (Zhang et al., 2011). The measure assumes that all opportunities within the geographic unit or container are equally accessible (Salze et al., 2011).

Contours are popular measurement in urban planning (such as recreational park and tourist market accessibility) and geographical studies (Bruinsma and Rietveld, 1998; Naude et al., 1999; Zhang et al., 2011). They might however, vary in approach. Some common approaches include: a simple assessment of the presence or absence of opportunities within the defined geographic unit; the total size of the opportunities within a defined neighborhood, and the total size of all opportunities averaged by the size of the local population (called coverage of each individual) (Omer, 2006; Zhang et al., 2011). The coverage of each individual (*Ci*) approach is mathematically formulated as following:

$$C_i = \frac{\sum S_j}{P_i} \qquad \text{(Equation 2.2)}$$

where *Ci* is the ratio between all opportunities *S* within the boundaries of neighborhood *i* and its population *P*.

Network distance is mostly employed in contour measures (Zhang et al., 2011). Wong et al. (2012) for instance, applied the shortest route algorithm based on road networks to estimate the distance to the closest health care facility within specific geographic zones. The goal was to find potential gaps within the local health service delivery. After a statistical test for significant differences among the zones, they identified the zones with wide service gaps; the ones with the lowest spatial accessibility but greatest number of under-served population. Similarly, Naude et al. (1999) implemented contour measure using a specialized GIS software called FlowMap to determine spatial accessibility to market centers in the Wild Coast area in South Africa.

Contour measures, like distance measures, are popular owing to their simplicity, easy interpretability and communicability (Geurs and van Wee, 2004). Yet, both distance and contour measures have been found to have significant limitations especially in relation to their theoretical foundations. First, they fail to account for the combined effect of land-use and transport components even though they incorporate some of these aspects (Geurs and van Wee, 2004). Secondly, they fail to account for competition effects. In addition, they overlook obvious aspects of travel behavior such as individual choice or preference (Haynes et al., 2003; Salze et al., 2011). They simply assume that "all opportunities are equally desirable, regardless of the time spent on travelling or the type of opportunity" (Geurs and van Wee, 2004, pp. 133). And that an individual would always patronize or visit the closest opportunity (Omer, 2006; Zhang et al., 2011). Salze et al., (2011) argued that, in reality, people do not always visit the nearest location. Such bias towards nearest destinations thus renders them unrealistic (Haynes et al., 2003). Again, due to the arbitrary delineation of isochrones of interest (defining boundary for travel distance or time), contour measures are criticized as being overly sensitive to travel time changes thus making them unsuitable for evaluating temporal improvements in accessibility (Geurs and Ritsema van Eck, 2001). Thus, both distance and contour measures are considered inappropriate for analyzing socio-economic aspects of accessibility (Geurs and van Wee, 2004).

Moreover, contour measures are susceptible to the "modifiable areal unit problem" (MAUP), a notable spatial analysis problem (Zhang et al., 2011). The MAUP states that emerging patterns in aggregated data might vary due to scaling or zoning (Fotheringham and Wong, 1991). For example, spatial accessibility based on contour measures might vary according to the spatial dimensions of the defined neighborhood. Besides, contour measures are also susceptible to other spatial analysis problems like edge effects due to neighborhood boundary constraints (Zhang et al., 2011). For instance, an individual could be denied access to an opportunity in a closer but different neighborhood (Hewko et al., 2002; Omer, 2006). This particular problem is seen as a major setback when evaluating land-use and transport changes using a contour measure (Geurs and van Wee, 2004).

A location measure that helps overcome some of the shortcomings of the previous measures is known as *geographic accessibility* (A(*G*)). Unlike the previous measures, *A*(*G*) measures accessibility of a destination or opportunity as the summation of all distances between the destination and various origins divided by the number of origins (Rodrigue et al., 2013). The most accessible destination is the one that has the lowest value. The measure is formulated as below:

$$A(G) = \sum_{i}^{n} \left(\sum_{j}^{n} d_{ij} \right) \Big/ n$$
$$d_{ij} = L \qquad \text{(Equation 2.3)}$$

where *A(G)* is geographic accessibility matrix, d_{ij} is the shortest path distance between locations *i* and *j*, *n* is the number of locations, and *L* is the valued graph matrix (Rodrigue et al., 2013).

A(*G*) is considered to be straightforward, simple to operationalize, and easy to interpret. Compared to distance and contour measures, it considers a many-to-manyaccessibility among a pre-defined origin-destination matrix. But it is criticized for its neglect of individual choice; it assumes all opportunities or destinations have similar features and thus, have equal chance of being chosen.

2.2.2 Potential Location-based Measures

To account for the individual factor of choice and preference in spatial accessibility, a set of location-based measures, known as *potential accessibility models* are prescribed for modelling spatial accessibility (Fellmann et al., 2003; Crawford, 2006; Ghosh and Ghosh, 2010; Zhang et al., 2011). As opposed to *realized accessibility* which is based on actual travel experiences, *potential accessibility* computes “likely” travel experiences of people. Potential models are fundamentally based on Newton's "Law of Gravity" which assumes that the level of attraction between two entities is proportional to their size and inversely proportional to the distance separating them (Wilson, 1974; Geurs and van Wee, 2004). Mathematically, it is expressed as:

$$F = G\frac{M_i M_j}{{d_{ij}}^2} \qquad \text{(Equation 2.4)}$$

where *F* is a function of the force of attraction or pull between two bodies of respective masses, M_i and M_j, separated by distance d_{ij}, and where *G* is a gravitational constant.

In the above model, the attraction (sometimes called interaction) between two spatial entities *i* and *j* are assumed to be directly proportional to the masses, such as physical size, population, number of functions of the entities, but inversely proportional to some function of spatial impedance, such as travel distance, time or cost. Based on the description, a gravity model may essentially be seen as modelling spatial interaction and not accessibility *per se*. Yet, it has been used extensively in modelling both concepts as evidenced in researches like Fellmann et al. (2003), Horner, (2004), Devkota (2007) and Zhang et al. (2011). Thus, the two terms, though quite distinct, tend to be used synonymously. For example, Fellmann et al. (2003) applied a simplified version of the gravity model to model spatial accessibility. Their derived equation is as following:

$$I_{ij} = \frac{P_i P_j}{{D_{ij}}^2} \qquad \text{(Equation 2.5)}$$

where I_{ij} is the spatial accessibility between two entities *i* and *j*, located at a distance *Dij* with population *Pi* and *Pj*.

Over the years, several variants of the conventional gravity-based measure have emerged. Some of these derivatives include the "Two-Step Floating Catchment Area" (2SFCA) (Luo and Wang, 2003; Wang, 2006; Salze et al., 2011), "Enhanced 2-step

Floating Catchment Area" (E2SFCA) method (Luo and Qi, 2009; Wan et al., 2011) and the "Three-Step Floating Catchment Area" (3SFCA) method (Wan et al., 2012). The E2SFCA which is recognized as an improved version of the normal gravity model (Wan et al., 2011) basically consist of two phases; the first involves the creation of a catchment zone *i* around the target entity *j* based on some distance function (such as travel distance or time). Geographic units like census units or zip code areas may also define a catchment zone (Wan et al., 2011). The catchment area is further divided into subzones of equal intervals, and then a supply-to-demand ratio is calculated for the spatial entity (Wan et al., 2011). This is expressed mathematically as:

$$R_j = \frac{S_j}{\sum_{j\epsilon(d_{kj}\epsilon\, D_r} P_k W_r} \qquad \text{(Equation 2.6)}$$

where R_j is the supply-to-demand ratio, S_j represents the capacity of the spatial entity *j*, P_k denotes the population of area unit *k* inside the catchment, d_{kj} represents the travel cost between j and k. D_r represents the r^th sub-zone of the catchment based on travel time and W_r denotes a predefined distance-weight for D_r (Luo and Qi, 2009).

The second phase involves calculation of a "Spatial Access Index" (SPAI), an absolute estimation of spatial access, of each catchment zone *i*. It is based on Equation 2.7.

$$A_i^F = \sum_{i\epsilon(d_{ik}\epsilon D_r)} R_k\, W_r \qquad \text{(Equation 2.7)}$$

where: A_i^F is the SPAI for *i*, R_k is the supply-to-demand ratio of the spatial entity *k* that falls inside the catchment of *i*, and d_{ik} is the travel cost between *k* and *i* (Luo and Qi, 2009).

The E2SFCA is generally acknowledged as very effective and useful particularly in modelling potential spatial access to medical services (Luo and Qi, 2009; Wan et al., 2011). The SPAI component, for example, if based on "evidence-derived impedance coefficient," is often considered as a true supply-to-demand ratio of an opportunity and thus assists in identifying deprived locations; a necessary step towards the enhancement of social equity (Wang and Luo, 2005; Luo and Qi, 2009; Wan et al., 2011). Yet, the SPAI component is criticized of being too sensitive to changes in the distance impedance (Wan et al., 2011). As a result, Wan et al. (2011) proposed an alternative function called the "Spatial Access Ratio" (SPAR) which they considered as a relative spatial access assessment approach. Wan et al. (2011) calculated SPAR as the ratio of a defined catchment zone's SPAI and the mean SPAI of all other catchment zones.

Wan et al. (2011) claimed that SPAR, unlike SPAI, is tolerant to variations in the distance impedance parameter thus provides a more stable result. They added that, SPAR is preferred over SPAI "in expressing the results of the E2SFCA method in the absence of an appropriate value of impedance coefficient" (pp. 298). Despite the above advantages, the E2SFCA is also prone to setbacks such as the MAUP and edge problems; modifying the catchment zones could significantly change the results. A latter extension of the E2SFCA is the 3SFCA. Unlike the E2SFCA, 3SFCA has the capacity of accounting for spatial competition. Yet, it shares almost all the other features of the former.

Another derivative of gravity-based measures is called, "Population-Weighted Distance" (PWD) (Zhang et al., 2011). The main objective of the PWD is to model spatial accessibility such that the limiting effects of MAUP and ecological fallacy are removed or reduced significantly (Zhang et al., 2011). The model is primarily based on the "Huff RetailModel." Assuming that nearby and bigger opportunities are more attractive, the Huff model estimates the propensity of people visiting a particular opportunity (Huff, 1964). In other words, if two facilities are of same distance from a demand point, people will patronize the one with a higher attraction value, holding all other conditions constant (Church and Murray, 2009). Yet, people will likely visit a less attractive facility if it is closer– dependent though on how much less attractive and how much closer (Mitchell, 2012). Unlike the conventional gravity model, the Huff model acknowledges that customers have a choice when deciding which location to patronize in view of other alternatives. Hence, a trade area is a continuum of probabilities, unless there are no other alternative destinations **(**Rodrigue et al., 2013).

In light of the above, the probability of a consumer visiting a given business location is a function of the distance to that site, its attractiveness, and the distance and attractiveness of competing sites (Esri, 2009). This is formulated as: ratio of a measure of the interaction between the demand point and the particular facility, divided by the sum of interaction measures between the demand point and all available facilities (Huff, 1964; Mitchell, 2012). It is expressed mathematically as below.

$$P_{ij} = \frac{A_j^{\alpha} D_{ij}^{-\beta}}{\sum_{j=1}^{n} A_j^{\alpha} D_{ij}^{-\beta}}$$

(Equation 2.8)

where: P_{ij} is the probability that a consumer located at *i* will choose to visit store *j*, A_j is a measure of attractiveness of store *j* (often based on size or square footage of a facility), D_{ij} is the distance from *i* to *j*, α is an attractiveness parameter estimated from empirical observations, β is distance decay parameter estimated from empirical observations, and n is the total number of stores including store j

The distance (between the demand point and the facility) parameter is controlled by a constant rate of decay function called distance decay or distance friction (Haynes et al., 2003; Liu, 2012; Mitchell, 2012). Distance decay accounts for a well-known travel behavior: people's inclination to travel to an opportunity declines steadily as distance increases (Mitchell, 2012).

Results from the Huff model, generally, provide a good indication of where consumers may be coming from, the distances that they are traveling, and areas that may be underserved (Mitchell, 2012). Overall, owning to its relative simplicity and general applicability to a wide range of problems particularly predicting consumer's spatial behavior, the "Huff Retail Model" has endeared many researchers (Dramowicz, 2005; Liu, 2012). It is commonly used in estimating retail trade areas involving more than two destinations (Church and Murray, 2009).

Nevertheless, the Huff model may be seen rather as, more appropriate and relevant for modelling spatial interaction than spatial accessibility. As noted earlier, the model estimates the probability to interact just as in some other gravity based models. Meanwhile, accessibility focuses specifically on the capacity to overcome the intervening space between two locations. The two problems obviously overlap but may not be judged as the same. Owning to that, the PWD based on Huff model may not be claimed as theoretically appropriate for addressing the problem of accessibility. Another variant of potential measures like the above is deemed more appropriate for modelling spatial accessibility; it focuses solely on accessibility while accounting for consumers' choice

(Haynes et al., 2003; Geurs and van Wee, 2004). It is expressed mathematically as shown in Equation 2.9.

$$Pi = \sum_{j=1}^{N} a_j \exp[-b(T_{ij})]$$

(Equation 2.9)

where: P_i is the potential accessibility for area *i*, *aj* is the attractiveness of service or opportunity *j*, T_{ij} is the travel impedance from area *i* to service or opportunity *j*, and *b* is a constant rate of decay (distance or time decay function) based on empirical data.

According to the above model, the potential spatial accessibility of a location to an opportunity is determined by the attractiveness of all known opportunities weighted by the proximity of the location to the opportunities (Haynes et al., 2003; Geurs and van Wee, 2004). Haynes et al. (2003) indicated that, this model is efficient in accounting for a mix of individual travel behavior traits such as the notion of convenience and choice. Though seen as the most efficient and reliable potential accessibility measure (Haynes et al., 2003; Geurs and van Wee, 2004), it has some limitations. The most notable limitation pertains to modelling the distance decay function (Geurs and van Wee, 2004). The distance decay function is normally modeled as a separate parameter (*β*); the larger the parameter, the more rapidly the travel drops off and vice versa (Mitchell, 2012). It might significantly influence the results of the analysis; thus, it must be carefully chosen and ideally, calibrated empirically (Geurs and van Wee, 2004).

However, often times, empirical data on travel behavior are not available. Thus, many researchers tend to arbitrarily determine the decay coefficients using varied functions such as the power, Gaussian or logistic functions (Haynes et al., 2003; Geurs and van Wee, 2004; Wan et al., 2011). Yet, a negative exponential function, either applied as a power or exponent, is the most commonly used and also seen as onethat is most closely tied to travel behavior theory (Handy and Niemeier, 1997; Haynes et al., 2003; Mitchell, 2012). According to Mitchell (2012), a power transformation function (also called gravity function) is most suitable for modelling cases involving rural or comparatively larger study areas. The reason is that, facilities in such areas tend to be widely spaced hence, travel distances to them from a given point, generally, tend to be longer. People therefore are not overly concerned about distance. A power function with a constant exponent value becomes just adequate for such cases (Mitchell, 2012). But in densely populated areas where facilities are often many and clustered, coupled with traffic congestion, convenience of distance plays a major role in consumer's choice. As a result, people are less likely to travel far to patronize a facility. In such situations, an exponential function is considered the appropriate option as it allows the modelling of distance decay over shorter distances (Mitchell, 2012). Figure 2.5 shows the relationship between the two transformation functions.

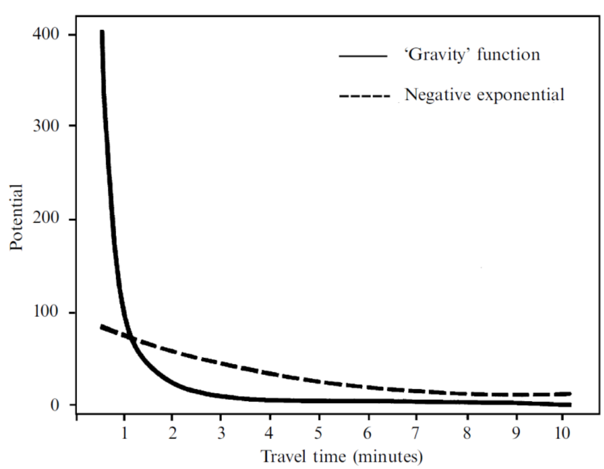

Figure 2.5: Comparing gravity and negative exponential functions
Source: Haynes et al. (2003)

Comparing the gravity (power) function and the negative exponential function (Figure 2.5), Haynes et al. (2003) observed that, with a decay rate of 0.29 per minute for example, the latter produces a more "gentle curve that is almost linear with increasing travel time" (pp. 1148). The former however, applying the conventional inverse distance or time squared formula, results in a steep curve. With such a steep curve, potential contacts at short distances are exaggerated. Moreover, such extreme influence on closer contacts may introduce some significant uncertainties in the analysis thereby limiting the overall usefulness of the analysis (Luo and Wang, 2003; Wan et al., 2011) especially in urban areas. But with cases involving rural areas, such outcomes are unlikely to cause any significant effects on the analysis (Mitchell, 2012).

In summary, potential accessibility models are recognized as having several practical advantages over the other measures. Comparatively, they are considered as more theoretically sound (Geurs and van Wee, 2004; Luo and Qi, 2009; Wan et al., 2011; Rodrigue et al., 2013). Unlike the other measures, they effectively account for most of the essential components that influence accessibility including land-use, transportation, temporal and individual elements (Geurs and van Wee, 2004). Particularly, they may account for individual travel behaviors like choice and preference (Haynes et al., 2003). Potential measures are also adept to evaluating both economic and social aspects. Besides, they are relatively easy to implement and are amenable with existing geospatial data (Geurs and van Wee, 2004). In terms of flaws, they are comparatively robust. The only major critique is their relatively difficult interpretation and communicability (Geurs and van Wee, 2004). The incorporation of several elements such as land-use and transport factors as well as the constant rate of decay function eventually make the measure quite complex (Geurs and van Wee, 2004; Rodrigue et al., 2013). Moreover, Zhang et al. (2011) noted that most potential models assume a source location could interact with all available opportunities within a study area hence considers all possible opportunities in the calculation. In reality, people tend to patronize a limited number of nearby opportunities out of all available options (Zhang et al., 2011). Potential measures are also sometimes criticized for being relatively ineffective in accounting for competition effects and temporal constraints (Geurs and van Wee, 2004). Despite all that, the robust nature as well as the sound theoretical foundation of potential measures makes them the choice measure for modelling spatial accessibility.

2.2.3 Modelling Spatial Accessibility based on Multi-Mode Transport System

The majority (if not all) of research involving spatial accessibility focuses on a single mode of transportation particularly road networks in estimating travel distance, travel time or travel cost. This has been admitted as a limitation (Naude et al., 1999; Tanser et al., 2006; Ahlström et al., 2011), yet, due mainly to the lack of data, it remains the most common approach. This research, however, attempts to model spatial accessibility based on multimode transport system to obtain a more realistic result. This is especially important in areas like in the developing world where transport needs are met by varied modes of transportation. Focusing on just a single mode, will either overestimate or underestimate the true state of spatial accessibility in the area. Various measures to handle common limitations associated with this approach are explained in the Methodology chapter of this research. A multi-mode transportation model provides a new perspective and approach in modelling spatial accessibility in many regions that have multi-mode transport systems.

To improve the level of access in areas with poor access conditions, this research proposed to first identify "areas of need" based on level of spatial accessibility and level of economic potential. In other words, what was the level of suitability based on those two factors? This idea stemmed from the notion of "Cost-Benefit Analysis" (CBA). The objective here was to determine whether or not the project was viable and worthwhile in consideration of its cost and consequences on individuals and society (Prest and Turvey, 1965; Willis, 1998; Lakshmanan et al., 2001; Olsson, 2009). The next section discusses previous literature on how to model economic potential and suitability.

2.3 Determining Level of Need

The top priority of most governments in the developing world is to ensure economic and social development. Ensuring spatial accessibility through transport development is a key part of this goal. (Devkota, 2007; Donnges, 2003). However, the limited efforts being implemented are often misplaced; they mostly benefit the rich than the poor (Tighe, 2006). Careful planning is therefore necessary to ensure that road improvements cover areas that need it most; those which are poor, isolated and have minimal access to social facilities. Nevertheless, providing road access in such areas are usually costly to maintain and not necessarily sustainable owning to low patronage and low vehicular traffic. (Donnges, 2003; Tighe, 2006). To minimize such risks, Tighe (2006) indicated that roads must be developed such that they link major hubs of activity or areas with copious economic potential such as major population centers and major produce areas. Accounting for the economic potential of an area apparently is a necessary measure to ensure the viability and sustainability of any new intervention (Tighe, 2006).

2.3.1 Estimating Economic Potential

Estimation of economic potential is common in marketing. It is associated with terms like "Trade Area Analysis" (Harris, 2008) and "Market Potential" (MP) (Kraemer and Dedrick, 1998; Hanson, 1999; Head and Mayer, 2010; Mundy and Bullen, 2010). In basic terms, it is described as the estimation of opportunities within an area for which there may be a significant local demand or an expected greater return in the long term (Kraemer and Dedrick, 1998; Harris, 2008). MP analysis is useful for several reasons. In marketing for example, it allows firms to classify regions into separate entities in order to tailor specific products to meet customer demands. Also, it allows them to quantify the prospect of a given product according to specific areas in the short or long term (Kraemer and Dedrick, 1998). Besides, such estimates may provide useful insights into the performance of different sectors of the economy as well as temporal changes in performance (Harris, 2008). Head and Mayer (2010) added that, market potential may be used as a measure of economic development of a region. Yet, they cautioned that, MP may be influenced by the geographical location of an area or the local demand within it.

To calculate MP, different methods are used. Harris (2008) identified two measures: "*Trade Area Capture*" (TAC) and "*Pull Factor*" (PF). The former is determined by dividing a sub-area's actual commercial sector sales by the larger area's per capita expenditure, adjusted by the relative per capita income between the sub-area and larger area. It is estimated as shown in Equation 2.10 below.

$$TAC_{ij} = \frac{AS_{ij}}{(AS_{ij}/P_s)(Y_c/Y_s)} \qquad \text{(Equation 2.10)}$$

where TAC_{ij} represents trade area capture for retail sector *j* in sub-area *i* measured by customer equivalents, AS_{ij} represents annual taxable retail sales in sector *j* in sub-area *i*,

AS_{ij} represents annual taxable retail sales in sector *j* for the larger area, P_s is the larger area's population, Y_c is the sub-area's per capita income, and Y_s is the larger area's per capita income.

According to Harris (2008), when *TAC* is not merely the population for a given area, it connotes that either the area "is capturing outside trade or residents have higher spending patterns than the [larger area's] average" (pp. 2). On the other hand, it is indicative of the area either losing potential trade or residents have lower spending patterns than the larger area's average.

On the other hand, *PF* is the ratio of [a subarea's] trade area capture to its population. A value greater than 1.0 is suggestive of the local area drawing in residents from neighboring areas for business. The otherwise may also hold but not always true. (Harris, 2008). Pull factor is calculated based on Equation 2.11.

$$PF_{ij} = \frac{TAC_{ij}}{POP_i} \qquad \text{(Equation 2.11)}$$

where PF_{ij} is the pull factor value for commercial sector *j* in area *i*, TAC_{ij} is the trade area capture value for commercial sector *j* in area *i*, and POP_i is population in area *i*.

Mundy and Bullen (2010) also proposed another measure which is a product of "the number of potential buyers, an average selling price and an estimate of usage for a specific period of time" (pp. 30). The product is given in monetary units showing an estimate of the amount of money clients may expect to make from the product or service they plan to market. According to Mundy and Bullen (2010), any potential estimate is only as good as the assumptions and the data used. Overestimation might be costly thus, one needs to be cautious and prudent when estimating the potential of anything. Their model is as formulated below.

$$MP = N \times MS \times P \times Q \qquad \text{(Equation 2.12)}$$

where: *MP* is the market potential, *N* is the total number of potential consumers, *MS* is the market share - percent of consumers buying from you, *P* is the average selling price and *Q* is the average annual consumption.

In this research, the term *"Economic Potential"* was used instead of *market potential.* This was ideal because it represented a broader perspective of objectives rather than just market prospects. The MP formula was adopted but minimally revised to suit the needs of this research. With the existing need (level of spatial accessibility) and economic potential of the area modeled, the two factors were then combined to determine "areas of need," or in other words, find suitable locations deserving and needing some intervention. The next section discusses notable approaches used in modelling similar suitability needs.

2.3.2 Modelling Suitability

The term *suitability* is used to describe the socio-economic potential of a land unit to support an activity (Qiu et al., 2014). *Suitability analysis* therefore constitutes a systematic process of assessing the socio-economic potential of a piece of land in relation to some specified criteria (Mitchell, 2013; Qiu et al., 2014). It usually involves the overlay, weighting, and rating of multiple relevant data layers associated with a land unit to express its varying levels of potential (Bolstad, 2012). Owing to its multivariate approach, it is also referred to as multi-criteria evaluation (Malczewski, 2000).

Suitability analysis is a common GIS analysis and is adaptable to either vector or raster datasets (Bolstad, 2012). GIS-based solutions for locational problems involve the assessment of various sites based on some criteria involving environmental and/or socioeconomic factors (Qiu et al., 2014). Generally, there are three key steps involved in the process: (1) defining the problem and evaluation criteria, (2) selecting relevant factors, and (3) choosing an aggregation method (Bolstad, 2012; Mitchell, 2013). The third step typically involves comparing the attributes of the sites of interest in relation to the desirability criteria, generating commensurate suitability values/ratings for each factor, and aggregating ratings of individual factors into a composite suitability layer depicting suitable areas (Qiu et al., 2014).

There are several ways of executing the aggregation phase. They include the following popular traditional map overlay approaches: pass/fail screening (also called "Boolean or Binary Overlay"), index overlay, graduated screening and weighted linear combination (WLC) (Atkinson, 2005; Qiu et al., 2014). It is worthy to note that, these approaches essentially rely on cartographic modelling provisions, such as overlay and map algebra functions within many GIS software (Tomlin 1990; Bolstad, 2012; Esri, 2012(a)).

2.2.2.1 Traditional Map Overlay Approaches

The "Boolean Overlay" method is based on crisp Boolean logic whereby a strict binary (pass or fail) approach is used to model a problem (Atkinson, 2005; Qiu et al., 2014). It is considered the simplest and the most appealing aggregation approach to many decision makers due to its easy implementation and robust approach to handling projects that are restrictive in nature like landfills. However, it may not be applied in situations that do not require such mutual exclusivity. Also, it only works best for discrete phenomena. Cases involving continuous data which may require some sort of relativity or flexibility, need other approaches. Again, it falls short in accounting for trade-offs, and fails to compensate the poor performance of one factor with the good of another (Qiu et al., 2014).

Another approach is *graduated screening*. This approach unlike the previous one, represents relative suitability rankings. It is based on the evaluation of the lowest rating a location received after a review of all factors (Hall et al., 1992). Instead of using binary suitability values, this method utilizes ordinal measurements to support the ranking of suitability among alternative sites. Despite the use of ordinal ratings which allow relative suitability rankings here, the problem of exclusivity still exists. The only difference is that, single crisp boundaries are replaced here by multiple ones. Similarly, it does not account for tradeoff among different factors. (Qiu et al., 2014).

Weighted linear combination (WLC) is yet another method for modelling suitability. This method, however, does a better job in relative ranking than graduated screening. Besides, it also introduces weighting which accounts for relative importance of the selected factors to each other (Malczewski, 2000). Despite these advantages (allowing trade-offs and accounting for relative importance of factors), WLC is criticized as subjective in determining the weights (Malczewski, 2000). Also, one cannot determine the specific factors that contributed to the values of the final suitability output.

In addition to the above drawbacks, another challenge is the inability to model situations that incorporate some level of vagueness. Such problems are handled differently using a different approach and it is discussed as below.

2.2.2.2 Dealing with Uncertain Boundaries

Vague circumstances make it difficult to determine the boundary between suitable and not-suitable. These often involve factors that have continuous values such as elevation and distance (Mitchell, 2012). An effective way to handle such blurry situations is the application of fuzzy logic (Zadeh, 1965; Malczewski, 2006). Fuzzy logic was first conceived by Lotfi Zadeh (1965) to describe fuzzy sets; sets of objects with "a continuum of grades of membership" (pp. 339). As opposed to crisp Boolean sets; true (1) or false (0), membership in a fuzzy set is expressed on a continuous scale from 1 (full membership) to 0 (full non-membership) (Atkinson et al., 2005). In other words, belonging to a set is simply a matter of degree of likelihood and it is possible to assign multi-class membership for a single entity (Malczewski, 1999, 2006; Gorsevski, et al., 2006; Mitchell, 2012). As a result, it may be applied to any of the conventional measurement scales: categorical, ordinal, interval and ratio variables (Atkinson et al., 2005). This aspect of fuzzy logic makes it suitable for addressing issues of vague boundaries as well as edge effects that tend to arise during suitability analysis and other spatial modelling projects (Abrahart and Openshaw, 2000); in addition, it allows trade-offs among different factors.

Different fuzzy classes are used to define fuzzy memberships. A class defines "the relationship between the observed values and fuzzy membership values that capture the best understanding of the phenomenon" (Mitchell, 2013, pp. 133). Because it relies heavily on an analyst's views, some level of expert knowledge is required. Owing to these facts, this part of fuzzy analysis is considered crucial because the accuracy of the whole process basically depends on it. Some of the popular classes with their respective functions are identified in Table 2.3 below.

Table 2.3: Classes of fuzzy membership

Fuzzy Class	**Function**
Fuzzy Linear	Fuzzy membership is based on a linear transformation; maximum or minimum observed values increase or decrease at a constant rate.
Fuzzy Large	High observed values are assigned full membership. It requires a user-defined midpoint (0.5) and a spread value.
Fuzzy Small	Exact opposite of Fuzzy Large; low or small observed values are assigned full membership. It also requires a user-defined midpoint (0.5) and a spread value.
Fuzzy Gaussian	Fuzzy membership is based on a normal distribution centered on a user-defined midpoint. It also requires a user-defined spread value that defines the rate of decrease towards zero. Values around the midpoint get highest membership.
Fuzzy Near	Similar to Fuzzy Gaussian. The only distinction is that, the spread parameter here is narrower.

Source: Esri (2012b).

After defining the membership, another operator is used to combine all the output layers to produce a final composite surface. This step may be likened to generating a final suitability layer in suitability modelling (Mitchell, 2012). Common operators used include:

- *Fuzzy And* (produces minimum of input values); best for finding suitable locations that meet all the criteria.

- *Fuzzy Or* (produces maximum of input values); best for finding suitable locations that meet any one criteria.
- *Fuzzy Product* (generates product of input values); best for finding locations with relatively high suitability.

- *Fuzzy Sum* (returns a transformed sum of input values); best for finding all locations that have varying potential suitability.
- *Fuzzy Gamma* (returns compromised values between *Fuzzy Sum* and *Fuzzy Product*); best for finding suitable locations with respect to expert knowledge.

From the above descriptions, an analyst must be familiar with their data and objective of the project in order to make the right choice for an operator (Mitchell, 2013). Without a clear understanding of the input data, problems such as multicollinearity might arise. This is often associated with the "combine" operators (i.e. *Fuzzy Sum*, *Fuzzy Product* or *Fuzzy Gamma*). For example, a factor such as precipitation tends to correlate with vegetation and temperature. Thus, when these factors are combined using any of the "combine" operators in an analysis, the effect of precipitation is likely to be more pronounced than the rest. In such cases, Mitchell (2013) recommends that one uses either the logical operators of "And" or "Or".

Moreover, *Fuzzy Sum* and *Fuzzy Product* are associated with increasing and decreasing effects respectively on output values (Bonham-Carter, 1994; Atkinson et al., 2005). Such effects might exaggerate the results if most input values are very high (in the case of *Fuzzy Sum*) or underestimate if most input values have very low fuzzy values (in the case of *Fuzzy Product*) (Esri, 2012(c); Esri, 2012(d); Mitchell, 2013). To control such effects, Atkinson et al. (2005) observed the *Fuzzy Gamma* operator to be more appropriate due to its relative compromise appeal. Unlike the others, the gamma operator permits some flexibility and user control. Mitchell (2012) noted that, the gamma operator is helpful in fine-tuning the model as it provides the chance of review of the outcome and possible changes. The gamma operator is based on Equation 2.13.

$$\textit{Fuzzy}\ \gamma = (\text{Algebraic sum})^{g}\ (\text{Algebraic product})^{1-g}$$

(Equation 2.13)

where *Fuzzy* **γ** is *Fuzzy Gamma* and **g** is a parameter (real number ranging between 0 and 1) which is determined by the researcher. Where **g** = 1, the output equals that of algebraic sum; where **g** = 0, the output is the same as the algebraic product (Atkinson et al., 2005; Mitchell, 2012).

According to Atkinson et al. (2005), the **g** value is essentially dependent on the range of values within the input factors and goal of the research. Choosing a value without any regard to such parameters might adversely affect the outcome of the study (Atkinson et al., 2005). As a result, one needs to select a value that accounts for these issues. Nevertheless, Mitchell (2012) indicated that selecting a higher or lower **g** value will emphasize higher or lower values respectively. Considering these facts, a **g** value that best fits the objectives of the analysis must be selected.

The robust nature of fuzzy logic in effectively handling cases involving uncertain boundaries has attracted many analysts to employit for varied GIS projects, such as suitability modelling (Baja et al., 2002), “Least Cost Path” (LCP) analysis (Atkinson et al., 2005) and geological mineral exploration (Mitchell, 2012). Atkinson et al. (2005), for example combined fuzzy logic with the “Analytic Hierarchical Process” (AHP) as part of LCP modelling to determine a potential route for an Arctic all-weather road. Except for a few limitations such as issues of data availability and scale, they admitted that, their method was very effective and may be applied to similar routing applications elsewhere. Qiu et al. (2014) also applied fuzzy logic to the traditional overlay models to analyze the distribution of kudzu in the conterminous United States. In their application, they introduced continuous suitability membership grades for the selected environmental factors. To them, this approach proved to be more efficient as it provided better predictive accuracies than the conventional counterparts. In view of these positive responses and the general fit of the method for answering some of the research questions, fuzzy logic was considered ideal for this research and thus was utilized.

2.4 Improving Spatial Accessibility

2.4.1 Fundamental Considerations

Finding the ideal location for a specific social or economic purpose such as roads and markets can be a real challenge. The essential roles of social services and infrastructures include enhancing the welfare and livelihoods of citizens (Devkota, 2007; Olsson, 2009) and promoting economic growth (Nichols, 1969; Rodrigue et al., 2013). For a myriad of reasons that could influence where to place specific facilities, it is widely acknowledged that ensuring reliable public access overshadows most of such decisions (Chang, 2009; USDoT, 2012(a); Church and Murray, 2009).

Spatial accessibility is considered as the general standard for measuring the value of a location or infrastructure in public service delivery (Church and Murray, 2009). There are two key solutions recognized in the literature as necessary for improving accessibility: 1) development or improvement of transport infrastructure (Guimarfies and Uhl, 1997; Devkota, 2007; Porter, 2007; Olsson, 2009; Murawski and Church, 2009; Rodrigue et al., 2013), and 2), locating new facilities (Oppong and Hodgson, 1994; Hodgson et al., 1998; Naude et al., 1999; Møller-Jensen, and Kofie, 2001; Ahlström et al. 2011; Wong et al., 2012). Even though these solutions are often treated as mutually exclusive, Hodgson et al. (1998) suggested that, they must be considered together in order to ensure a comprehensive improvement of local spatial accessibility. For example, locating new health centers may not necessarily improve spatial accessibility to such social services. Similarly, Tighe (2006) observed that a simple investment in roads may have little impact on improving accessibility to local services. Hence, investment in road networks must be implemented "within the larger context of making services more accessible" (pp. 1). Thus, there is a need to explore the combining effects of both solutions towards the improvement of spatial accessibility.

2.4.2 Developing New Road Networks

The importance of transportation networks in the promotion of economic development is well established in the literature. Nichols (1969), for example attributed the rapid growth of USA since the 19^{th} centuries mostly to the development of efficient transport networks like canals, railways and roads. Regarding the importance of transportation in rural areas, USDoT (2012(b)) noted that, rural transportation generally enhances the quality of life of residents and contributes towards "regional economic growth and development by connecting business to customers, goods to markets, and tourists to destinations". Transportation networks essentially link rural areas to the outside world (USDoT, 2012(b)).

Among all transportation systems, the road system is regarded the most popular worldwide especially for short distance travels. Its popularity is attributed to the relatively low initial setup cost, high speed, and flexible routes (Rodrigue et al., 2013). In general, in planning rural road networks, some common questions include: 1) Is a road network the best option for improving access to services? 2) Which model of network best meets local needs for access? 3) What type of road is the most appropriate to the needs of the traffic using them? 4) What techniques of construction and maintenance are the most appropriate? and 5) How to ensure that knowledge and funds will be available to those who must manage and maintain them? (Donnges, 2001; Tighe, 2008; Donnges, 2003; USDoT, 2012(b)). Among these questions, this research focuses primarily on finding a network model that best improves spatial accessibility in Afram Plains.

2.3.2.1 Types of Network Models

One common and important goal in new road development is building least cost routes to connect separate locations (Zhan, 1997; Zhan and Noon, 1998; 2000; Shehzad and Shah, 2009). The term least cost, usually refers to the cheapest observed routes relative to a specified cost unit (Esri, 2011(b)). Some popular cost units include: travel distance, travel time or travel cost (Waugh, 2000; Chang, 2009; Herzog, 2013) and construction cost (Atkinson et al., 2005; Tighe, 2008). The identified cost units may seem different, but they tend to converge on a similar solution.

Based on the objective of least cost, different network models have been identified. They include (a) least-cost network to the user, (b) least-cost network to the builder, (c) Delauney triangulation networks, (d) Dendritic networks, and (e) Central point networks (Donnges, 2003; Tighe, 2008; Global Transport Knowledge Partnership (gTKP), 2009; Mission 2014, n.d.(b); Herzog, n.d.(b); 2013). However, they are sometimes broadly categorized as extensive or intensive models (Guimarfies and Uhl, 1997). These are illustrated by Figure 2.6 while a summary of their features is presented in Table 2.4.

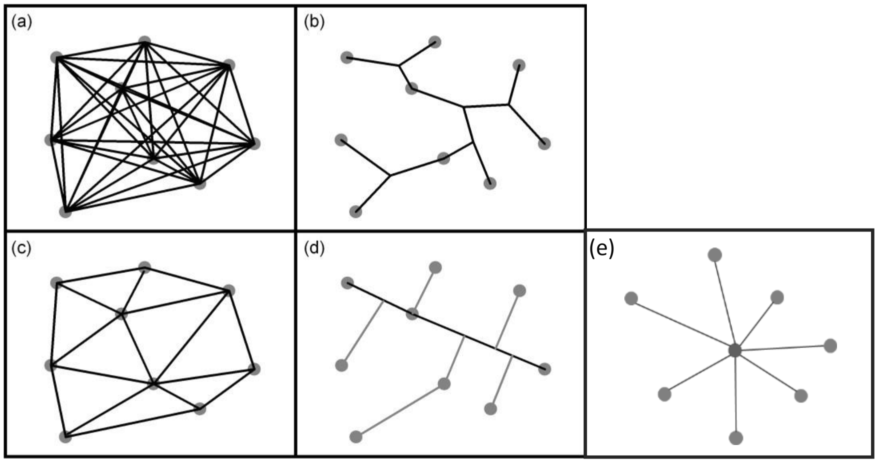

Figure 2.6: Road network models
Source: Herzog, 2013

Table 2.4: Summary of common network models

Model	Category	Description	Remark
(a) *Least-cost network to the user*	Intensive	Network connects each pair of sites in a region; the number of connections required has a quadratic growth rate.	Highly redundant and has no centrality.
(b) *Least-cost network to the builder*	Extensive	Networks connect all sites but minimize the total costs of route construction; all site locations must be known.	Common in areas with sparse population and in places where road construction costs are high; it has no centrality.
(c) *Delauney Triangulation Network*	Intensive	A heuristic based approach whereby network connects each site with its immediate neighbors thus creating triangular spaces.	Emphasizes interaction with immediate neighbors than distant locations; useful in maintaining supply of resources through intermediate stops. It does not account for centrality.
(d) *Dendritic Networks*	Extensive	Networks develop from a central line feature.	It accounts for centrality as well as later development of secondary networks from an original central line.
(e) *Central Point Networks*	Extensive	Networks spread from a single point feature	Maintains a high degree of centrality.

Source: Adapted from Herzog, n.d.(b); Herzog, 2013.

Generally, intensive network models tend to focus on developing sufficient roads in a region such that all neighboring settlements are interconnected (Guimarfies and Uhl, 1997). These models theoretically, are ideal for ensuring sustained local interaction and access to social facilities like markets, health centers and schools (Guimarfies and Uhl, 1997; Herzog (n.d). They are also known for fostering agricultural intensification, local trading and effective maintenance of infrastructure (Guimarfies and Uhl, 1997).

Notwithstanding, intensive models may be extremely expensive to implement. Also, they are comparatively less efficient due to the many presence of redundant networks in them. The redundancy also makes them intolerable in areas where large scale agriculture is practiced as they lead to partitioning of farmlands. Examples of such models include *least-cost network to the user* and *Delauney Triangulation*. The former is notorious for redundancy.

Extensive models on the other hand, focus on building trunk or major roads over longer distances (e.g. over 100 kilometers) across a region with the anticipation that arterial roads will be developed to connect nearby villages to it (Guimarfies and Uhl, 1997). Unlike intensive models, these models do not focus on ensuring sustained local interaction. Rather, they aim at regional interaction; a situation that may end up alienating some communities. Nevertheless, each community could still reach every community within the network (Herzog, n.d.(b)). In addition, such networks might be environmentally costly as long strips of vegetation would have to be cleared prior to developing them. Due to their very nature, they tend to solicit very little engagement. Thus, regular maintenance is often neglected making their rate of deterioration comparatively greater (Guimarfies and Uhl, 1997). Nevertheless, their emphasis on centrality makes them considerably suitable for areas with sparse and scattered population. In such instance, it is fair to the many scattered communities to have one main central road leading to the major town which they can join through a subsidiary road (Herzog, n.d.(b)); a common phenomenon in in rural SSA (Tighe, 2008). Also, they barely have no redundant networks and hence, are very efficient and cost effective. The most typical form of this model is the *Dendritic* model. The *Dendritic* model usually has arterial roads joining the trunk road in right angles. Others include *Least-cost network to the builder* and *Central Point Network*.

Having recognized the major network models, the next important thing is to make a choice. According to Herzog (n.d.(b)), this must be done with respect to the physical, social and historical conditions pertaining to the targeted area. She cites road systems used by different civilizations to back her claim, andnotes that: 1) Californian Native American roads were related to the model of the least-cost network to the user, 2) German roads followed a Delauney Triangulation format, 3) Roman roads had a Dendritic network style, while 4) the English usedmore of the Central Point networks. As noted earlier, each network model has unique benefits, yet, not every network may suit every location or situation. Thus, understanding context is necessary for selecting a suitable model.

In rural SSA, due to pervasive poverty and high usage of non-motorized modes of transport, many scholars acknowledge that, it is best to implement a road network model that helps ensure that majority of rural residents are within a reasonable walking distance (as defined by the country) from a motorable road (Donnges, 2003; Tighe, 2008; gTKP, 2009). In relation to that, Tighe (2008) suggested a model called *core network model*, a basic road network that incorporates various levels of networks such as paths, tracks and earth roads. It also connects to a higher-level network as well as all major local hubs of activity. The lower networks are vital as they allow most residents who cannot afford motorized services to access their destinations via IMTs. Owning to that, a neglect of lower networks for higher level networks would likely not improve the spatial access of most people in the area. The linking of major local hubs also assures sustainability as it encourages community involvement. However, an ideal core network cannot be overly extensive, else it cannot be maintained due to the lack of resources in most rural areas (Tighe, 2008; Donnges, 2001; 2003).

In view of the complex conditions in Afram Plains, an ideal network model for rural development must consider the sparse distribution of communities, varied transport modes and periodicity of markets. As a result, some modelling procedure will be required to maximize the outcome based on multiple criteria. The following sections identify some of these techniques.

2.3.2.2 Selecting an Algorithm for Implementing Network Models

Various algorithms are used to implement network models. These are categorized into two main classes: exact and heuristic algorithms (Sanders, 2007; Church and Murray 2009). Exact algorithms guarantee the absolute best solution, provided the problem is bounded by some pre-defined criteria and logic (Sanders, 2007). However, such algorithms are limited to the size or nature of a problem; usually, they cannot handle very large or complex problems. Common examples of exact algorithm include *Dijkstra shortest path* (least-cost) algorithm and linear programming (Church and Murray, 2009).

Heuristic algorithms on the other hand are primarily based on “best practice” or rules of thumb (Sanders, 2007; Arifin, 2010). As a result, they are generally acknowledged as algorithms which can provide decent or near optimal solutions but do not guarantee absolute ideal solutions (Church and Murray, 2009). Nonetheless, unlike exact algorithms, heuristic algorithms are considered as both cost effective and time efficient, as they are relatively cheaper and are able to handle very large and complex problems within a limited time (Church and Murray, 2009). Thus, many complex spatial problems such as, location allocation problems which are described as *"Non-Deterministic Polynomial time* (NP) hard" (computer intensive), tend to rely on heuristic methods (Alp et al., 2003; Arifin, 2011). Typical examples of heuristic algorithms include genetic algorithms and simulated annealing (Sanders, 2007; Church and Murray, 2009; Davari et al., 2011).

The next section describes an exact method called Least Cost Path (LCP) Analysis and explains how it is relevant to this research.LCP modelling (also called shortest path analysis) is a popular route planning approach (Saha et al., 2005; Atkinson et al., 2005; Zeng and Church, 2009). It basically finds paths with the minimum cost from an origin to one or more destinations over a landscape of impedances (Chang, 2009). LCP modelling acknowledges that, in reality, landscapes are not homogenous; they often contain various impedances that constrain movement. As a result, in LCP modelling, various friction or cost factors pertaining to an area of interest are first determined and modeled into an accumulated cost surface. This surface defines the cost of movement from a source location to a specified destination (Collischonn and Pilar, 2000; Chang, 2009; Esri, 2011(b)).

To predict the optimal path from the accumulated cost surface, different LCP algorithms are used. The famous one is the Dijkstra's algorithm, an exact approach (Zhan, and Noon 1998; Collischonn and Pilar, 2000; Zeng and Church, 2009; Mitchell, 2012). Other known algorithms include the G Route and A*(Eh Star) (Zhan, 1997; Saha et al., 2005). The Dijkstra algorithm was "designed for tracing the shortest path in a network with nodes connected by weighted links" (Yu et al., 2003, pp. 362). It strictly requires positive weight values to function (Herzog, 2013). The Dijkstra algorithm uses a 3 x 3 roving window or a *queen pattern window* in searching for the next cell to link to (Dijkstra, 1959; Yu et al., 2003). Since the queen pattern has only 8 neighborhood directions, a node may only be linked to one of its immediate neighbors. Thus, the least cost path is identified by linking neighboring cells that have the least weights or values (Collischonn and Pilar, 2000; Mitchell, 2012). This is however based on the assumption that the accumulated surface is isotropic (Yu et al., 2003).

The popularity of Dijkstra's algorithm for route planning has soared with the advent of GIS software such as ArcGIS (Chang, 2009). For example, it has been used to predict an all-weather road network in an ecologically-vulnerable area in northern Canada (Atkinson et al., 2005). It has also been incorporated with multi-criteria techniques to determine new least susceptible roads in a landslide prone area in the Himalayas (Saha et al., 2005). Yet, the efficiency of the Dijkstra algorithm has been challenged. As an exact algorithm, it has been criticized for its inept handling of larger dataset (Gonen, n.d). As a result, other approaches such as genetic algorithm have been explored to improve performance of the Dijkstra algorithm (Qishi and Shan, 2000; Li and Yeh, 2005; Sasaki, et al., 2010). In this research, however, these issues were not of major concern due to the relatively small size of source-destination combinations. Thus, the Dijkstra algorithm was adopted in this research in conjunction with a multi-criteria technique.

2.4.3 Locating New Market Centers

2.4.3.1 The Concept of Location Allocation

Besides building new roads, spatial accessibility to social facilities can also be improved if the number of the facilities is increased (Hodgson et al., 1998; Naude et al., 2009). Naude et al. (2009), for example, found that increasing the number of local markets would improve residents' accessibility to tourist markets than adding a new road in their study in South Africa. Nonetheless, identifying the most ideal location for any new service can be quite challenging (Sanders, 2007). In the developing world, often times, decisions concerning ideal locations are influenced by partisan politics which do not necessarily produce effective results (Tewari, 1992; Porter, 2007). However, Devkota (2007) acknowledged that the application of sound planning principles and spatial modelling in such decisions is necessary and effective.

The planning and modelling process notwithstanding, can be puzzling. It is so because, they incorporate several procedures, such as identification of the needs, prioritization of interventions, funding for the facilities, organization and control of service providers, the arbitrage between users, and the impact on the physical environment (Sanders, 2007). For instance, an analyst must ensure that any identified suitable site meets a fair share of local demand (Naude et al., 2009). In other words, what is the spatial adequacy between demand and supply? (Sanders, 2007). As fiscal resources are often scarce, it is important for decision makers to have a clear understanding of existing needs and available supply in order to locate and allocate new facilities efficiently (Sanders, 2007; Olsson, 2009; Gibson et al., 2010; Ahlström et al., 2011). Understanding the nature of local demand helps to ensure spatial equityas well as meeting the needs of the poor and the underprivileged (Apparicio and Seguin, 2005; Omer, 2006). The above issues collectively border on the concept of location-allocation (LA).

The concept of location-allocation is a combination of two terms: location and allocation. The first term location, in this context refers to finding the ideal site for a specific facility, service or purpose (Chang, 2009; Mitchell, 2012). The second term allocation, refers to the process of determining who is served by which facility or service (Church and Murray, 2009). In light of the two terms, location-allocation is defined as a systematic process of determining optimal sites for multiple facilities and assigning demand to them such that every demand is served in the most efficient way (Devkota, 2007; Church and Murray, 2009). LA is based on the third law of location science: "sites of an optimal multisite pattern must be selected simultaneously rather than independently" (Church and Murray, 2009). The basic requirements for modelling such problems include the facilities to be located (supply centers), demand centers (might be points or centroids of polygons depending on data type, quality and level of spatial aggregation) and distance measures (might be network or Euclidean distance, travel time or travel cost) (Sanders, 2007; Chang, 2009).

2.4.3.2 Location Allocation Problems

There are different kinds of models with varying objectives and degrees of efficiency for solving location allocation problems, including: Location Set Covering Problem (LSCP), Maximal Covering Location Problem (MCLP)), and P-Median Problem (PMP). However, over time, due to certain limitations and changing demands, variants of these models have emerged, thereby expanding the scope of LA models (Church and Murray, 2009).

Furthermore, a variety of algorithms including exact, heuristic and metaheuristic methods have been used in solving or implementing these problem models (Correa et al., 2004; Davari et al., 2011; Yaghini et al., 2013). Nevertheless, due to the complex nature of most LA problems (e.g. combinatorial optimization issues), heuristics and metaheuristics are preferred for implementing LA models than exact methods. Heuristics, compared to exact or exhaustive techniques have the capacity to handle combinatorial issues effectively (Esri, 2013). In general, heuristics have been proven to be faster and simpler in yielding results (Alp et al., 2003; Correa et al., 2004). Alp et al. (2003), for example remarked that their novel Genetic Algorithm (GA) technique applied in solving a P-Median produced near optimal results; 85 percent of generated solutions were within 0.1 percent of the optimum with the worst solution being only 0.41 percent away from the optimum within a relatively shorter time.

GA is the commonly used heuristic method in LA modelling (Reese, 2006). Other notable heuristic algorithms include “Simulated Annealing” (Arifin, 2011); column generation (Lorena and Senne, 2004), a hybrid intelligent algorithm (based on GA, a Simplex method and fuzzy simulation) (Mousavi and Niaki, 2013), and a hybridized method of local branching and relaxation induced neighborhood search methods (Yaghini et al., 2013). The following sections briefly describe the notable LA problems, their formulation and some practical cases in which they have been applied.

a. The Location Set Covering Problem (LSCP):

The LSCP was first introduced by Toregas et al. (1971). Its main goal is to minimize the number of facilities needed to cover all demand within a specified area (ReVelle et al., 1976). The optimal solution here guarantees that only the necessary number of facilities covering all demand is selected hence, eliminates redundancy. Nevertheless, it is limited in many aspects like allocation of demand, accounting for capacity and cost of building as well as budgetary constraints. Thus, it cannot be applied to many other real world cases like the problem at hand in this research. LSCP is mathematically stated as:

$$Minimize \sum_{j=1}^{m} X_j$$

(Equation 2.14)

Subject to these constraints:

$$\sum_{j=1}^{m} a_{ij} X_j \geq 1 \text{ for each } i = 1, 2 \ldots n \text{ and } j = 1, 2 \ldots m$$

$X_j = \{0, 1\}$ for each i = 1, 2,…,n

where *j* is index of potential facility sites so that j = 1, 2,…..m, *i* is index of demand centers where i = 1,2,…..n, d_{ij} is the shortest distance between a demand center *i* and a potential facility site *j* and a_i is the amount of demand at demand center *i*

$$a_{ij} \begin{cases} 1 & \text{if facility located at site j covers demand unit i} \\ 0 & \text{Otherwise} \end{cases}$$

$$X_j \begin{cases} 1 & \text{if a facility is located at potential site j} \\ 0 & \text{Otherwise} \end{cases}$$

b. The Maximal Covering Location Problem (MCLP):

MCLP was developed purposely to cater for situations whereby the number of facilities to be located is constrained by budget, but a large demand coverage is desired (Church and ReVelle 1974; ReVelle et al., 2008). Unlike LSCP, MCLP enhances coverage from limited available resources. It is therefore preferred in instances where budgetary constraints restrict the development of enough facilities to cover all demand (Chang, 2009; Davari et al., 2011). In line with that, MCLP is always subject to a predefined number of facilities ***p***, to be developed (as allowed by budget) (ReVelle, and Hogan, 1989; Church and Murray, 2009). Due to such restriction, MCLP does not guarantee total service coverage (Church and Murray, 2009). Besides, at times, an analyst may impose some form of restriction on MCLP to ensure that it conforms to an expected goal. For instance, a preferred distance or time limit can be prescribed so that the model, while maximizing coverage, will also ensure that all covered demand are within the imposed constraint (Wang, 2006; Chang, 2009). MCLP is popularly used in locating public services like emergency services, movie theatres, and fast-food restaurants (Chang, 2009). Despite its usefulness, MCLP does not guarantee coverage, cost efficiency in travelling and cannot allocate demand. It is formulated as:

$$Maximize \sum_{i=1}^{n} g_i Y_i \quad \text{(Equation 2.15)}$$

The model is subject to the following conditions:

$$\sum_{j=1}^{m} X_j \geq Y_i \quad \text{for each } i=1, 2\ldots n$$

$$\sum X_j = p$$

X_j={0, 1} for each j=1,2…m

Y_i={0, 1} for each i=1,2…n

where: g_i is the service demand in unit i = 1, 2…n, p is the number of facilities to locate,

$$Y_i \begin{cases} 1 \text{ if unit i is covered by at least one facility} \\ 0 \text{ Otherwise} \end{cases}$$

and $$X_j \begin{cases} 1 \text{ if a facility is allocated to site j} \\ 0 \text{ Otherwise} \end{cases}$$

c. The Minimum Distance Problem (P-Median / PMP):

There are also situations where a local area working with a fixed budget may not be so interested in only maximizing coverage but also ensuring that overall travel impedance incurred by the public towards reaching facilities is minimized. Such problems are effectively handled by the model popularly called the P-Median (or K-Median) (Hakimi, 1964; ReVelle and Swain, 1970). The P-Median is the most popular among all LA problems (Correa et al., 2004; Yaghini et al., 2013). It is particularly famous for planning public services like libraries and health facilities (Chang, 2009).

Unlike the previous models, the P-Median is used specifically for locating facilities and allocating demand to the facilities[1] simultaneously (Sanders, 2007). Essentially, it is an extension of Alfred Weber's theory; selecting a median (ideal location) from multiple medians (Cooper, 1963; Arifin, 2010). The P-Median effectively resolves a critical problem of the conventional MCLP: the inability to equitably locate facilities since some people end up undertaking unfairly long journey to a facility than

[1] Allocation is to the nearest facility based on the assumption that each customer is served by the closest facility.

others (Mitchell, 2012). With its primary goal being minimizing overall cost, P-Median addresses this problem (Sanders, 2007).

As noted already, it is often assumed that, consumers visit the nearest facility. However, in reality, certain factors like product variety may influence consumers to choose or ignore the nearest facility (Arifin, 2010). Yet, in cases where the facility is large enough, it is expected that such needs will be catered for (Berry et al., 1988). Based on such assumption, P-Median starts with determining the amount of demand and travel impedance between each demand area and their closest facility (Mitchell, 2012). The demand for each facility is then multiplied by the total impedance to the facility (from all the allocated demands) (Equation 2.16). The resultant value represents the facility's level of cost efficiency (Church and Murray, 2009). These values are then summed up for all facilities across all demand areas. The facilities with the least values are subsequently selected as the optimal sites (Church and Murray, 2009; Mitchell, 2012). Equation 2.17 shows the overall formula for the model.

$$a_i d_{ij} Y_{ij} \qquad \text{(Equation 2.16)}$$

$$Minimize \sum_{i=1}^{n} \sum_{j=1}^{m} a_i d_{ij} \, Y_{ij} \qquad \text{(Equation 2.17)}$$

The formula is subject to the following constraints:

$$\sum_{j=1}^{m} Y_{ij}=1 \quad \text{for each } i=1, 2\ldots n$$

$$Y_{ij} \leq X_j \quad \text{for each } i=1, 2\ldots n \text{ and } j=1, 2\ldots m$$

$$\sum_{j=1}^{m} X_j=p$$

X_j ={0, 1} for each i=1, 2…, m

Y_{ij}={0, 1} for each i=1, 2…n and j=1, 2…m

where *i* is index of demand centers where *i* = 1, 2,...*n, j* is index of potential facility sites where *j* = 1, 2,…..*n*, d_{ij} is the shortest distance between a demand center *i* and a potential facility site j, a_i is the amount of demand at demand center *i*, *p* is the number of facilities allowed by budget to be developed or located. X_j will be valued at **1** if facility at site j is located and **0** if otherwise. Similarly, Y_{ij} *valued* at **1** if demand arising at demand center *i* is covered by facility *j* and **0** if otherwise.

In spite of the general popularity of the conventional P-Median in service planning, the model has been criticized as inadequate for certain tasks. For example, it does not address issues of capacity and possible constraints on individuals' movement such as travel time threshold (Wang, 2006; Chang, 2009). As a result, several variants of the P-Median have been developed to address such limitations and enhance its usefulness. One of such variants relevant to this study is discussed below.

d. Capacitated P-Median Problem (CPMP):

As noted above, the ordinary P-Median does not account for capacity; it assumes that each facility will have the capacity to handle the demand which is assigned to it. Also, it neglects another key element: the factor of variable cost of building facilities. In reality, location tend to influence the cost of facilities thus, building cost cannot be assumed as simply ubiquitous as in the case of the P-Median. Owning to these limitations, the *"Capacitated P-Median"* was introduced. This variant of P-Median is applied to problems popularly called the fixed charge capacitated location allocation problem (Church and Murray, 2009). With the CPMP, a candidate facility has a fixed service capacity (a maximum number of demand centers it can serve) and cannot exceed it (Correa et al., 2004; Lorenaa and Senne, 2004). When a facility exceeds its capacity, the response is either to expand or locate a new one. It also accounts for all costs associated with the siting of a new facility and shipment to customers. (Church and Murray, 2009). Below is the mathematical formula for the CPMP:

$$\text{Minimize} \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij} Z_{ij} + \sum_{j=1}^{m} f_j X_j$$

(Equation 2.18)

The model is subject to the following constraints:

$$\sum_{j=1}^{m} Z_{ij} = a_i \quad \text{for each } i=1, 2\ldots n$$

$$\sum_{j=1}^{n} Z_{ij} \leq b_j X_j \quad \text{for each } j=1, 2\ldots m$$

$$X_j = \{0, 1\} \quad \text{for each } i=1, 2\ldots, m$$

$$Z_{ij} \geq 0 \quad \text{for each } i=1, 2\ldots n \text{ and } j=1, 2\ldots m$$

Where i is index of demand centers such that $i = 1,2,\ldots..n$, j is index of potential facility sites where $j = 1,2,\ldots..n$, a_i is the amount of demand at demand center i, c_{ij} is the cost per unit to ship from supply center j to demand center i, f_j is the fixed cost to build a facility at supply center j and b_j is the capacity of facility at supply center j. X_j equals to **1** if facility at supply center j is located and **0** if otherwise; and Z_{ij} is the amount of demand i served by facility at supply center j.

CPMP has very practical implications. Correa et al. (2004) for example, applied it to locate examination centers in the city of Curitiba, Brazil. They devised a new GA: a combination of traditional genetic operators and a new heuristic “hypermutation” operator to solve their problem. Their approach proved efficient in locating 26 facilities out of 43 possible ones and assigned 19710 students to them such that the overall distance between students’ home and a facility was minimized. In this research, the author explored the strengths of CPMP, PMP and MCLP and adapted them to create a new LA model used for locating new market centers and allocating demand to them. It is worthy to note that, prior to applying any LA model, it is assumed that ideal areas where the facilities could be located had been identified using similar suitability analysis (Church and Murray, 2009) techniques as noted in section 2.2.2. In this study, WLC was applied towards finding suitable locations for new market facilities.

3. METHODOLOGY

The primary purpose of this research was first, to model spatial accessibility of residents in the Afram Plains to market centers based on a multi-mode transportation system. The second aspect was to explore an efficient solution to the spatial accessibility problem above. The solution included new road networks and/or market centers. This section describes the study area and discusses the methods used in addressing the problem.

3.1 Study Area

3.1.1 Precincts

The Afram Plains area (now divided into two districts: Kwahu Afram Plains North and Kwahu Afram Plains South) is located in the northern part of the Eastern Region of Ghana between latitudes 6º 33' N and 7º 12' N and longitudes 0º 15' E and 0º 45' W. It occupies a total area of approximately 5,300 km^2 (solid areas constitute about 3,752 km^2), and shares a boundary with the following districts: Sekyere Afram Plains to the North West and West, Kwahu East to the South West, Kwahu South to the South, Kpando to the East, and Sene and Atebubu districts to the North. There are over 300 towns, villages and hamlets in the district. Donkorkrom and Maame Krobo are the major towns; the former is the largest town in terms of size and population while the latter hosts the largest market center in the area. Figures 3.1 and 3.2 show the location and some of the geographic features.

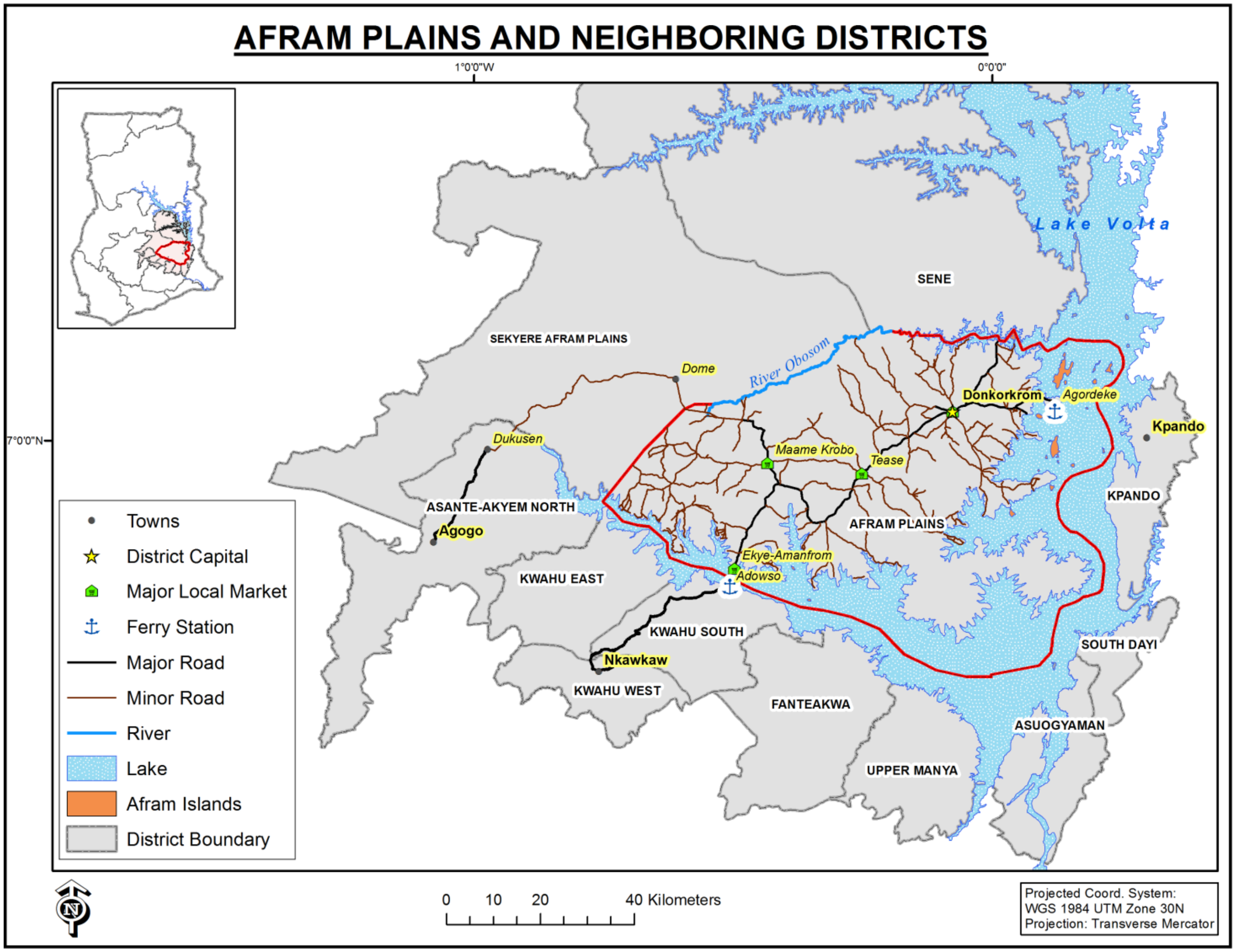

Figure 3.1: Study area

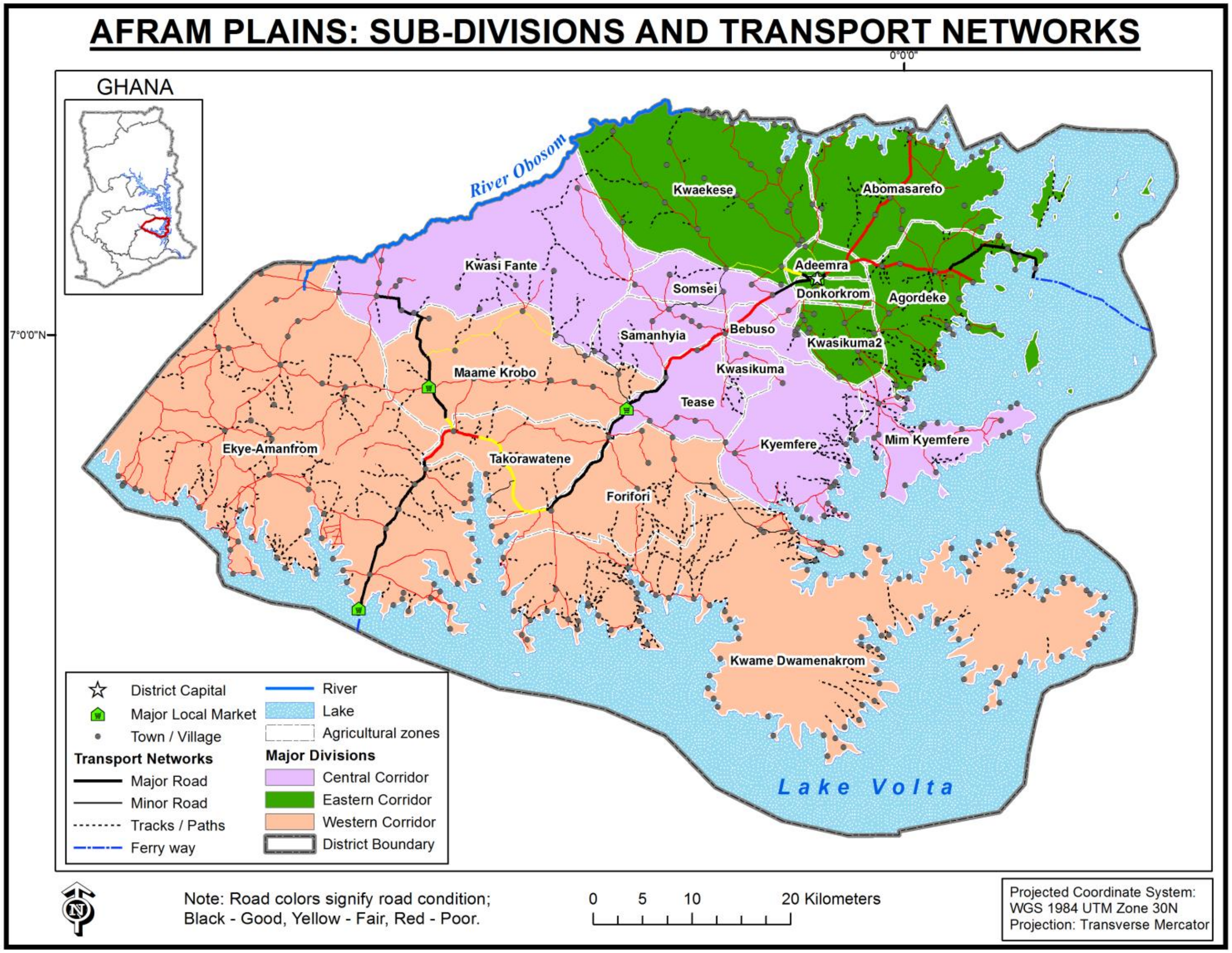

Figure 3.2: Sub-divisions and transport networks in Afram Plains

3.1.2 Physical Landscape

The Afram Plains, as the name suggests, is predominantly flat with the highest point reaching about 122 meters above sea level (Ghana District News, 2010). The area is drained by several water bodies, such as the Afram and Obosom rivers and Lake Volta. The drainage system contributes to the virtual isolation and poor spatial accessibility of the area (APCAP, 2010(a)). Regarding soils, there are 15 distinct soil types in the area. Generally, all the soil types are fertile and can support a wide range of crop farming. Yet, the dominant one, Haplic luvisols (40 percent), is known to be best for crop farming. Soil quality thus, is not a challenge to agriculture in the area (MOFA, 2013).

The area experiences two distinct seasons in a year: the wet (rainy) and dry seasons. The wet season occurs mainly between April and mid-July, but also in the months of September and October. The first period of the wet season records over three-quarters of the total annual rainfall and the highest mean monthly precipitation; 385mm (APCAP, 2010(a); MOFA, 2013). Incidents like flooded farmlands and blocked farm to market roads normally occur during this time. The second period though is mild; it is characterized by moderate rains and least disruptions to farming activities. As a result, it is the preferred season for farmers as it allows them to achieve greater yields and profits (MOFA, 2013). Following the wet season is a long dry season which begins in November and usually ends in March. The dry season is characterized by “Harmattan” weather; a very dry, hazy, dusty and drought-prone weather (APCAP, 2010(a); MOFA, 2013). Both the warmest (February/March ≈ 37^{o}C [98^{o}F]) and coolest (December/January ≈ 20^{o}C [68^{o}F]) monthly temperatures are recorded during this period. The lowest mean monthly precipitation (0mm) is also recorded at this time. (APCAP, 2010(a); KNDA, 2013). The dry season is noted to be a period where many residents suffer severe hardships in the form of famine and water scarcity. But, spatial accessibility during this time is considerably better than the wet season due to the dry road conditions (APCAP, 2010(a)).

3.1.3 Demographics

According to Ghana's 2010 Population and Housing Census, the population in Afram Plains increased from 135,928 in 2000 to 218,235 in 2010, representing a 61 percent change and a growth rate of 4.85 within the ten-year period (Ghana Statistical Service (GSS), 2011). The population density is about 41 persons/km^2 overall but, considering only dry land, it is approximately 58 persons/km^2.

Due to the influx of male economic immigrants from other parts of the country, the Afram Plains is dominated by males; 53 percent (Ghana District News, 2010). Majority of the population are in the active labor force group: 15-64 years (53.3 percent) followed by the young dependent group: 0-14 years (43.5 percent)[2]. The population is largely rural (80.4 precent). The average household size is about 4.7 (GSS, 2011). Population distribution is disproportional among the communities; about 20 in the hamlets and over 10,000 in the large towns like Donkorkrom and Maame Krobo.

3.1.4 Economy

3.1.4.1 Economic Activities

Agriculture remains the predominant form of employment and is also the main source of livelihood in the area. It accounts for about 80 percent of the employed labor force; 87.2 percent of that are subsistence farmers and the rest, agro-industry or

[2] A fairly large younger population indicates, a promising future labor force.

commercial farmers (MOFA, 2013). Moreover, agriculture in the area is categorized as crop farming, animal husbandry and mixed farming (a combination of crop farming and animal husbandry). Some limited fishing activities also take place especially along the Volta Lake. Crop farming with emphasis on food crop production is common (94 precent).

Even though subsistence farming is popular in the area, in recent years, due to steady improvement in agro-production (Figure 3.3), commercialization and cash crops are becoming popular practices as well. Common cash crops cultivated in the area include cocoa, cashew, citrus and oil palm. Table 3.1 shows the top ten crops and the areas under cultivation in the area. Current farm size varies between 2 and 200 acres. Regarding animal husbandry, it is mostly done as a supplement to crop farming. Common domestic animals include, local fowls, cattle, goats and sheep (MOFA, 2013). The Ministry of Food and Agriculture of Ghana administers agriculture in the area according to agricultural zones; currently, there are 20 zones, including the Dome agro-zone.

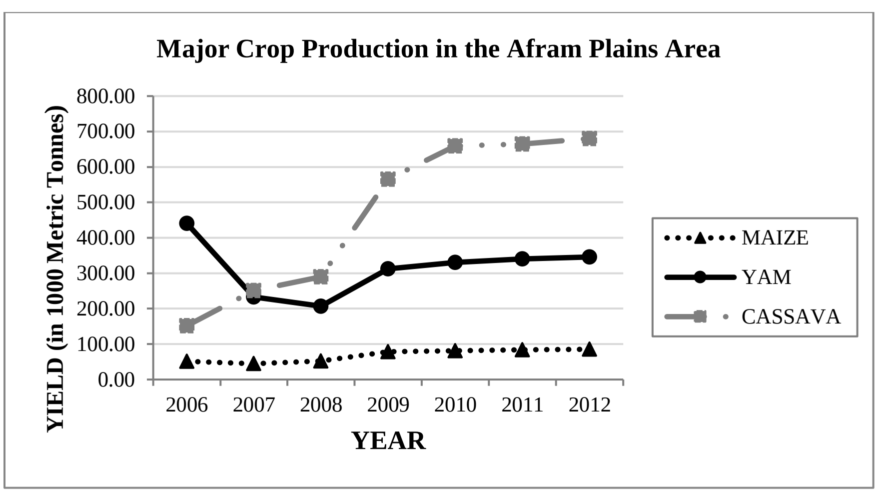

Figure 3.3: Production of major crops

3.1.4.2 Market

Markets in the Afram Plains are all periodic. There are four major market centers in the Afram Plains. In order of size, they comprise Maame Krobo, Donkorkrom, Ekye Amanfrom and Tease markets (Figures 3.1 and 3.2). Maame Krobo market is noted for trade in yam and maize. All the markets attract traders from all over the country and even beyond the borders of Ghana (KNDA, 2013; MOFA, 2013).

Table 3.1: Major crop production

Type of Crop	**Area under cultivation (in hectares)**
Maize	31,086.5
Yam	22,041.0
Cassava	11,233.8
Cowpea	6,517.6
Groundnut	6,414.8
Oil Palm*	5,075.0
Cashew*	3,002.0
Pepper	2,085.6
Plantain	458.2
Citrus*	281.2
Total	**88,195.7**

Source: MOFA (2013). ** Cash crops*

3.1.5 Transportation and Spatial Accessibility

Some aspects of spatial accessibility and transportation in the area have been highlighted in previous sections. For example, it was noted that, by virtue of its geography, spatial accessibility to and within the Afram Plains, is constrained. The main access to the area currently, is a three-kilometer ferry journey across the Volta Lake from Adawso to Ekye-Amanfrom (APCAP, 2010(b)). Another entry point (also by ferry) is a two-hour journey (approximately 33 kilometers or 18 nautical miles) across the Volta Lake from Kpandu-Torkor in the Volta Region to Agordeke. Figure 3.1 shows these entry points. The ferries are operated by the Volta Lake Transport Company (VLTC). Private entities also provide water transport services via canoes (Figure 3.4). Presently, the only entry by land is a 120 kilometer route from Agogo via Dukunsen to Maame Krobo in the north-western section of the area. The current condition of this route discourages automobile users from using it. Consequently, it is admitted that there is essentially no access road to Afram Plains from surrounding regions (APCAP, 2010(b); APCAP, 2010(d)). This entry route is however earmarked for future construction.

Figure 3.4: Canoe operators

Figure 3.5: Section of main trunk road

Furthermore, out of 690 kilometers paved roads within the area, only 39 percent are considered motorable all year round (APCAP, 2010(b); MOFA, 2013). There is only one major road in the area stretching for a distance of 100 kilometers from Ekye Amanfrom to Agordeke (Figures 1.2 and 3.2). While sections of this road are improved with asphalt, the remainder are "dirt" or feeder roads (Figures 3.2 and 3.5). Unlike concrete or asphalt coated roads, the latter ones are susceptible to erosion, and hence deteriorate faster (Figure 3.6). Even worse, there are "island communities" within the area that are virtually cut off or not linked by roads (Figure 3.1).

Figure 3.6: A section of Donkorkrom-Kwaekese road

Due to such limited spatial access, the economic potential of the area remains virtually untapped. Despite recent increase in agriculture production, it has yet to reach its optimum (MOFA, 2013). Currently, the majority of farmers are over 7 kilometers away from the nearest motorable road (APCAP, 2010(b); MOFA, 2013). This impedes efforts in visiting a market to sell their products; a situation partly blamed for significant post-harvest losses recorded in the area (APCAP, 2010(b)). The situation also affects residents' access to other social facilities such as, health centers, schools, credit facilities, and agricultural extension services. These in turn negatively affect agriculture and other economic activities and hence limit the economic development of the area.

3.2 Research Design

3.2.1 Research Approach

To assess current spatial accessibility to market in the Afram Plains, an embedded design (Greene, 2007; Creswell and Plano Clark, 2011; Creswell, 2014) was adopted for this study. The embedded approach is a mixed-method design where the researcher "combines the collection and analysis of both quantitative and qualitative data within a traditional quantitative or qualitative research design" (Creswell and Plano Clark, 2011;

pp. 90). The purpose of this design was to ensure that all research questions were answered adequately, as in some situations, a single dataset is insufficient to provide adequate answers and thus needs to be supported with other dataset. This research mainly applied quantitative methods to assess spatial accessibility but was supplemented by qualitative data acquired from personal interviews. The qualitative data provided insights and in-depth explanations for some of the research questions. Also, due to certain limitations in either the quantitative or qualitative dataset (e.g. incompleteness) used in this research, the embedded mixed method approach provided the right balance and thus, was deemed appropriate for this study (Figure 3.7).

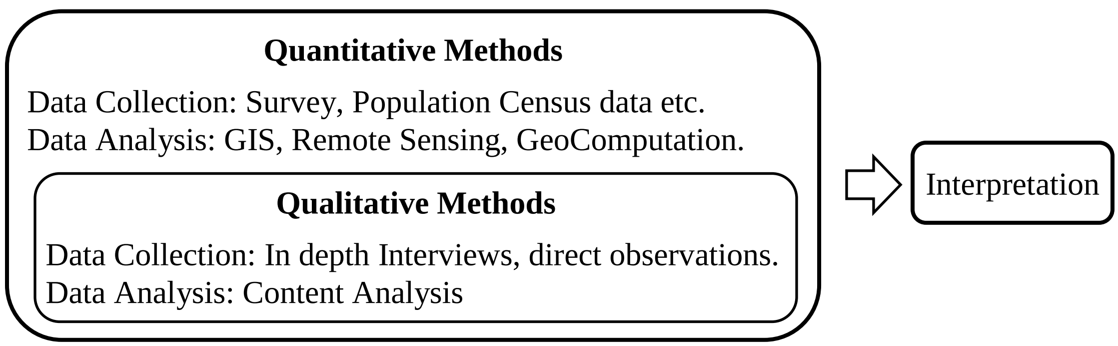

Figure 3.7: Embedded research design
Source: Adapted from Creswell (2014)

In embedded designs, the collection and analysis of a supplementary dataset (in this case the interview data) may occur before, during, and/or after the implementation of the principal dataset. The decision depends on the intent for incorporating and utilizing the supplementary data (Creswell et al., 2003; Creswell and Plano Clark, 2011). Common reasons for employing the embedded approach include the need for: 1) preliminary results before the principal stage (before/sequential), 2) a comprehensive understanding of the process (during/concurrent), and 3) a follow-up explanation after the principal stage (after/sequential) (Creswell and Plano Clark, 2011). In this research, the concurrent method was adopted. The principal dataset was largely quantitative analysed using GIS and statistics. The supplementary dataset on the other hand involved interviews, direct observation, and participatory research concerning spatial accessibility in the area. This information was used in determining weights for relevant factors when assessing ideal locations for new roads and new markets.

3.2.2 Data

3.2.2.1 Survey and Interview Data

In addition to the primary quantitative analysis, a survey was developed to gather the supplementary data. A survey questionnaire was created and implemented to provide data for additional understanding of the human experience in trying to reach markets. The quantitative data collected by survey instrument accounted for variables, such as a resident's traveling experience to a market in terms of metrics like total travel time and average number of trips in a week to a market. Thesurvey instrument also included open-ended questions to acquire qualitative data, that is, "worded" data, and/or subjective opinions. These questions sought in-depth information such as a brief description of the journey to market.

Using a stratified random sampling approach, a total of 202 households were sampled out of 378 "recognized communities"[3] with population ranging between 20 and over 10,000 and spreading over 19 agricultural zones[4] in the Afram Plains. In Ghana, the smallest geographic unit for collecting population data is the community; this is

[3] Communities that were identified and digitized as GIS data points.
[4] The 19 agricultural zones exclude the Dome agro-zone which was considered a satellite zone during the time of data collection.

equivalent to towns or cites in the USA. To ensure sampling representativeness, the sampling was stratified among the top 20 largest (population) communities across the 19 agricultural zones. Using population size as weights, the proportionate sample size of each community was determined.

A travel grant obtained from the West African Research Association (WARA) allowed the researcher to visit the study area to conduct the in-person survey. The survey was aimed at heads of households. In the absence of the head of household, the spouse or next available adult household member (over 18 years old) was recruited. Each respondent was recruited after they had voluntarily given their consent to participate in the survey. The survey questionnaire was structured into different sections covering the following topics: accessibility in the area, estimating economic potential, improving accessibility, and demographic and socio-economic factors of the household of the respondent (Appendix A). Tables 3.2 and 3.3 below show a breakdown of the characteristics of all the respondents.

In addition to the survey, the author also conducted personal interviews with one opinion leader (a council member), four transport operators, and two local government officials in the study area to askfor their opinions about the state of spatial accessibility in the area. The interviews consisted of the following questions: the main social and physical factors that hindered transport development in the area, potential locations for new roads and markets to be developed, alternative solutions for improving spatial accessibility problems in the area, and their justifications. With prior consent from the interviewees, all conversations during the interview were recorded with an audio recording device and later transcribed. The recorded interviews constituted the qualitative data which supplemented the quantitative data in this study. These data provided an in-depth understanding of some of the data collected using the survey. The explanations served as the basis for weighting the cost factors when modelling new road networks and locations for new markets.

Table 3.2: Socio-demographic characteristics of survey respondents

Demographic Variable	Group	Frequency	Percent[5]
Sex	Male	129	64.5
	Female	71	35.5
	Total	**200**	**100**
Age	18 – 25	16	8.2
	26 – 35	51	26
	36 – 45	48	24.5
	46 -60	58	29.6
	> 60	23	11.7
	Total	**196**	**100**
Size of household	< 5 persons	47	31.1
	5-7 persons	59	39.1
	> 7 persons	45	29.8
	Total	**151**	**100**
Ethnic origin	Akan	62	31.3
	Ewe	43	21.7
	Northern Tribe	64	32.3
	Other	29	14.6
	Total	**198**	**100.0**
Highest level of Education	None	51	25.9
	Basic/Primary	97	49.2
	Secondary/High School	46	23.4
	Tertiary/Polytechnic	3	1.5
	Total	**197**	**100**

[5] Percent represents only those who answered the question.

Table 3.3: Economic characteristics of survey respondents

Demographic Variable	Group	Frequency	Percent
Primary occupation	Artisanal	2	1
	Farming	189	95
	Trading	4	2
	Other	3	1.5
	Unemployed	1	0.5
	Total	**199**	**100**
Secondary occupation	Artisanal	5	33.3
	Trading	1	6.7
	Other	8	53.3
	Unemployed	1	6.7
	Total	**15**	**100**
Average Monthly Household Income	<GHC100	2	11.1
	GHC100-200	4	22.2
	GHC200.1-300	5	27.8
	GHC300.1-400	1	5.6
	GHC400.1-500	1	5.6
	>GHC500	5	27.8
	Total	**18**	**100**
Average Seasonal Household income	<GHC1000	85	49.7
	GHC1000-2000	24	14
	GHC2000.1-3000	5	2.9
	GHC3000.1-4000	2	1.2
	GHC4000.1-5000	2	1.2
	>GHC5000	6	3.5
	Can't tell	47	27.5
	Total	**171**	**100**

Prior to conducting the survey and interviews, the author sought approval from the Institutional Review Board (IRB) at Texas State University to ensure that the rights and privacy of all research participant were duly protected (Appendix B). For each survey or interview conducted, a voluntary informed consent was sought from the participants (Appendix B). To ensure anonymity of participants and maintain confidentiality, the final report does not disseminate any personal information or individual response. Any Personal Identification Information (PII) was removed during digital encoding and each participant was given an identity number for analysis.

3.2.2.2 Spatial Data

Table 3.4 summarizes the types of geospatial data used in this study and their sources. The data were employed in evaluating spatial accessibility and modelling the new road networks and market locations. To ensure the quality of these datasets, the author verified them based on a recent (2013) topographical map (topo map) of the Afram Plains. The data (e.g. communities, road networks and rivers) were updated based on the topo map as well as other sources like remotely sensed imageries, direct observation, and local knowledge through public participation. For example, a cloud-free Landsat 8 panchromatic images (at 15 meter resolution acquired on April 28, 2013 and May 22, 2013) were used in the updating process. The panchromatic images in combination with the topo map helped in identifying the locations and current toponyms of new settlements, administrative boundaries, roads, water bodies and social facilities.

There were instances where the panchromatic images were fuzzy and blurry, thus making it difficult to verify the existence of some geographic features. In such cases, the author relied on the high-resolution (ranged between 1 to 5 meters) orthophotos provided by Google Earth and Microsoft Bing Maps. These online-based images, however, did not cover the entire study area and thus were very limited in use. To make up for the gap, the author engaged the services of some local experts (mostly taxi drivers). They helped with verifying the location and names of the remaining features.

Table 3.4: Spatial data and their sources

Spatial data	Source
Afram Plains area topographical map (paper map)	Afram Plains Development Organization
Afram Plains area boundary (shapefile)	Ghana Survey Department (2006)
Afram Plains Towns and Villages (shapefile)	Ghana Survey Department (2006)
Afram Plains Roads and Water bodies (shapefiles)	Ghana Survey Department (2006)
Agricultural sub-division boundaries or agro-zones (digital map; JPEG)	Ministry of Food and Agriculture, Ghana (2013)
Landuse / landcover (LULC) (raster)	United States Geological Survey (USGS) (2014); Unsupervised classification by author
Landsat 8 image (panchromatic); 15m resolution	USGS (2014)
Digital Elevation Model (DEM); 30m resolution	Earth Remote Sensing Data Analysis Center's (ERSDAC, 2011)

Based on these series of checks and verifications, the quality of spatial data acquired for the study was improved. For instance, 378 communities were identified and verified. Though this number fell short of the estimated number of communities in the area (over 500 according to the 2010 Census), some interviewees revealed that some of the smaller communities tended to be temporary due to migratory farming practiced by some folks in the area. They also added that, community name-change is a common practice in the area even though, the national census tends to stick with the old names. These factors might possibly explain why certain communities could not be identified.

Moreover, other spatial data, including Digital Elevation Model (DEM), agro-zones and land cover data were also acquired. The DEM provided terrain features like elevation and slope which were incorporated in evaluating the impact of physiographical factors on spatial accessibility. The agro-zones map was georeferenced and digitized to provide geographic unit boundaries for the study (Figure 3.2). Unfortunately, the existing land cover dataset for the study area were unreliable or defective. Hence, this study undertook the following steps to produce a new land cover data:

a. Image Acquisition and Pre-processing:

For a full coverage of the study area, two satellite imageries from USGS's Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) were acquired through the Global Visualization Viewer (GLOVIS) website. The two imageries had the specifications identified in Table 3.5. The images were already georeferenced upon download. Since bands 2 to 7 of Landsat images (they cover the visible, infrared and short wave infrared regions), are effective in revealing surface features (Biradar et al., 2003; Aronoff, 2005), they were selected for the image classification analysis. To enhance efficiency in the spatial processing, the two separate imageries were mosaicked and clipped to the study area.

Table 3.5: Imagery features

Feature	**Imagery 1**	**Imagery 2**
Dates Acquired	May 22, 2013	April 24, 2013
Cloud Cover	8%	7%
Path numbers	193	194
Row number	55	
Number of bands	1111	
Grid Cell Size	30 meters except band 8 – panchromatic; 15 meters	
Map Projection	UTM Zone 31	
Earth Ellipsoid	WGS84	

To improve the spatial resolution of the multispectral imagery for better interpretability, the author performed "pan-sharpening" using the panchromatic image (ERDAS, 2013). With the panchromatic image as the finer spatial resolution input data, Principal Component method coupled with Nearest Neighbor resampling technique was applied to produce a finer spatial resolution (15 meters) multispectral imagery. The Principal Component and Nearest Neighbor resampling techniques are known as best for preserving spectral information of input bands (ERDAS, 2013).

b. Image Classification:

The author adopted unsupervised classification technique to classify the enhanced imagery. This method was chosen over the supervised technique due to the difficulty in finding or distinguishing surface features from the Landsat imagery despite the spatial enhancement. In such cases, unsupervised classification is deemed as more appropriate as it can group features with similar spectral values into unique classes (Aronoff, 2005, ERDAS, 2013). The author employed the Iterative Self-Organizing Data Analysis Technique (ISODATA) for clustering. ISODATA "uses spectral distance as in the sequential method, but iteratively classifies the pixels, redefines the criteria for each class, and classifies again, so that the spectral distance patterns in the data gradually emerge" (ERDAS,1999; pp. 430). Since it is self-organizing, an analyst only specifies values for the clustering parameters including the convergence threshold (prevents ISODATA from running indefinitely), maximum number of classes and maximum number of iterations. In this study, the following values: 0.95, 30 and 50 were assigned respectively to the parameters noted earlier. Generally, higher values for the clustering parameters are recommended for better results.

c. Assigning Class Names, Regrouping and Accuracy Assessment:

Anderson et al.'s (1972) classification of land cover/use was used as reference in assigning names to the classes identified by the unsupervised classification technique. Through the classification, six major land cover types were identified. They included: Developed or Built-up, Barrenland, Cultivated lands, Forest, Shrubs/Herbaceous and Water features. After the class assignment, the author proceeded with an accuracy assessment of the classified image. A total of 150 control points was sampled from the classes using a stratified sampling approach; equal samples were picked from each class. Manual interpretation of the land cover based on Google Earth's and Bing Map's high resolution (1 meter) imagery served as the reference data to evaluate the accuracy of the classes derived from ISODATA.

Overall, the accuracy assessment revealed reasonably good classification with an overall accuracy of 80.7 percent (Table 3.6), which is above the general acceptable range of 65-75 percent (Jensen, 2016). In general, developed/built-up areas as well as cultivated land were mostly misclassified and thus, had lower accuracy. This wass possibly due to the large number of pixels with mixed spectral values found amongst these classes. Built up areas usually had a mixture of trees and grasses while cultivated areas tended to have a mixture of shrubs, grasses and some human developments like sheds, thus, making them difficult to accurately distinguish.

3.2.2.3 Attribute Data

Apart from the above spatial datasets, some attribute data were also acquired to supplement the analysis (Table 3.7). They included population data which were extracted from the 2010 Ghana population and housing census (Ghana Statistical Service, 2011).

Table 3.6: Accuracy assessment results

	Class Name	Reference Image (Panchromatic 15m 2013; Bing Images 2012)						
		Barren land	*Cultivated land*	*Developed*	*Forest*	*Shrubs / Herbaceous*	*Water bodies*	***Row Total***
User	Barrenland	**22**	0	0	0	2	1	**25**
	Cultivated land	2	**12**	1	0	10	0	**25**
	Developed / Built-up	1	5	**15**	0	4	0	**25**
	Forest	0	0	0	**23**	2	0	**25**
	Shrubs / Herbaceous	0	0	0	1	**24**	0	**25**
	Water bodies	0	0	0	0	0	**25**	**25**
	Column Total	**25**	**17**	**16**	**24**	**42**	**26**	**150**

Overall Classification Accuracy = 80.7%
Overall Kappa Statistics = 76.8%

Table 3.7: Attribute data and their sources

Attribute data	**Source**
Population and Housing data	Ghana Statistical Service (2011); Afram Plains Development Organization
Agricultural production data	Ministry of Food and Agriculture, Ghana (2013)
Market/Economic data	Afram Plains Development Organization; District Assemblies

These data were later joined to the town and agro-zones spatial datasets mentioned earlier. It is worthwhile to note that, at the time of this research, Ghana's census data were aggregated at the city/town/village level, the finest level of census information accessible. The census data provided insights about population distribution as well as social amenities in the area. The population data were used to estimate the potential demand for market facilities in the area. In addition, agricultural and economic data were obtained from the local directorate of the Ministry of Food and Agriculture. They were used in determining prevailing agricultural productivity levels and modelling economic potential of settlements in the area.

3.2.3 Data Analysis

3.2.3.1 Survey Data Preparation or Preprocessing and Basic Analysis

The responses from the structured questionnaire were first entered as digital data into IBM Statistical Package for the Social Sciences (S.P.S.S.). Afterwards, statistical analyses consisting both descriptive and inferential statistics were conducted to assess perceived and actual spatial accessibility in the study area. Categorical variables, such as the socio-demographic attributes, were analyzed using descriptive statistics such as frequency distribution to provide basic understanding of the distribution of the responses.

Moreover, Chi Square/Cross tabulation analyses were performed to assess the association between major sub-divisional areas and the following: mode of transportation, choice of market, and suggestions for improvement in accessibility. Similarly, several tests of means (e.g. t-test, ANOVA or equivalent) were conducted to test whether there were any statistically significant differences among the spatial accessibility indicators. These analyses primarily exploited any significant differences between actual, perceived, and potential spatial accessibility in the area. Other portions of the survey data, including market preference, estimated average travel time, and cost, were integrated with the spatial data for modelling spatial accessibility. Figure 3.8 below summarizes the modelling procedures for addressing research questions 1 to 3.

A new potential spatial accessibility model, named *Multi-Mode Accessibility Model* (Multi-MODAM), was developed in this study to model "*the spatial accessibility of the inhabitants to market centers based on a multi-mode transportation system*" as captured by research question 1. The goal of the new model was to quantify or model spatial accessibility according to multi-mode transport systems. It is worthwhile to note that, spatial accessibility in this study was modeled for the worst-case scenario, that is, during the wet season where most road networks were barely navigable in the Afram Plains.

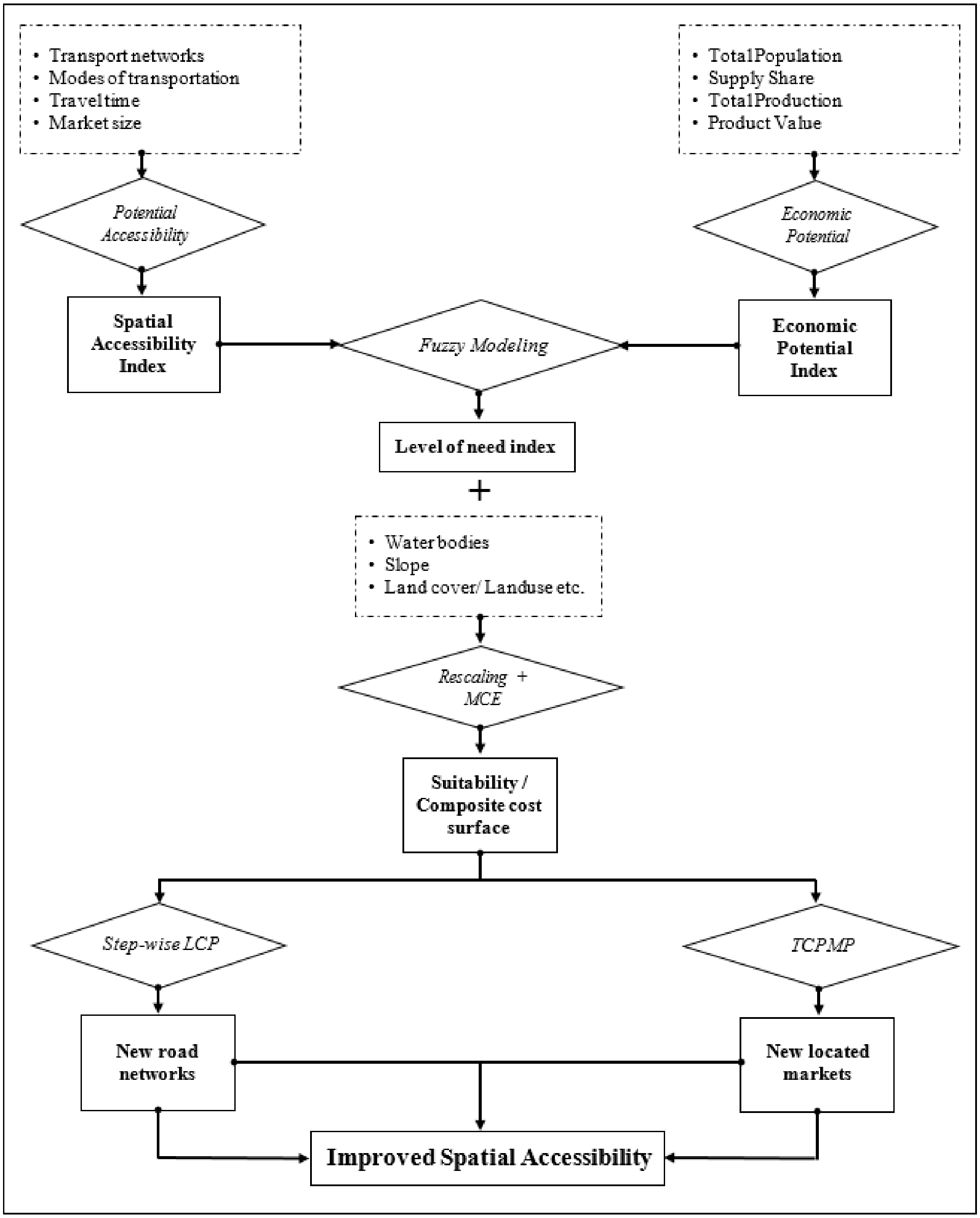

Figure 3.8: Methodological framework

3.2.3.2 Modelling Spatial Accessibility

As discussed earlier, travel conditions in the dry season are comparatively better and thus this research focused on the wet season in terms of assessment and explore an improvement for it.

In this study, Potential Spatial Accessibility (***PSA***) was defined as the capacity to overcome the geographic space between settlement (***i***) and market center (***j***) based on a specific transportation mode (***α)*** in the Afram Plains. A separate ***PSA*** was modeled for each major mode of transportation identified in the area. $\boldsymbol{PSA_{i\alpha}}$ was therefore formulated mathematically as shown in Equation 3.1 below.

$$PSA_{i\alpha} = \sum_{i=1}^{M} A_j / {T_{ij_\alpha}}^{\beta}$$

(Equation 3.1)

T = network distance * velocity (1/ Speed layer) according to road condition

where $PSA_{i\alpha}$ is the potential spatial accessibility for settlement *i* based on transport mode *α*, A_j is the attractiveness of market center *j* out of all markets *M* (measured as total area of market), $T_{ij\alpha}$ is the travel cost factor from settlement *i* to market center *j* based on transport mode *α* (measured as travel time), and *β* is a general constant rate of decay. The author used a value of 2 for the distance decay parameter. An initial statistical tests to determine the distance decay value empirically yielded a statistically non-significant result hence, the decision to use the default value of 2. Further explanation has been provided in a paragraph below.

The new model, *Multi-MODAM*, essentially considered spatial accessibility as an interplay between consumer choice of market and a specified travel cost factor. The choice here was determined by an attraction indicator based on the size of the destination feature (Table 3.8), whereas the travel cost factor was estimated based on travel time. These parameters were normalized to range from 1 to 10 where values closer to 10 indicated greater attractiveness or travel time. The model was built upon the premise that farmers will choose to sell their produce at a market center that will provide them the best offer in order to avoid a loss. In short, the *Multi-MODAM* aimed at estimating the total capacity of a source location to overcome travel impedance to a market.

Table 3.8: Size of major local markets

Market	Size (square meters)	Size rescale value (1-10)
Ekye-Amanfrom	6968.4	3.1
Donkorkrom	7079.4	3.2
Maame Krobo	16145.6	10.0
Tease	4175.2	1.0

The capacity of overcoming travel impedance to a market was estimated for each source location (communities) to all markets within the study area based on travel time. The model assumes that, ceteris paribus, the odds of making profit by the shortest travel time to the market are the initial drive for movement. This drive is influenced by the size of a market as an attraction; the larger the market center, the more likely it can offer better and competitive prices and vice versa. Notwithstanding, such attraction is normalized by a cost of travel factor. In other words, the appeal of a market is devalued by the cost of overcoming the intervening space to reach it. In this research, the cost of travel was based on travel time pertaining to the existing transport networks from the communities to the local markets with travel time ($T_{ij\alpha}$) raised to the power β, which is the constant rate of decay function (Equation 3.1). In essence, the farther the market, the higher the travel cost, and thus, the greater its devaluation. As a result, nearer destinations were preferred over the farther ones. In reference to these underlying assumptions and the interplay of the attraction and travel cost factors, the *Multi-MODAM* model determined a location's potential spatial accessibility. The most accessible location was the one that had the highest value and vice versa.

Moreover, as noted above, the estimation of travel time for the spatial accessibility model was estimated as the ratio of the network distance to the common speed limit operated by a transport mode on such networks. Mwase (1989) and Riverson and Carapetis (1991) acknowledged that, road condition influences the operational speed limit in varying degrees. For example, in Ghana, the official speed limit for vehicles is 80 kilometers per hour (km/hr) outside town/city limits and 50 km/hr within city/town limits. These speed limits however, are rarely achieved in the rural areas (Addo, 2005; Agyekum, 2008). In reality, local vehicle drivers are only able to travel at about 20-30 km/hr for the most part instead of 50 km/hr due to prevailing road conditions.

In view of such factors, the existing road networks in the area were first categorized per road characteristics, including road type (Major roads, Minor roads and Tracks/Paths), quality or surface covering (Asphalt, Feeder - Earth & Gravel and Feeder - Earth) and condition (*Good* - without any impediments; *Fair* - with some impediments; and *Poor* - with substantial impediments). Then, relying on responses from local commercial drivers, varying speed limits were assigned to each of the networks. This was done in accordance with the six major land-based modes of transportation identified in the area (Table 3.9).

To avoid producing an unrealistic surface showing null or no recorded values for intervening spaces, appropriate speed limits were also assigned to different land cover /

land use (LC/LU) types that occupy the intervening spaces (Table 3.10). These speed limits were determined based on the opinions of the local drivers and the author's field observation.

Table 3.9: Speed limits for different modes of transportation

Speed limits (km/hr) on Afram Roads							
Mode of Transport	Trunk Roads			Feeder Roads			Tracks / Paths
	Good	*Fair*	*Poor*	*Good*	*Fair*	*Poor*	*Poor*
Car / Van	80/60[6]	55/50	35/30	60	50	30	15
Asian truck	80/60	55/50	45/40	60	50	40	30
Tractor	50	40	30/25	50	40	25	20
Motorbike / Motorcycle + cart	60	50	40	60	50	40	30
Bicycle	20/18	15	10	18	15	10	8
Walking	3	3	3	3	3	3	2

Table 3.10: Speed limits for different land cover types

Speed limits (km/hr)						
Mode of Transport	*Car / Van*	*Asian truck*	*Tractor*	*Motorbike / Motorcycle + cart*	*Bicycle*	*Walking*
Developed	20	20	20	20	18	3
Barren land	15	30	20	30	7	2
Cultivated	10	15	15	10	5	2
Shrubs / Herbaceous	2	5	5	2	1	1
Forest	1	3	3	1	0.5	0.5
Lake / Major River	0.1	0.1	0.1	0.1	0.1	0.1
Minor River	0.5	0.5	0.5	0.5	0.5	0.5
Intermittent rivulets	1	1	1	1	1	1

Water features were treated as the greatest form of obstruction (except those that have bridges) hence, they were assigned the lowest speed limits among the land cover

[6] Where two separate speed values are given, the greater value is for asphalted road whereas the lower value is for non-asphalted road.

features. Yet, among the water features, different speed limits were allocated based on their sizes. For instance, relatively higher crossing speeds were assigned to intermittent rivulets while lower speeds were assigned to major rivers and lakes.

While many water bodies in the area do not have bridges or culverts, there are some rivers that have bridges across them. It would therefore be unrealistic to classify such portions of rivers the same as the remaining parts. Due to the lack of bridge location data, however, the author devised some reasonable criteria to establish likely locations of bridges/culverts based on field observation. The criteria included the following:

1. All major/perennial rivers crossing a major/minor road (not paths or tracks) had a bridge/culvert at their intersections.
2. All major roads intersected by any river or stream had a bridge/culvert.
3. All minor rivers within 5 kilometer radius of a community with at least 500 people and crossing a major/minor road (not paths or tracks) had a bridge/culvert.

Based on the above criteria, respective speed limits equivalent to the type and condition of transport network at that location (Table 3.9) were assigned to such river/road intersections.

Having derived the above cost factors, the author proceeded with creating a composite cost surface. First, all speed limits were converted into meters per minutes to match the map units which was in meters. The author then converted all the vector data including the road data into raster data based on their respective speed limits. In the case of the road data, the conversion produced six separate raster datasets. Afterwards, all the raster datasets combined to produce the composite cost surface.

Next, the author produced a velocity layer (1/Speed layer) which was simply a reciprocal of the composite cost surface. Following that, an incremental time layer was created using ArcGIS's path distance (PD) tool. This produced a continuous surface of estimated cumulative travel time to market centers. The PD tool is comparable to the cost distance (CD) tool as both are used to determine the minimum accumulative cost of movement from a source point to every location in a raster surface. Unlike the CD tool, however, PD can account for terrain features such as elevation therefore producing a true surface distance (Esri, 2011(a)). Altogether, 24 travel time surfaces were generated: six modes of transport for each of the 4 major markets.

The travel time surfaces were used to implement the $PSA_{i\alpha}$ model by normalizing all the surfaces into the range of 1-10 (Equation 3.1). As noted earlier, the cost of travel was controlled by a constant rate of decay function (β) to account for the rate of influence of distance on the devaluation of a markets appeal or attraction. In other words, it is the rate at which consumers' trips to a market center drops with an increase in distance from the market center. Mitchell (2012) noted that power transformation functions generally suit distance friction modelling in rural areas. With both population and facilities being mostly sparsely distributed and journeys between demand and supply centers tending to be long, a power function adequately provided the means to account for distance friction.

The value of the decay parameter though, depends on the nature or function of the destination and the number of alternative destinations (Mitchell, 2012). Destinations with scarce or important functions tend to attract lower values than those that perform common functions because consumers are more willing to travel longer distances to scarce-function destinations. A lower decay value for the power function therefore signifies less motivation to longer travel distance and vice versa. For best results, it is recommended that the value must be empirically determined. However, due to relatively insufficient data, this value could not be determined empirically in this study. Instead, the value of 2 was chosen signifying, the appeal of a market drops in proportion to the square of the distance from the communities. It is a value that is popularly used for modelling access to public facilities such as clinics that seek for equity in usage (Esri, 2013). The destinations in this research (i.e. local markets) were similar in nature because they represented public facilities that performed important functions in the livelihood of the local people. In addition, the local people had limited options to choose from, thus, long travels to a market were tolerable.

Upon establishing all the parameters, the author implemented the $PSA_{i\alpha}$ model using map algebra. A total of six outputs were produced representing each of the six modes of transport. Following the $\boldsymbol{PSA_{i\alpha}}$ modelling, the author proceeded to model the overall spatial accessibility for the study area. This was based on the Equation 3.2 below:

$$\mathrm{O}PSA_i = \sum_{\alpha=1}^{i} (PSA_{i\alpha} * n_\alpha / N)$$

(Equation 3.2)

where $\mathrm{O}PSA_i$ is the Overall Potential Spatial Accessibility of settlement i, $PSA_{i\alpha}$ is the Potential Spatial Accessibility for settlement i based on transportation mode α, n_α is the number of participants adopting a specific transportation mode α, and N is the total participants. The α parameter was based on responses from the survey.

The output was further used to model the level of need index to be discussed below under section *3.2.3.4*. For mapping purposes, the output was classified manually using a regular break value of 2.5.

Once the spatial accessibility for the area had been determined, the next thing was to answer the two sub-questions for research question 1: *"Is there any geographic disparity of spatial accessibility to market centers in the area among the different agricultural zones?"* and "*Is there any significant difference in the spatial accessibility to market centers by various modes of transportation?"* They were answered based on these hypotheses:

H_o1: *There is no significant difference in the mean overall potential spatial accessibility among the different agricultural zones, so that* $OPSA_1 = OPSA_2 = \ldots = OPSA_n$

H_o2: *There is no significant difference in the mean potential spatial accessibility among the six modes of transportation, so that* $PSA_{\alpha, i} = PSA_{\beta, i} = \ldots = PSA_{n, i}$

Since the independent variables (agricultural zones) were more than two, an Analysis of Variance (ANOVA) statistics was considered appropriate for testing this hypothesis. ANOVA was therefore used to test if there were any significant differences in OPSA among the different agricultural zones (H_o1). In the second hypothesis, which was finding significant differences among the PSA's of the modes of transportation (H_o2), an ANOVA with repeated measures was used. ANOVA with repeated measures was appropriate for this test because the variables were related and were more than two. In each case, a probability of ≤ 0.05 was considered as statistically significant. In addition, Tukey's post-hoc statistics was employed to test for any pair-wise significant differences in the variables in the first hypothesis (P *where* $\alpha \neq \beta$) while Bonferroni test was applied in the second hypothesis test.

To obtain the tabular data for the statistical analyses above, a fishnet with a size of 50 meters was created. The fishnet (having 1,459,027 individual records) was associated with the agro-zones and major divisions. The fishnet was then used as the zones or quadrats to extract the mean PSA and OPSA surfaces for each of the six transportation modes. The summary tables were joined for subsequent statistical analysis in SPSS.

3.2.3.3 Modelling Economic Potential (EP)

Besides the accessibility model, an EP model was also developed to determine areas with substantial economic prospects. In the context of Ghana, the EP of an area referred to the estimated economic viability of an area for agro-business. In this research, a modified version of Mundy and Bullen's (2010) Market Potential model was used. This model was selected for its relative simplicity and data requirements. Other models, such as Trade Area Capture, required data like taxation that did not exist at the geographic unit considered in this study, and hence was not selected. Mundy and Bullen's (2010) Market Potential model was modified to reflect the objectives of this research. It was formulated as below:

$$EP_i = N_i \times SS_i \times \sum_k P_i \, w_k$$

(Equation 3.3)

where EP_i is the economic potential of settlement i, N_i is total number of potential producers (total population) within an agro-zone i (based on the 2013 projected population), SS_i is the supply share (proportion of population considered as part of the active labor force in an agro-zone *i*), *P* is the per capita yield of all major produce within an agro-zone *i*, w_k is the relative importance assigned to each major produce *k*.

Due to insufficient data, only 126 towns representing about 33 percent of the identified towns had per capita yield data (i.e. *P*) for three identified major produce for the area; maize, yam, and cassava. The author therefore, employed Inverse Distance Weighting (IDW) interpolation[7] to produce a continuous surface to represent each of the major produce. The IDW interpolation was found to be the best method among several different methods such as Spline and Kriging as it yielded the most realistic surfaces and one with least root mean square errors for the 3 outputs. The relative importance (*w*) were 0.5, 0.3 and 0.2 for the major produce (*k*) – maize, yam, and cassava respectively. The weight assignment was based on expert knowledge of the local agricultural officers. According to the officers, the following factors: perishability, local and industrial demand, yield returns (how much is obtained per every hectare of land), and cost of production per every hectare of land were factored into their weights determination. The EP_i model's output was subsequently combined with the $OPSA_i$ output to model levels of need as discussed under section *3.2.3.4*.

3.2.3.4 Determining Areas of Greatest Need

The second research question in this study explored how spatial accessibility in the study area could be improved by prioritizing the areas in need. The "level of need" was determined by the degree of potential spatial accessibility in comparison with the

[7] Respective interpolation parameters and Root-Mean Square Error (RMSE) for Maize, Yam and Cassava are: Optimized Power (1.62; 1 and 1.03), Neighbors (15; include at least 10 in each case), Radius (15 km in each case), RMSE (5.49; 35.49 and 61.45).

level of economic potential. Relatively speaking, areas of need were defined as places that recorded low levels of spatial accessibility but had high levels of economic potential.

The "level of need" analysis employed fuzzy modelling and used both $OPSA_i$ and EP_i outputs as input datasets. But first, both input datasets were normalized to have the same numerical values: 1-10. This was to ensure that, all the two datasets had equal influence in the fuzzy modelling. The normalization was based on the Equations below:

$$Normalized\ OPSA_i = 10 * (OPSA_i / max(OPSA_i)$$

(Equation 3.4)

$$Normalized\ EP_i = 10 * (EP_i \ / \ \max(EP_i)$$

(Equation 3.5)

where *Normalized* $OPSA_i$ is the Normalized Overall Potential Spatial Accessibility of settlement i, max($OPSA_i$) is the maximum value within the Overall Potential Accessibility of settlement i, *Normalized* EP_i is the Normalized Economic Potential of settlement i, and $max(EP_i)$ is the maximum value within the economic potential of settlement i.

Fuzzy logic was appropriate for this study because of the vagueness in defining crisp boundaries separating different classes of needs (e.g. low, medium and high) over a continuum spectra in both factors. In geographical analysis, uncertainties associated with boundary effects occur when multiple classes are represented over space. Fuzzy modelling helps in minimizing these setbacks and standardizing various input factors into the same dimension of membership. This quality enables an analyst to deduce consistent meaning and conclusions from output features hence allowing comparison across multiple factors.

The steps involved in the fuzzy modelling included:

a. Preprocessing of input factors

b. Determine fuzzy membership

c. Compute consequence per rule

d. Defuzzification (conclusion)

a. Preprocessing of Input Factors:

The two input factors, *Normalized* $OPSA_i$ and *Normalized* EP_i both had a non-normal distribution or moderately skewed values. This situation posed a problem in the fuzzy membership as it made the designation of midpoints or thresholds virtually impossible (Goertz and Mahoney, 2012). To alleviate this limitation, it is recommended that one transforms the data. Data transformation reduces the skewness by achieving normality (Field, 2009). Although data transformation has been associated with some controversies, by and large, it is considered as a useful technique (Field, 2009).

According to Goertz and Mahoney (2012), the steps involved in spatial data transformation are analogous to data transformation in conventional statistics. For instance, the selection of a particular method is often based on the nature of the problem under study. Typically, a log10 transformation is considered useful in transforming moderately positively skewed data (Field, 2005; 2009). And since the two input factors for the fuzzy modelling were moderately positively skewed, the author used a log10 transformation for their transformation. After the transformation, the EP_i output had some negative values (because there were some < 1 values in the original EP_i); a condition not acceptable by both Fuzzy Small and Large membership functions. To fix this problem, the author rescaled both the log10 transformed $OPSA_i$ and EP_i outputs using a linear function to range from 1 to 10. The rescaled outputs became the final inputs for the fuzzy modelling.

b. Determine Fuzzy Membership:

This step involved identifying the most suitable fuzzy membership type for each specific category within the factors. These are shown in Table 3.11 and illustrated by Figure 3.9. As shown in Table 3.11, three distinct class layers (high, moderate and low) were generated separately for both *OPSA* and *EP* surfaces. A Fuzzy Gaussian was applied to generate the moderate class in both surfaces. This fuzzy membership type assigned full membership (1) to medium ranging values with fringe values receiving the least membership (0). With the moderate class being the focus here, Fuzzy Gaussian was best suited for deriving such membership. Fuzzy Large and Fuzzy Small, on the other hand, were used inversely in assigning membership to High and low classes in the two surfaces. This selection of memberships was done in view of the objective of research question 2: areas of need are equivalent to places with relatively *low spatial accessibility but have high economic potential*.

Table 3.11: Fuzzy membership

Factor	Suitability Assessment	Fuzzy membership
Overall Spatial Accessibility Index	$OPSA_i$ = High	Fuzzy Small; midpoint - 5, spread - 5
	$OPSA_i$ = Moderate	Fuzzy Gaussian; mean as midpoint – 5; spread - 0.5
	$OPSA_i$ = Low	Fuzzy Large; mean as midpoint – 5; spread - 5
Economic Potential Index	EP_i = High	Fuzzy Large; mean as midpoint - 5; spread - 5
	EP_i = Moderate	Fuzzy Gaussian; mean as midpoint - 5; spread - 0.5
	EP_i = Low	Fuzzy Small; mean as midpoint - 5; spread - 5

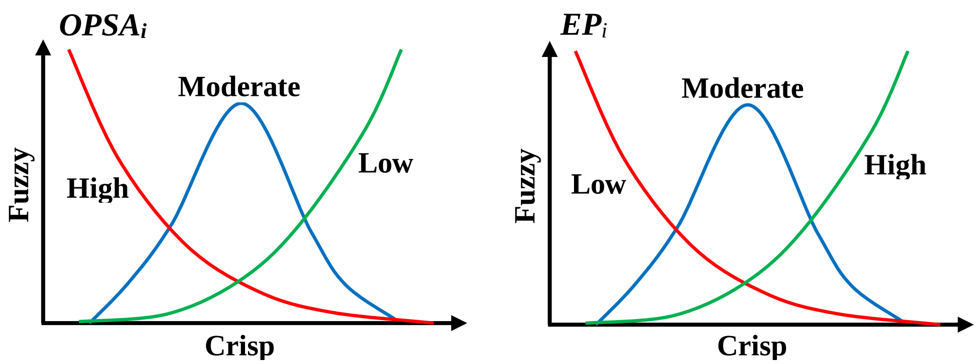

Figure 3.9: A three-set fuzzy membership

c. Compute Consequence Per Rule:

After step *b*, the Fuzzy Gamma operator was applied to compute the consequence rules as outlined in Table 3.12. The Fuzzy Gamma operator was based on Equation 3.6 (See section 2.2.2.2 for description).

$$Fuzzy\ \gamma_i = (Algebraic\ sum)^g\ (Algebraic\ product)^{1-g} \qquad \text{(Equation 3.6)}$$

where *Fuzzy* γ_i is the Fuzzy Gamma output and g is the gamma parameter.

Table 3.12: Rules for fuzzy membership

Fuzzification process		
Rule	*Consequence* (c_i)	*Interpretation (Level of Need)*
Rule 1: If $OPSA_i$ = High & EP_i = High	$c_i = 3$	Low
Rule 2: If $OPSA_i$ = High & EP_i = Moderate	$c_i = 2$	Very Low
Rule 3: If $OPSAi$ = High & EP_i = Low	$c_i = 1$	Extremely Low
Rule 4: If $OPSA_i$ = Moderate & EP_i = High	$c_i = 7$	High
Rule 5: If $OPSA_i$ = Moderate & EP_i = Moderate	$c_i = 6$	Moderately High
Rule 6: If $OPSA_i$ = Moderate & EP_i = Low	$c_i = 4$	Moderately Low
Rule 7: If $OPSA_i$ = Low & EP_i = High	$c_i = 9$	Extremely High
Rule 8: If $OPSA_i$ = Low & EP_i = Moderate	$c_i = 8$	Very High
Rule 9: If $OPSA_i$ = Low & EP_i = Low	$c_i = 5$	Moderate

This Fuzzy Gamma operator was appropriate due to its flexibility to fine-tuning the model in an attempt to mimic reality (Mitchell, 2012). The selection of gamma value (g), which is the only variable in this operator, was determined based on the goal of the study (Atkinson et al., 2005). Higher *g* values are used in cases where one wants to identify or bring out high membership values in any of the input factors and vice versa (Esri, 2012(d); Mitchell, 2012). In this study, a *g* value of 0.6 was used as it helped return fuzzy membership which were essentially the mean of all input factors (Esri, 2012(b); Esri, 2012(d)). This was considered appropriate as both input factors were treated as having equal influence in the outcome. Next, involved the implementation of different consequence rules which were set by the author based on Equation 3.7:

$$c'_i = \gamma_i \bullet c_i \qquad \text{(Equation 3.7)}$$

where $c'i$ is the consequence output, γ_i is the Fuzzy Gamma output, and c_i is the consequence rule crisp values.

According to the nine rules and associated consequent weights, the higher the weights, the more desirable (i.e. greater need) for infrastructural improvement. Areas with low $OPSA_i$ but high EP_i were weighted the highest (9) while those with high $OPSA_i$ but low *EP* were weighted the lowest (1). In general, the seeming bias in the rules (for *OPSA* over *EP*) reflects a slight preference for social benefits over economic benefits in the overall improvement of spatial accessibility.

d. Defuzzification:

Defuzzification involves the conversion of fuzzy sets back to the original format (meaningful classic set) for result interpretation (Van Leekwijck and Kerre 1999; Sladoje et al., 2011). In this study, the centroid (also called center of gravity) method, which calculates the center of gravity of the area under the membership function (Van Leekwijck and Kerre 1999) was used. The formula is as shown in Equation 3.8 below.

$$D = \sum_{i=1}^{n} c'_i \Big/ \sum_{i=1}^{n} \gamma_i$$

(Equation 3.8)

where D is the defuzzified output, c' is the consequence output, and γ_i is the Fuzzy Gamma output. The final output was presented in a map showing the different classes of need.

3.2.3.5 Determining New Roads

This section describes the steps involved in answering research question 3: *How best can spatial accessibility be improved?* To answer this question, this study explored two solutions: new roads and/or new markets. The first solution addressed this sub-question: *If new roads are developed, where should they be constructed to better improve spatial accessibility within the area?* A modified approach termed, "Step-wise Least Cost Path" (LCP) analysis was developed and employed in modelling new routes to connect communities in the area that previously were not connected by a road network. The total number of such communities was 152. Each of the communities served as the source location for the new routes that were modeled. It was the expectation of the author to realize that most of the communities (if not all) could ultimately reach a market within sixty minutes of traveling. Some python scripting was incorporated here to automate the process and optimize computing time (item 1 in Appendix C).

Normally, LCP involves these main steps: create a composite cost surface layer, create cost distance and cost direction surface and generate the cost path or route. However, with the adoption of the step-wise approach in this study, new steps were included. The primary goal of the step-wise approach was to prevent the emergence of redundant routes thus, ensuring a meaningful and realistic network. Details of all the steps undertaken are as following:

i. Create a composite cost surface layer
ii. Determine origin: order communities based on the distance from the closest market
iii. Create cost distance and cost direction surface
iv. Determine destination: closest point on an existing network to connect
v. Generate cost path or route then append new cost path to existing network. Repeat steps from *iv* above until all destinations are connected.

i. Create a composite cost surface layer

In view of the diversity in the terrain of the study area, terrain distance rather than planimetric Euclidean distance was used in this study. Terrain distance provided a better and practical measure for estimating cost of movement in the area (Mitchell, 2012). Terrain distance was used in modelling these factors: distance from lake, rivers and towns. These factors were subsequently combined with other impedance factors to create a composite cost surface. Prior to combining the factors, some rescaling using appropriate transformation functions were done to ensure commonality and comparability in measurement scale across the cost factors. The cost factors were classified as following: environmental/engineering and socio-economic factors. Table 3.13 describes the cost factors, suitable transformation functions used to rescale them and specific justification or goal each factor addresses.

Table 3.13: Route cost factors and their associated transformation functions

Category	Factor	Transformation	Goal/Justification
Environmental/ Engineering	Path distance from Lake	Small; midpoint – 1000 m spread – 2.5; lower threshold - 200m; including 30.48 m [8] riparian buffer and flood prone zone.	Avoid bodies of water.
	Path distance from Rivers	Small; midpoint – 500 m spread – 2.5; lower threshold – 150 m; including 30.48 m riparian buffer and flood prone zone.	Avoid flood prone areas and minimize stream crossings.
	Slope layer	Large; midpoint – 6.84º or 12%; spread – 2.5; upper threshold – 8.53º or 15%.	Maintain low grade; preferably < 15% or 8.531º.
Socio-economic	Land cover	Categorical (Table 3.14).	Avoid sensitive wildlife and cultural sites
	Areas of Need	Small; midpoint – 5; spread – 5; lower threshold – 3.49.	Ensure roads are built in areas of greatest need.
	Path distance from towns	Large; midpoint – 1.5 km; spread – 5; lower threshold – 0.5 km.	Maximize coverage of populated areas.

The land cover factor was categorical and thus, its rescaling was done manually (Table 3.14). According to the table, forests and water were assigned the highest rescaled values. Areas with high values indicate high travel cost, and thus, they were theoretically undesirable and expected to have been mostly avoided in the final cost path delineation. In the case of distance from rivers and lake and areas of need (see section 3.2.3.4), the Small function was used. This function assigned lower values to areas with higher input values (desirable areas). On the contrary, the Large function was used to rescale the slope and distance from towns' factors so that higher input values were assigned higher cost and vice versa. In short, desirable locations were assigned low = values in conformity to the goal of LCP modelling.

[8] Equivalent to 100 ft.

Table 3.14: Rescaling of landcover for route suitability analysis

Class		Factor Rating
Barrenland		1
Cultivated		3
Forest		8
Shrubs/Herbaceous		4
Water		10
Developed - Towns		0.5
Developed - Other		1
Roads	Major Road - Asphalt - Good	0.1
	Major Road - Asphalt - Fair	0.2
	Major Road - Asphalt - Poor	0.3
	Major Road - Feeder - Earth & Gravel - Good	0.2
	Major Road - Feeder - Earth & Gravel - Fair	0.3
	Major Road - Feeder - Earth & Gravel - Poor	0.4
	Minor Road - Feeder - Earth & Gravel - Good	0.2
	Minor Road - Feeder - Earth & Gravel - Fair	0.4
	Minor Road - Feeder - Earth - Good	0.3
	Minor Road - Feeder - Earth - Fair	0.4
	Minor Road - Feeder - Earth - Poor	0.5
	Tracks / Paths - Feeder - Earth - Poor	1

Since several factors or criteria were involved, it was important to account for the varying impact of each factor over the problem by introducing some weighting parameters (Zeleny, 1998; Opricovic and Tzeng, 2004). WLC was employed here to fulfill this purpose. The weights were determined from experts and stakeholders' opinions collected through interviews and survey from the study area. NVivo (a qualitative data analysis computer software package) was used for the text analysis and it formed the basis of the weight assignment (Table 3.15). The weights (which were scaled from 0.1-1) were then assigned to their corresponding factors by multiplying them before all the cost factors were combined as a weighted sum of factors to produce a final composite surface.

Table 3.15: Road cost factors' weights

Factor	Weight
Distance from lake	0.1
Distance from river	0.2
Landcover	0.25
Slope	0.1
Areas of need	0.15
Distance from towns	0.2
Total	**1.0**

ii. Determine origin: order communities based on the distance from the closest market

Next, the author determined the travel time to the closest market within the area for each of the 152 focus communities. Based on their travel times, the communities were sorted in a descending order. The highest ordered or farthest community was selected to be the first source location for a new road network.

iii. Create cost distance and cost direction surface

Using the ordered communities as source locations or origin and the composite cost surface, a cost distance surface representing the cumulative cost of moving away from the origin was created based on terrain distance. In addition, a cost direction surface (representing the direction of travel from individual cells to adjoining cells that had least cost values) was also created. Cost direction simply assigns values ranging from 1 to 8 to each cell with respect to the direction of the neighboring least cost cell. This provides a guide to identify and link the adjoining cells in the cost distance surface to produce the least cost route from the origin (Mitchell, 2012).

iv. Determine destination: closest point on an existing network to connect

The destination for any of the new routes was determined as the closest point (based on terrain distance) to the point of origin on an existing road network.

v. Generate cost path or route

The final step involved the creation of the least cost route between the point of origin and the destination based on the two surfaces (cost distance and cost direction) created in step iii. The first route created linked the highest ordered community in step ii to the closest point on the existing road network. The new route was subsequently appended to the existing road network. The modified road network (existing plus appended route) was then used to determine the next destination in the next iteration. Steps ii through iv were repeated until all the 152 communities were connected to the existing network with a new route. Figure 3.10 below illustrates the steps involved in the LCP analysis.

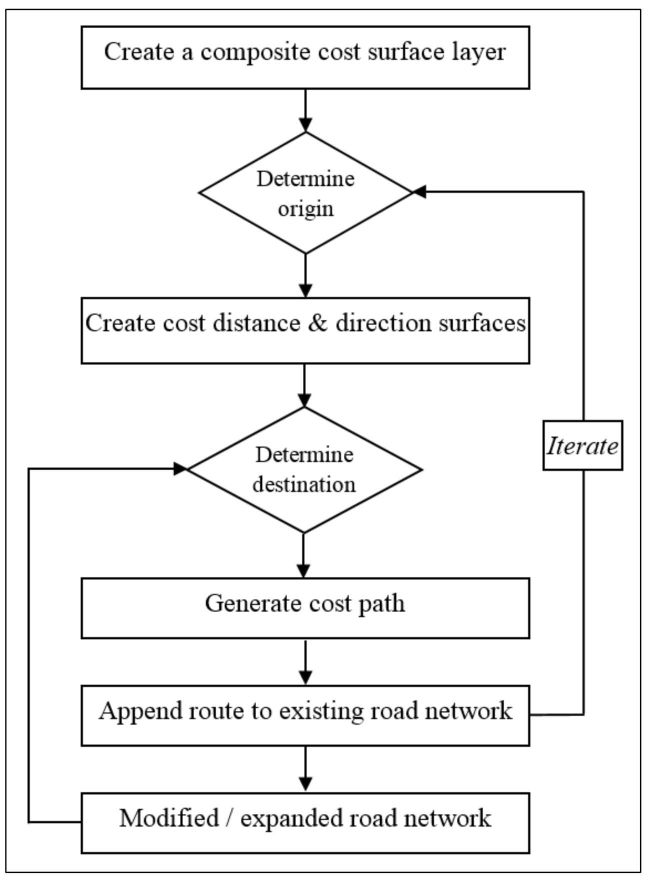

Figure 3.10: Step-wise LCP modelling process

3.2.3.6 Locating New Market Centers

Apart from modelling new roads, this study also considered expanding the number of existing market centers in the area as an alternative for improving spatial accessibility in the Afram Plains. This section thus, focused on research question 3b: *If new markets are developed, where should they be located?* This was addressed using a Location-Allocation (LA) process coupled with suitability analysis.

a. Suitability Analysis:

The suitability analysis helped identify ideal locations to site a new facility. In doing this, some cost factors used in the LCP modelling above were modified using different transformation functions. Unlike the LCP modelling, all cost factors meeting a set of ideal criteria were assigned higher values and vice versa. Table 3.16 below identifies all the cost factors, suitable transformation functions used to rescale them and a justification for them or the specific goal each factor addresses.

Table 3.16: Market suitability cost factors

Class	Factor	Transformation Function	Justification
Environmental/ Engineering	Path distance from Lake	Large; midpoint – 1000 m spread – 2.5; lower threshold – 200 m;	Avoid bodies of water
	Path distance from Rivers	Large; midpoint – 500 m spread – 2.5; lower threshold – 150 m;	Avoid flood prone areas; minimize stream crossings
	Slope layer	Small; midpoint – 6.84^o or 12%; spread – 2.5; upper threshold – 8.53^o or 15%	Maintain low grade; preferably < 15% or 8.531^o

Table 3.16 continuation: Market suitability cost factors

Class	Factor	Transformation Function	Justification
Socio-economic	Distance from existing markets	Large; midpoint – 20 km; spread – 5; lower threshold – 10 km; upper threshold – 25 km	Will ensure attainment of market threshold; enhance economies of scale; encourage itinerant trading
	Distance from Roads	Small; midpoint – 19899.367; spread – 5; lower threshold – 250 m	Enhance visibility and accessibility
	Distance from towns	Small; midpoint – 1.5 km (30 minutes); spread – 5; lower threshold – 0.5 km (10 minutes)	Maximize coverage of populated areas; reduce travel time to market
	Land cover	Categorical (See Table 3.19)	Avoid sensitive wildlife and ecological sites
	Areas of Need	Large; midpoint – 5; spread – 5; lower threshold – 3.49	Ensure roads are built in areas of greatest need.

Just like in the LCP modelling, the landcover factor was reclassified by assigning specific values to the classes (Table 3.17). Besides, the final suitability surface was modeled using WLC. Thus, all the factors were weighted before deriving the final output.

Table 3.17: Rescaling of landcover for market suitability analysis

CLASS		Factor Rating
Barrenland		8
Cultivated		6
Forest		1
Shrubs/Herbaceous		5
Water		0.1
Developed - Towns		10
Developed - Other		8
Roads	Major Road - Asphalt - Good	2
	Major Road - Asphalt - Fair	2
	Major Road - Asphalt - Poor	2
	Major Road - Feeder - Earth & Gravel - Good	2
	Major Road - Feeder - Earth & Gravel - Fair	2
	Major Road - Feeder - Earth & Gravel - Poor	2
	Minor Road - Feeder - Earth & Gravel - Good	2
	Minor Road - Feeder - Earth & Gravel - Fair	2
	Minor Road - Feeder - Earth - Good	2
	Minor Road - Feeder - Earth - Fair	2
	Minor Road - Feeder - Earth - Poor	2
	Tracks / Paths - Feeder - Earth - Poor	2

The weights were determined from experts and stakeholders' opinions collected through interviews and survey as well as the author's observations in the field. NVivo was used for the text analysis of the open-ended answers collected from the area. Table 3.18 shows the final weights used.

Table 3.18: Market cost factors' weights

Factor	**Weight**
Path distance from Lake	0.05
Path distance from Rivers	0.1
Slope layer	0.05
Distance from existing markets	0.2
Distance from Roads	0.25
Distance from towns	0.1
Land cover	0.05
Areas of Need	0.2
Total	**1.0**

After producing the suitability surface, the author then manually classified the output into three classes: High (7.01 -10), Moderate (5.51-7.0) and Low (0.1-5.5). Afterwards, all the communities were overlaid on the classified surface. A combination of spatial query (towns within the high suitability classification) and attribute query (towns with population $\geq$ 500) was then applied to select potential market locations. The queries produced 13 towns. Yet, 3 more towns were added to the 13 based on recommendations by survey participants to consider them for new market locations. These towns included Mmradan, Forifori, and Dedeso. It is worthy to note that these towns met the attribute query criterion but were not within the high suitability classification. So overall, 16 towns were selected for consideration in the subsequent location-allocation modelling.

b. Location-Allocation Modelling:

The P-Median is one of the best known LA models along with several variants such as CPMP. As discussed in the literature review, the P-Median however, falls short in accounting for certain important planning factors like cost of building a facility, which in fact, ultimately influences the decision to build a facility at a site or not. Moreover, the P-Median focuses mainly on minimizing impedance with no direct consideration for coverage of demand.

Based on these limitations, this study proposed a new variant of the P-Median termed *Total Coverage P-Median Problem (TCPMP)*. This new variant was inspired by both the Maximum Coverage Location Problem (MCLP) and Capacitated P-Median Problem (CPMP). The new variant was referred to as Total Coverage because it focuses on covering every demand in the study area with no limitation on impedance. This was aimed at fulfilling the goal of ensuring that every single community in the study area has access to at least a market. It was formulated as below (Equation 3.9):

$$Maximize \left[\sum_{i=1}^{n} a_i Y_{ij} \bigg/ \left(\sum_{j=1}^{m} {d_{ij}}^2 + \sum_{j=1}^{m} f_j X_j \right) \right] \quad \text{(Equation 3.9)}$$

Equation 3.9 is subject to the following constraints:

$$\sum_{j=1}^{m} X_j \geq Y_{ij} \text{ for each } i = 1, 2 \ldots n \text{ and } j = 1, 2 \ldots m$$

$$\sum_{j=1}^{m} Y_{ij} \geq 1 \quad \text{for each } i = 1, 2 \ldots n$$

$$\sum_{j=1}^{m} X_j = p \leq \$$$

$fj \leq {}^{\$}/_{p}$

$X_j \;\; = \{0, 1\}$ for each $j = 1, 2 \ldots, m$

$Y_{ij} = \{0, 1\}$ for each $i = 1, 2 \ldots n$ and $j = 1, 2 \ldots m$

where i is the index of demand centers (communities in the study area), so that i = 1, 2...n, j is the index of potential facility sites where j = 1, 2,…..m, a_i is the amount of demand (population) at demand center i, d_{ij} is the travel impedance (minimum travel time) from facility site j to demand center i, p is the number of facilities (medians) allowed by budget to be developed or located. Other parameters include: f_j, the fixed cost to build a facility at supply center j, $ is the budget allocation thus $/p is the budget proportion of each median, Y_{ij} is a case of allocated demand and it is valued at 1 if demand arising at demand center i is covered by at least one facility at center j and 0 if otherwise, and X_j is a case of located facility and it is valued at 1 if facility at site j is located (a median) and 0 if otherwise.

The overall objective of the *TCPMP* was to choose facilities such that the ratio of the sum of all coverage (demand allocated to a facility) to that of the sum of all weighted impedances (cost of building a facility multiplied by the impedance to the facility) was maximized. In other words, the model considered the set of facilities (medians) that had the maximum ratio for overall demand coverage and weighted impedances. Similar to the LCP analysis, the LA also involved a series of steps while python scripting was applied to help automate the process and optimize computing time (item 2 in Appendix C).

Prior to executing the LA model, it was conceived that, four scenarios with four potential outcomes were possibilities that could develop from the model. These scenarios are captured in Table 3.19 below. Each scenario was subsequently modeled based on the following steps:

i. Generating the set of medians

ii. Fitness Assessment

iii. Solve the Total Coverage P-Median Problem

Table 3.19: Scenarios for new markets

Scenario	**Description**	**State of Roads**		**Number of potential market towns**	**Remark**
		Additional New Roads	*Existing Roads Improved*		
1	Additional markets based on current road conditions.	No	No	14	None.
2	Additional markets based on current roads with improved conditions.	No	Yes	14	Minimum road speed limit is 50 km per hour and journey is by a tractor.
3	Additional markets based on expanded road network without any improvement in existing roads.	Yes	No	16	None.
4	Additional markets based on expanded road network with improved conditions.	Yes	Yes	16	Minimum road speed limit is 50 km per hour and journey is by a tractor.

i. Generating the set of medians

A factorial combination was used to generate sets of 5 towns (***p***); stipulated number of facilities allowed by a hypothetical budget (**$**) to develop. The sets were generated out of the 16 towns identified previously (3.2.3.6 *a*) as potential locations for a new market. Due to lack of roads connecting two of the potential market locations to the existing road network, those two locations were excluded from the larger set from which the 5 medians were picked. This was done only under Scenarios 1 and 2. The factorial combination was based on Equation 3.10.

Scenarios 1 and 2: C(n, r) = n! / (r! (n - r)!) → C(**14**, 5) = 16! / (5! (**14** - 5)!)

Scenarios 3 and 4: C(n, r) = n! / (r! (n - r)!) → C(**16**, 5) = 16! / (5! (**16** - 5)!)

Equation 3.10

where *n* is the total potential locations and *r* is the desired subset or the ideal towns to be selected for development. Equation 3.10 produced a total of 2002 unique candidate sets in the cases of Scenarios 1 and 2 and 4,386 in the cases of Scenarios 3 and 4.

ii. Fitness Assessment

The fitness of each of the 2002/4,386 candidate sets was evaluated against the objective constraints of this model. Below are the objectives and their associated constraints:

a) Ensure the minimum overall weighted travel impedance (travel time) between demand centers and a selected median. Generally, travel impedance (e.g. time), is known to be strongly correlated with the utilization of services in Ghana (Buor, 2002). Reduction in travel impedance can be expected to yield greater returns. To account for such impact on the choice of selected facilities, a power impedance transformation with a parameter of 2 was used. This option, besides enhancing the influence of travel impedance, also helps ensure equity of service (Esri, 2013). It equalizes the overall impedance that demand centers must overcome to reach the nearest facility. As a result, everyone is treated fairly in how much travelling they may have to do. (Esri, 2013). This objective was addressed by Equation 3.11.

$Cost\ of\ movement = impedance_{ij}^{\lambda}$ where λ is the impedance parameter; 2 → ${d_{ij}}^2$

(Equation 3.11)

The minimum travel distance and time for each of the 2002/4,386 candidate sets were generated and recorded. In the final equation (Equation 3.9), travel impedance was weighted by the fixed cost to build a facility at a selected location (discussed in sub-section [d] below).

b) Ensure total coverage by allocating all demand centers to at least one median. To achieve this, the parameter for facilities to locate was set as 9; which included the 4 required or existing markets and the 5 candidate or new markets to be located. The inclusion of the existing markets was a conventional procedure meant to ensure that new located facilities (in association with the existing ones) were indeed bringing about a positive improvement in coverage or minimizing impedance. This procedure was directed by the third law of location science which states that "sites of an optimal multisite pattern must be selected simultaneously rather than independently" (Church and Murray, 2009). In light of this proposition, each demand center was allocated to the closest facility in each iteration. In addition, no impedance cutoff **"**the maximum impedance at which a demand point can be allocated to a facility" (Esri, 2013), was included to guarantee that every demand center was allocated. The constraint/equation below (Equation 3.12) handled this objective:

$$\sum_{j=1}^{m} X_j \geq Y_{ij} \text{ for each } i = 1, 2 \ldots n \text{ and } j = 1, 2 \ldots m$$

(Equation 3.12)

c) A demand center was allocated to at least one market center. This took care of potential itinerant traders who might be interested in exploring other market centers. The objective was handled by Equation 3.13:

$$\sum_{j=1}^{m} Y_{ij} \geq 1 \quad \text{for each } i = 1, 2 \ldots n$$

(Equation 3.13)

d) Locate only the number of *p* medians (5 new market centers and 4 existing centers) from candidate facilities allowed by budget to be developed. With a fixed budget, these two scenarios were likely:

   i. A preference for small-facilities meant more facilities could be developed.

   ii. A preference for large facilities meant fewer facilities could be developed.

Generally, a large facility is preferable or attractive than a smaller one because they tend to offer a variety of goods and services to attract more patrons and customers (Berry et al., 1988; Huff, 1964). In Afram Plains, Maame Krobo market is the largest in the area and it attracts more people than the remaining markets. Furthermore, higher patronage leads to increased competitiveness, productivity and income levels. It also benefits customers as they enjoy reduced prices and improved quality of goods and services. Such changes eventually contribute towards local economic growth (Kilkenny, 1998; Olsson, 2009). Besides, regulating the number of markets by size will also guarantee that at least each center could realize its threshold demand: the minimum demand necessary for a center to remain profitable and operational (Rodrigue et al., 2013). In light of these facts, scenario two, “preference for a large facility(ies)" was adopted in this model. This objective was assessed by this constraint (Equation 3.14):

$$\sum_{j=1}^{m} X_j = p \leq \$$$

(Equation 3.14)

To develop a hypothetical budget (**$**) for the 5 new markets, the author relied on the estimated contract values of 5 recently developed markets (contracts were completed in November-December 2010) obtained from the two local District Assemblies. The estimated value covered the following items of a basic crop market: 1 building with 10 closed stores, 1 building with 3 closed stores, 1 open shed with 10 stalls for perishable produce, 1 open shed, 1 garbage disposal site, and a 6-seater KVIP toilet facility. It must be noted here that, these new crop markets are relatively smaller in size to the 4 existing markets. Figure 3.11 shows an example of a completed crop market while Table 3.20 provides a summary of the contract of the 5 recently developed markets.

Figure 3.11: A new crop market
Source: Afram Plains Agriculture Directorate (2014)

Table 3.20 Estimated cost of previously developed crop markets

Contract Location	Date Commenced	Contract period (month)	Expected completion date	Estimated value of contract
Kwesi Fanti	June 4, 2010	6	Dec. 3, 2010	GHC226,829.06 ($158,069.03)
Forifori	May 27, 2010	6	Nov. 26, 2010	GHC316,134.34 ($220,302.67)
Tease	June 23, 2010	6	Dec. 22, 2010	GHC277,301.39 ($193,241.39)
Dome	May 27, 2010	6	Nov. 26, 2010	GHC340,770.56 ($237,470.77)
Supon	June 15, 2010	6	Dec. 24 2010	GHC206,640.01 ($144,000.01)

Source: Afram Plains Agriculture Directorate (2014)

The original cost values were quoted in the local currency, Ghana Cedis but were converted into US dollars based on the exchange rate of June 2010 ($1 = GHC 1.4350; Exchange-Rates.org, 2016) to obtain its dollar equivalent. The conversion was necessary since the US dollar is widely considered as a stable currency and thus, would provide a better gauge for current cost of development for a similar crop market.

Using the above values as reference, the author developed estimates for the 16 selected towns for the LA model (Table 3.21). Some towns were part of the 16 so their values were maintained. The rest were determined based on their spatial proximity to markets in Table 3.20. According to a local agricultural extension officer, such estimation was fairly accurate but noted that factors like the bidding process and varying labor cost also tend to affect the final cost values (Mensah, 2016). But, practically, there were virtually no data accounting for these factors. As a result, this research made efforts to account for factors which had data available or could be quantified with some degree of certainty.

In Table 3.20, the cost ranged from **$144,000.01** to **$220,302.67**. The author therefore estimated that, at most, each located market would cost $220,302.67. Hence, the budget ceiling was fixed at **$1,101,513.35** ($220,302.67 x 5). As a result, all candidate sets fulfilled this constraint (table not included).

e) Ensure that the fixed cost to build a median at a supply center is less or equal to the budget proportion of each median (budget/*p*). Equation 3.15 addressed this objective:

$$fj \leq {}^{\$}/_{p} \qquad \text{(Equation 3.15)}$$

Table 3.21: Estimated cost for crop markets at potential locations

Community	Major Division	Agro-zone	Population 2013	Market Cost
Agordeke	Eastern	Agordeke	1,147	$193,241.39
Amankwa Tornu	Eastern	Agordeke	1,511	$193,241.39
Asayanso	Central	Kwasi Fante	2,234	$158,069.03
Awua Apesika	Eastern	Kwaekese	1,245	$144,000.01
Bonkrom	Western	Ekye-Amanfrom	1,674	$158,069.03
Dadesenkope	Central	Kyemfere	1,208	$220,302.67
Dedeso	Central	Tease	1,611	$193,241.39
Forifori	Western	Forifori	3,658	$220,302.67
Foso	Western	Forifori	2,829	$220,302.67
Kadekope	Western	Kwame Dwamenakrom	1,600	$220,302.67
Kwame Dwamena	Western	Kwame Dwamenakrom	1,254	$220,302.67
Mem Kyemfere	Central	Mim Kyemfere	1,895	$193,241.39
Mmradan	Central	Samanhyia	598	$193,241.39
New Kyease	Eastern	Abomasarefo	1,229	$144,000.01
Vuvlakope	Western	Kwame Dwamenakrom	1,226	$220,302.67
Wongwong	Eastern	Kwaekese	559	$144,000.01

iii. Solve the Total Coverage P-Median Problem

After the successive fitness checks, the overall success of a fit **p** was calculated using the *TCPMP* equation (Equation 3.9). The model would favor candidate sets that had both the least sum of all weighted impedances and the most sum of all demand coverage. But since no distance or time impedance threshold was set, the overall demand or coverage was the same for all candidate sets.

After executing Equation 3.9, the resultant values for all 2002/4,386 candidate sets were then sorted in a descending order to identify the best candidate set; one with the maximum TCPMP value. The best candidate set was chosen and developed into a map.

3.2.3.7 Assessment of the Impact of the Proposed Interventions

After modelling the two main solutions; new roads and new markets, they were evaluated to determine their overall efficiency or how they impact spatial accessibility in the area ultimately. A third case: a situation whereby both interventions were applied simultaneously was also evaluated. In each of the three cases, several scenarios were also conceived owing to the possibility that both existing roads and markets could experience a future improvement or renovation. Table 3.22 below outlines all the possible scenarios.

Table 3.22: Scenarios for possible impact on spatial accessibility

Scenario	Intervention	State of Roads		State of Markets		Modeled
		New Roads	Existing Roads Improved	New Markets	Existing Markets Improved	
1	Expansion of road network	√	X	-	X	Yes
3		√	√	-	X	Yes
2		√	X	-	√	-
4		√	√	-	√	-
5	Locating new markets	-	X	√	X	Yes
6		-	X	√	√	Yes
7		-	√	√	X	-
8		-	√	√	√	-
9	Both	√	X	√	X	Yes
10		√	X	√	√	-
11		√	√	√	X	Yes
12		√	√	√	√	-

However, as shown in Table 3.22, only six out of the twelve possible scenarios were modeled and evaluated in this study. Overall Potential Spatial Accessibility in each case was modeled based on the *Multi-MODAM* model (Equations 3.1 and 3.2).

After modelling the six scenarios, they were subjected to a statistical test to determine if there were any significant differences between them. An ANOVA with repeated measures was used to assess for any differences between all the scenarios. The result was also applied in determining which scenario best improved spatial accessibility in the area. A Bonferroni post-hoc test was used. The null hypothesis was formulated as:

H_o3: *There is no significant difference in the mean overall potential spatial accessibility among the scenarios indicating* $OPSA_{Sc1} = OPSA_{Sc2} = \ldots = OPSA_{Sc\ n}$

After determining which scenario(s) best improved spatial accessibility in the area, they were subjected to ANOVA test to examine any geographic disparity among the agro-zones. This test focused on answering this hypothesis:

H_o4: *There is no significant difference in the mean overall potential spatial accessibility among the different agricultural zones, so that* $OPSA_1 = OPSA_2 = \ldots = OPSAn$

Apart from the above tests, the expanded road network was also evaluated using connectivity measures. Connectivity is regarded as the prime objective of any transportation network (Dill, 2004; Twaddell, 2005; Victoria Transport Policy Institute (VTPI), 2014). It is defined as the density of connections in a network and how direct the links are within a specified area (Montana Department of Transportation (MDT), 2014; VTPI, 2014). Several research have shown that the more connected a network is, the less the travel distance or travel time. It also means more route options thus, enhancing general accessibility of local population to various destinations as well as encouraging the use of alternative means of transportation like walking and biking. (Twaddell, 2005; MDT, 2014; VTPI, 2014). Various measures (collectively called Connectivity Indices or measures) have been developed to assess connectivity quantitatively. Table 3.23 summarizes some of the common measures used. In this study, the following measures were employed: Street Density (SD), Gamma Index (GI) and Detour Index (DI).

Table 3.23: Summary of common connectivity measures

Measure	Description	Formula	Remark
Street Density (SD)	The number of linear distance of streets per area of land (e.g. kilometers per square kilometer).	$SD=\frac{network\ distance\ D(N)}{Area}$	A higher value denotes more networks and, presumably, higher connectivity.
Alpha Index	It evaluates the number of cycles in comparison with the maximum number of cycles in a network.	$\alpha=\frac{(Links\text{-}Nodes)+1}{2(Nodes)\text{-}5}$	Values range from 0 to 1. The higher the index, the more a network is connected
Link[9]-Node[10] Ratio (Beta Index)	It looks at the relationship between the number of links over the number of nodes in a network within an area.	$\beta=\frac{Links}{Nodes}$	A high value shows a more connected network. Complex networks tend to have values greater than 1. A value of 1.4 is the minimum needed for a walkable community.
Gamma Index (GI)	It tests the relationship between the number of observed links in the network to the number of maximum possible links between nodes.	$\gamma=\frac{Links}{3(Nodes\text{-}2)}$	Values range from 0 to 1. The higher the value, the better. A value of 1 is highly unlikely; such networks are likely to have redundancies.
Detour Index (DI)	A test of how well a network minimizes travel distance.	$DI=\frac{straight\ distance\ D(S)}{network\ distance\ D(N)}$	Values ranges from 0 to 1. It is influenced by the nature of the terrain.

Source: Dill, 2004; Tresidder, 2005; Ducruet and Rodrigue, 2013; VTPI; 2014.

[9] A link refers to a road segment bounded by two nodes.
[10] A node is an intersection of two links or the end of a link (commonly called a cul-de-sac).

These three measures were selected primarily for the following reasons. First, they were relevant to this study, considering their objectives. For example, *DI* revealed how direct the links were thus, providing an idea about cost of travel and travel time. *SD* and *GI* on the other hand, showed overall sufficiency of networks in an area and could track the growth of a network over time respectively (Ducruet and Rodrigue, 2013). Second, they are not data intensive or demand excessive computer processing especially *SD* (Dill, 2004). Third, their output values, with the exception of street density, are comparable along the same scale (i.e. range from 0 to1) and are easy to interpret.

Nevertheless, a logistic function was applied to the values of SD to normalize them to range from 0 to 1 where 1 represented a heavily dense network and vice versa. The normalization allowed for direct comparison between the three measures. Equation 3.16 shows the logistic function used.

$$SD(x) = \left({}^{1}\!/_{(1 + e^{-x})} \right) * 2 - 1 \qquad \text{(Equation 3.16)}$$

where ***x*** is the Street Density value for a particular area which was defined here as the Afram Plains mainland and the various agricultural zones in the study area.

Apart from the above advantages, the relative simplicity and easy interpretation of the chosen measures (Dill, 2004; Ducruet and Rodrigue, 2013) also made them ideal for this research. The following steps were implemented to determine the connectivity measure indices.

For Afram Plains mainland:

First, the author ensured that all the roads were unique line segments separated at each intersection by editing the lines and deleting all duplicate features.

Street density

A. Calculate the length of all roads in kilometers.
B. Calculate the area of Afram Plains mainland in square kilometers.
C. Divide A values by B values to get Street Density

Gamma Index

A. Obtain the total number of unique line segments from the road layer's attribute table.
B. Generate unique nodes for the roads.
C. Calculate Gamma Index based on GI Equation (Table 3.23).

Detour Index

A. Calculate sinuosity (Esri, 2011(c)) for each segment of road feature to derive DI.
B. Determine the overall descriptive statistics for all road features. The mean represented the DI for the entire area.

For agro-zones:

In doing this, the author first obtained all roads that were within each agro-zone. Similar steps carried out for each of the indices for the entire study as presented above were implemented here. The only difference this time was that they were computed for each separate agro-zone.

Based on the results of the above tests particularly the *SD* and *GI*, the author could determine whether the expanded road network was intensive or extensive. Where the values were closer to 1, it denoted an intensive network and vice versa. Afterwards, the connectivity indices (*SD*, *GI*, and *RI*) were matched against the mean overall potential spatial accessibility index ($OPSA_i$) for all the modeled scenarios (Table 3.23) according to the agricultural zones to test for any significant relationship between them. This was tested using Pearson's correlation coefficient based on this null hypothesis:

H_o5: *There is no correlation between the variables ($\rho = 0$).*

The variables were also plotted against each other in a chart for comparison purposes.

4. MODELLING SPATIAL ACCESSIBILITY FOR A MULTI-MODE TRANSPORTATION SYSTEM

In this chapter, the author presents the results from the GIS modelling of spatial accessibility based on the popular mode of transport in the Aframs Plains. The results are responses to research question 1: *What is the spatial accessibility of the inhabitants to market centers based on a multi-mode transportation system?* And its two sub-questions: *Is there any geographic disparity of spatial accessibility to market centers in the area among the agricultural zones? Is there any significant difference in the spatial accessibility to market centers by various modes of transportation across the agricultural zones?*

4.1 Existing Landscape of Spatial Accessibility

It was established in the background information and literature review that spatial access to market in the Afram Plains is limited or constrained. However, the extent of the problem, was not well documented. For example, no existing study had yet quantified the level of spatial accessibility to market in the area. With the ultimate aim of this study being improving spatial accessibility in the area, the author began by gauging the existing landscape of spatial accessibility in the area based on a survey questionnaire.

4.1.1 Residents' Travel Experiences

This section details the views of sampled residents concerning their travel experience from farm to market as captured through the research survey. There were three main questions posed to the respondents to capture their views. The first question asked the respondents to indicate their subjective perception about spatial accessibility to their most frequently visited market on a scale of 1 to 10, where “1” means “extremely easy” and “10”, means “extremely difficult”. The results are illustrated by Figure 4.1 below.

Based on Figure 4.1, over 70 percent of the respondents who answered the question (*n*=190) perceived spatial accessibility to their most frequently visited market as extremely difficult.

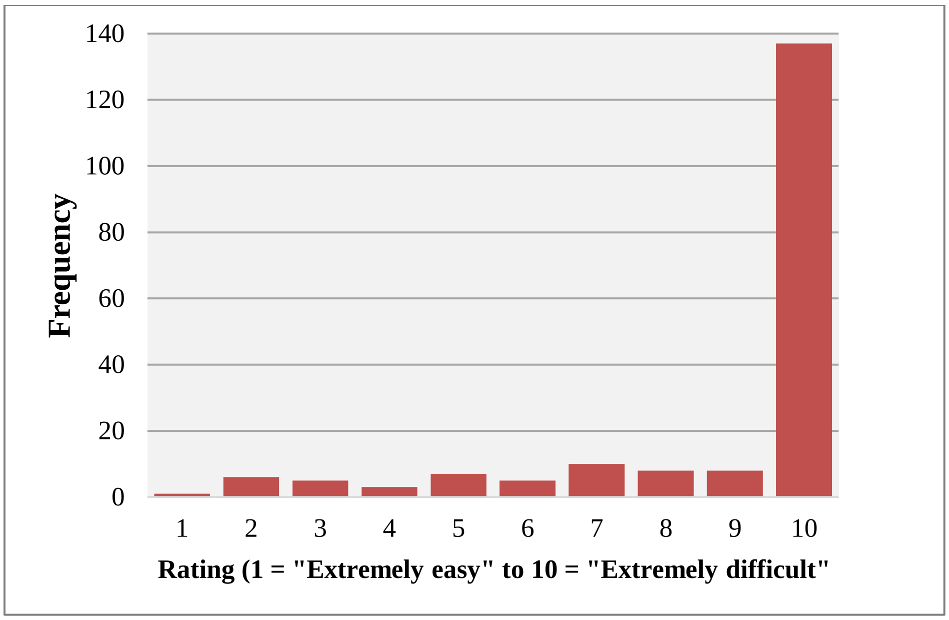

Figure 4.1: Perception of spatial accessibility to market

The second question was concerned about the main challenge(s) of spatial accessibility to market in the area and the rating of such challenge(s) on a scale from 1 to 10, where “1” means the “least critical” and “10” means “very critical”. Figures 4.2 and 4.3 show that the poor nature of existing roads is clearly a major concern to most residents in the area. The majority (80.9 percent) of the respondents (*n* = 141) rated poor road condition as a very critical challenge to spatial accessibility to market in the area. The next critical challenge as identified by the respondents was the lack of vehicles.

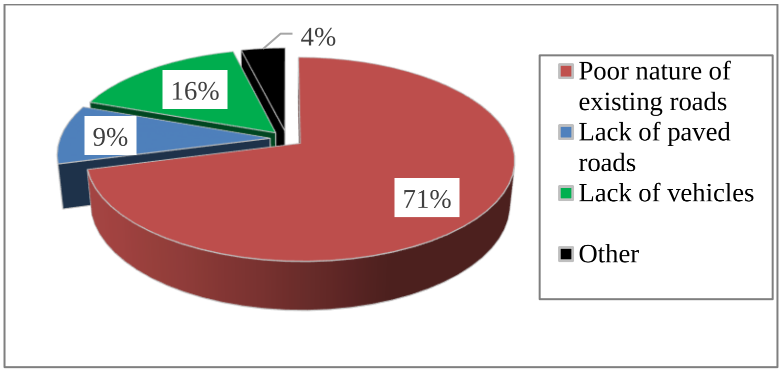

Figure 4.2: Main challenges to spatial accessibility

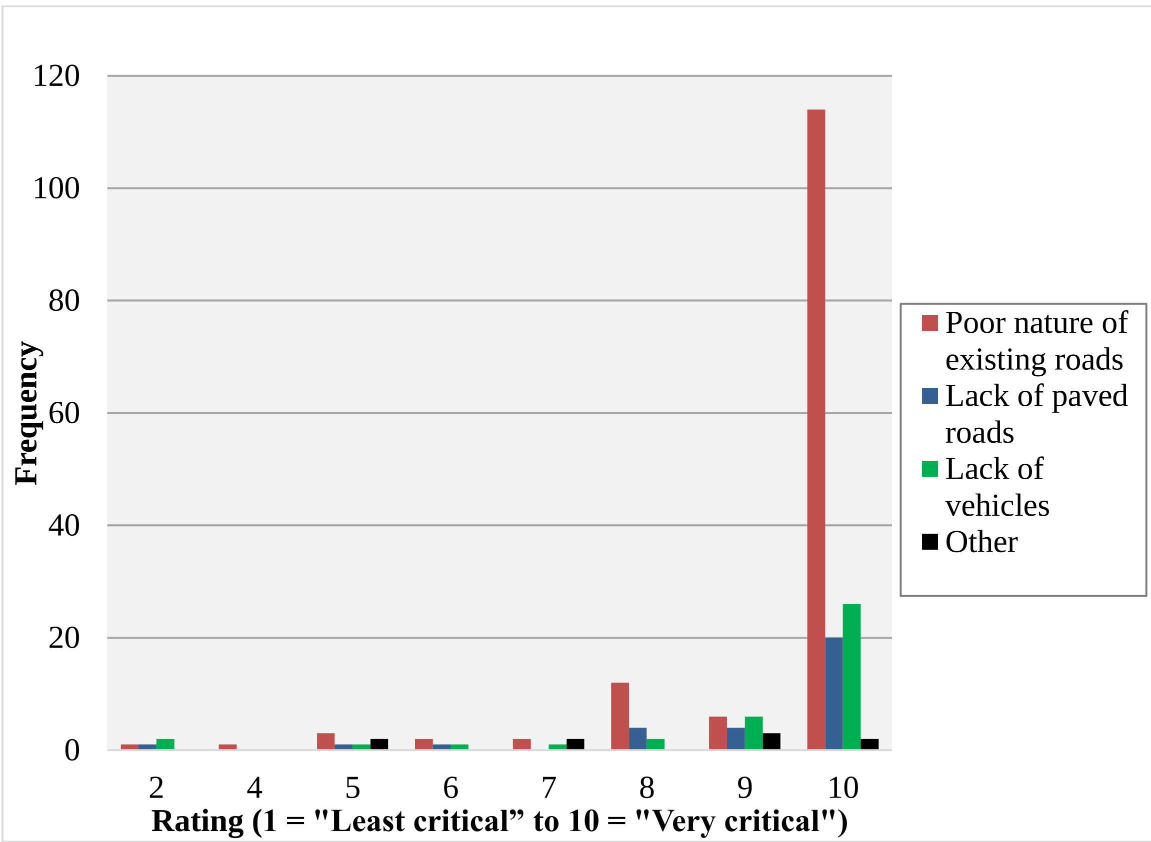

Figure 4.3: Rating of challenges to spatial accessibility

The third question simply asked the respondents to provide a brief description of their journey to their most frequently visited market (including point of origin, nature of roads or paths, challenges or hazard(s) and how such challenges affect their entire trip). The author used NVivo to analyze their responses based on the frequency of each word

(Table 4.1). According to Table 4.1, snake infestation is the common problem encountered by the residents. Many attributed this to the bushy nature and narrowness of the farm paths. In fact, these transport networks are footpaths or tracks created by individual farmers or vehicles (usually tractors) as opposed to formal networks created by civil engineers or road contractors. As a result, the roads are often quickly taken over by weeds (which subsequently become hideouts for poisonous snakes) if not maintained regularly. A check with the local health centers in the area revealed that snake bites are among the commonly reported health cases in the area thus confirming this problem.

Table 4.1: Problems encountered during farm-market trips

Problem	Count	Weighted Percentage (%)
Snakes	56	11.1
Bad roads	35	6.9
Vehicular breakdown / accidents	22	4.4
Loss of produce	17	3.1
Flood / Waterlogged roads / vehicles get stuck in mud	14	2.8
Potholes	12	2.4

The next major problem was bad roads, including issues like narrow paths, drenching from dew on weeds, rough terrain, and collapsed or no bridges. Following this problem was vehicular breakdowns and accidents, which was associated with road condition as farmers revealed that their means of transportation, especially the cars and trucks, often overturned or broke down due to the poor nature of the roads. They indicated that some roads were badly eroded with presence of huge gullies and thus, making vehicular movement precarious and even impossible.

In other instances, many road networks in the area were prone to flooding and limited mobility. When the waters receded, they left behind puddles, soggy and muddy roads. Vehicles that attempted crossing them often got stuck in them. The floods and continuous use of the roads also wore down the roads and created potholes, one of the main causes of vehicular breakdowns in the area. Road blockage and vehicular breakdown due to floodings and deteriorated roads respectively, directly contributed to post-harvest losses. Other problems noted from the NVivo analysis included loss of buyers, long travel distances, longer delays in travel, increasing cost of transportation and decreasing number of transport operators.

The results presented in this section affirmed almost all the problems noted in the literature review. Besides, it also revealed new problems such as snake infestation/bites, narrow paths, drenching from dew on weeds and collapsed or no bridges.

4.1.2 GIS Model of Spatial Accessibility to Market

Having understood the current nature of spatial accessibility in the study area based on the views of the respondents, the author proceeded to quantify the current situation using GIS. The results are presented in the following subsections.

4.1.2.1 Travel Time to Market

One of the steps for determining Potential Spatial Accessibility (PSA) (likely travel experiences of people) to market in this study was to model the incremental travel time from the communities as well as any location in the area to a market. This step utilized the terrain distance instead of planimetric distance in modelling for impedance, and thus presented a more realistic output for travel time. The outputs were further processed to show the minimum travel time needed to visit a market (Figure 4.4).

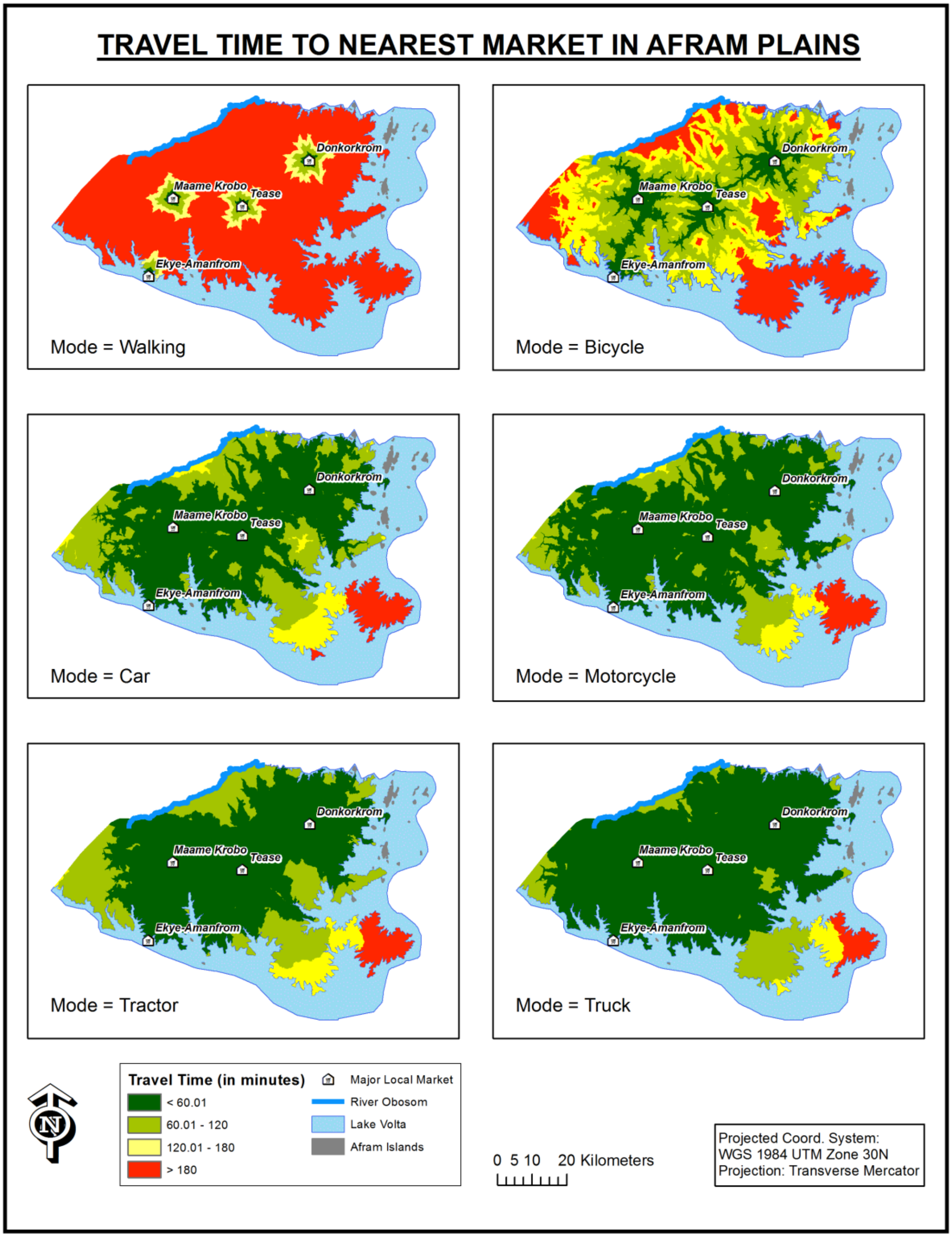

Figure 4.4: Travel time to nearest market

Figure 4.4 shows six hypothetical travel experiences in the Afram Plains assuming each travel mode was the sole means of transportation. From the map, walking provides the worst experience in terms of travel time whereas truck provides the best-case scenario. Spatially, areas near the four main markets consistently showed up as within an hour's reach from a market.

The above finding was not too surprising as some of the best road networks in the entire area were found around the main market towns. Besides, they were among the largest towns with relatively large population and contained major social facilities like high schools and medical centers. Thus, they attracted more transportation investment.

On the other hand, the south-eastern corner of Afram Plan (the south-eastern peninsula area) suffered from poor spatial accessibility. People in this area required over three hours to travel to the nearest market regardless of transportation mode. This area is known to have the fewest road networks (excluding tracks/paths) but have many small towns and villages scattered along the lake shore which represent a sizeable population (48,080 or 21.5 percent of the area's population). The acute lack of roads in this area makes travelling to markets within the area very expensive. As a result, there is very minimal interaction between residents here and other parts of the Afram Plains. Instead, the residents often prefer to spend two hours crossing the lake to Fanteakwa district in the south to visit Dzemeni market, a very well-known market outside of Afram Plain.

In general, constructing new roads and introducing more reliable vehicles in the area could enhance spatial access to markets. One way this could be done is by the government incentivizing private investors to invest in the transport business or assisting farmers' unions in procuring tractors for their activities. Yet, in the more deprived areas, roads are still needed to improve the overall spatial accessibility in the area.

4.1.2.2 Potential Spatial Accessibility by Separate Modes of Transportation

A multi-mode potential spatial accessibility model would be classified as part of location-based spatial accessibility group of models adopted in this study (Figure 4.5). Based on Figure 4.5, the general trend was that, the western part of Afram Plains had better capacity to reach a market than the rest of the area. Among the modes of transport, truck, motorcycle and car provided expansive and better potential access to market than the others. Walking recorded the worst form of potential spatial access to market. In addition, it was clear that, proximity to a market and presence of road networks enhanced a location's capacity to reach a market. It was also clear that, size of a market (an indicator for attraction) indeed counted; the size of Maame Krobo market made it stood out as the market with the best level of potential spatial accessibility. Nevertheless, it is necessary to point out that, areas around Maame Krobo market also had the best road networks (good asphalt roads motorable all year round) in the entire area.

Though the above observations provided a general picture of potential spatial accessibility in the area, they did not reflect a comprehensive description of spatial accessibility in the area. This was because, the residents did not rely on just one mode of transportation when visiting a market. Hence, any conclusion made based on one of the six outputs in Figure 4.5 would be erroneous; it would either exaggerate or understate the problem. Hence, an Overall Potential Spatial Accessibility (OPSA); a holistic measurement that accounted for all modes of transportation based on the residents' actual travel experience was needed.

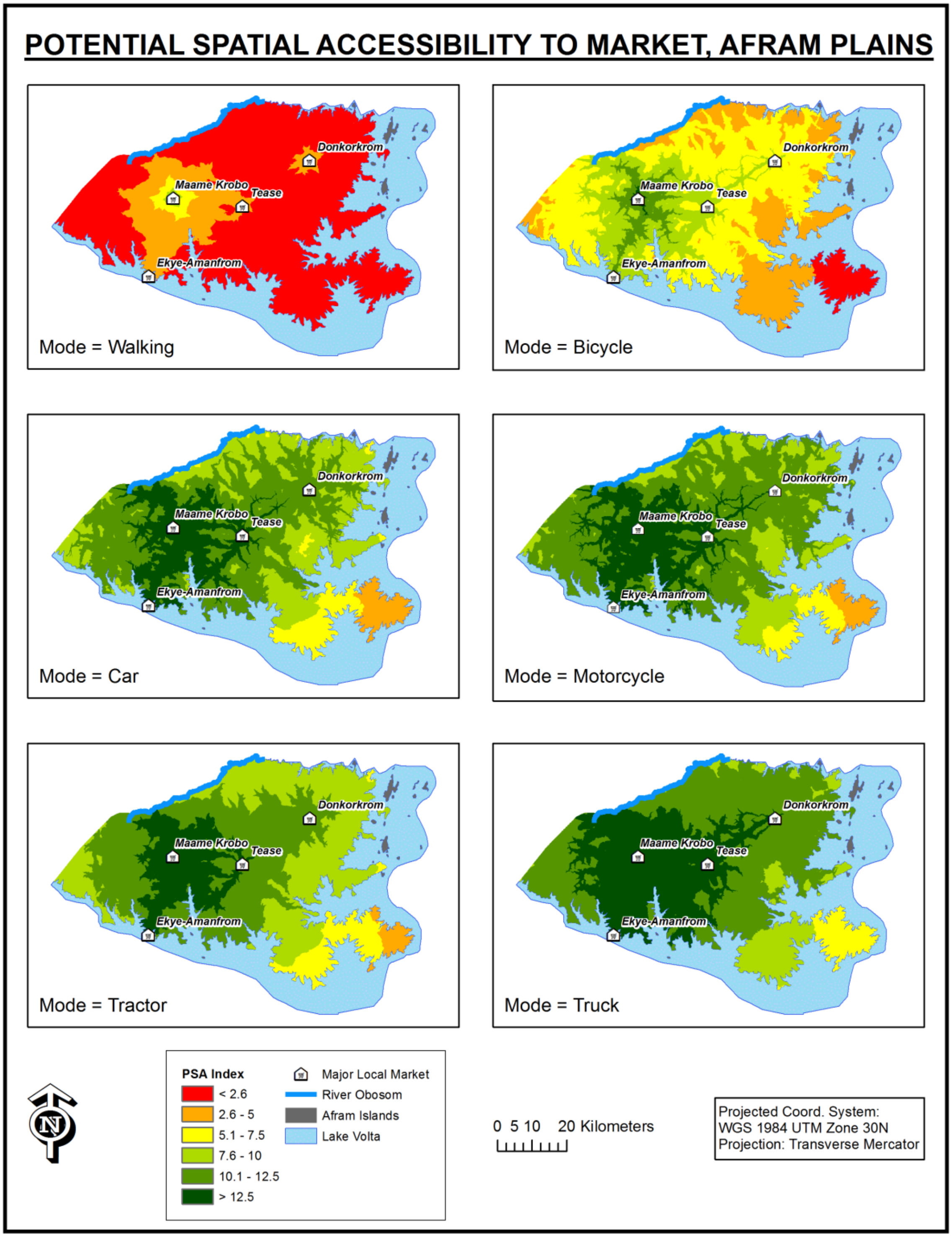

Figure 4.5: Potential Spatial Accessibility to market

4.1.2.3 Overall Potential Spatial Accessibility

This section presents the result of the OPSA model that accounted for potential travel experiences of residents in Afram Plains. The OPSA was based on weighted PSAs for each transportation mode. The weights were derived from survey responses indicating preferred means of transportation when visiting a market. The survey responses are shown in Table 4.2 below.

Table 4.2: Residents preferred mode of transportation to market

Mode of transportation	**Frequency**	**Percentage**
Bicycle	17	9.3
Car	12	6.6
Motorbike	8	4.4
Tractor	62	34.1
Truck	12	6.6
Walking (Headloading)	71	39.0
Total	**182**	**100**

According to Table 4.2, most the survey participants (73.1 percent) travel to market either by walking or by a tractor. Motorbike is comparatively the least (4.4 percent) utilized mode of transportation in the area when visiting a market. The responses ultimately influenced the modelling of OPSA for the area (Figure 4.6).

From Figure 4.6, one can see how the weighting impacted the spatial pattern of OPSA in the area. The OPSA output conformed more to the popular modes of transportation in the area particularly tractor. Nevertheless, the general pattern remained virtually the same; the western half of the area and the immediate surroundings of the four main markets had better capacity to reach a market than the rest of the area. On the contrary, the south-eastern peninsula or Kwame Dwamenakrom agro-zone, as well as parts of the northern and eastern fringes had low level of access to market.

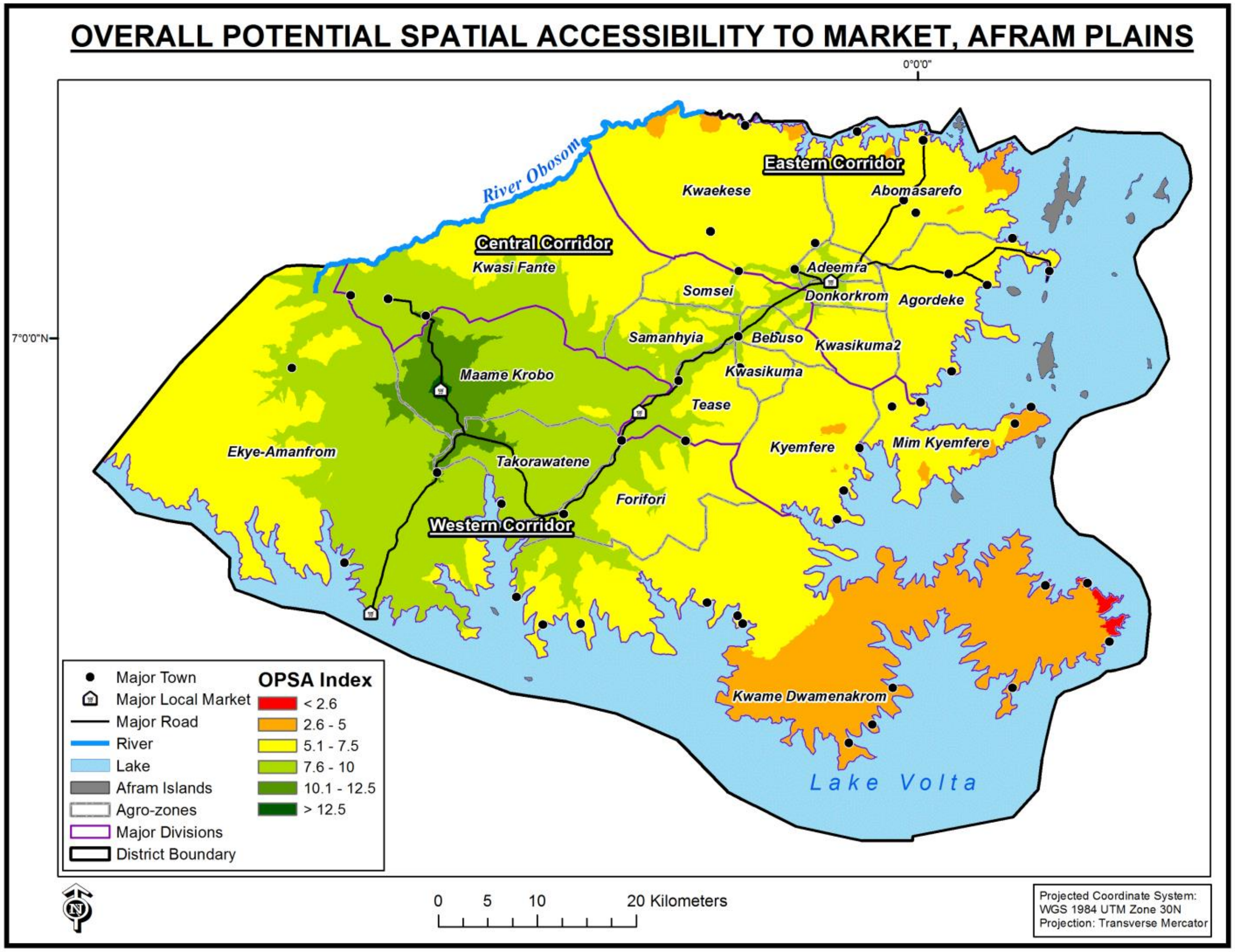

Figure 4.6: Overall Potential Spatial Accessibility to market

The following agro-zones recorded the best (Maame Krobo: $\bar{x} = 9.54$ and Takoratwene: $\bar{x} = 9.04$) and worst (Kwame Dwamenakrom: $\bar{x} = 4.93$ and Mim Kyemfere: $\bar{x} = 5.41$) OPSA to market.

4.2 Testing for Geographic Disparities in Spatial Accessibility

The first research question for this study sought to find if there was any spatial disparity in accessibility within Afram Plains particularly among the agricultural zones. In answering the question, two hypotheses were posed:

H_o1: *There is no significant difference in the mean overall potential spatial accessibility among the different agricultural zones, so that* $OPSA_1 = OPSA_2 = \ldots = OPSA_n$

H_o2: *There is no significant difference in the mean spatial accessibility among the six modes of transportation, so that* $OPSA_i = PSA_{\alpha, i} = PSA_{\beta, i} = \ldots = PSA_{n, i}$

Regarding the first hypothesis, ANOVA was used in the testing. The ANOVA test results showed that there was significant difference in the means of OPSA among the 19 agricultural zones ($F = 128106.412$, $df = 18; 1459007$, $p < 0.001$). A Tukey post-hoc test analysis revealed that each of the agricultural zone's mean OPSA was statistically different from the other in a pair-wise comparison ($p < 0.01$ in each case) except in these two cases: Adeemra versus Tease ($p = 0.998$) and Ekye-Amanfrom versus Samanhyia ($p = 0.74$). One could possibly infer from Figure 4.6 why the two cases were not significantly different; they seemed to have similar levels of OPSA (mostly between 5.1 and 10). In view of this result, the first null hypothesis (H_o1) was rejected, thus, concluding that potential spatial accessibility in the area significantly differed among the agricultural zones.

Regarding the second hypothesis, an ANOVA with repeated measures was used for the test. The repeated measures test result which was based on Greenhouse-Geisser correction indicated that, the mean PSAs for the six modes of transportation differed significantly from each other; $F = 48516474.53$, $df = 1.65$, $p < 0.001$. The Greenhouse-Geisser correction was considered since, Mauchly's test (test of sphericity) revealed that the assumption of sphericity had been violated; $\chi^2 = 9929428.41$, $df = 14$, $p < 0.001$. Hence, the Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.329$) was applied to correct the degrees of freedom. The Bonferroni post-hoc test also revealed that, in a pair-wise comparison, each of the variables differed significantly from the other ($p < 0.001$). The Bonferroni post-hoc test corroborated the maps in Figure 4.5 which showed differences among the six modes of transportation across the area. Like the first hypothesis, the results provided evidence for the rejection of the second null hypothesis (H_o2).

4.3 Comparing Spatial Accessibility: Perceived versus Modeled

The mixed method approach provided the author the chance to compare local perception of spatial accessibility to modeled spatial accessibility to market. Perceived spatial accessibility was based on survey respondents' journey experience to their preferred market while the modeled spatial accessibility was based on the incremental travel time surface discussed in sub-section 4.1.2.1. Concerning the latter, the author simply identified the travel time from a respondent's identified location to his or her preferred market by her preferred mode of transportation. Both Chi Square and Kruskal-Wallis H tests were used in this analysis.

The two statistical tests showed that both perceived and modeled spatial accessibility varied across the area. Regarding perceived accessibility, the Kruskal-Wallis H test indicated that there was a significant difference among the three major sub-divisions ($\chi^2 = 9.673$, df = 2, $p = 0.008$). The mean rank travel time to market were as following: 78.06 minutes for the Central corridor, 90.88 minutes for the Eastern corridor and 107.92 minutes for the Western corridor. In a post-hoc analysis, the results showed that, the differences existed only between the Central and Western corridor (p = 0.006) but not between the Central versus Eastern (p> 0.05) and Eastern versus Western (p > 0.05) pairings. The results from the Chi Square analysis ($\chi^2 = 10.582$, df = 2, $p = 0.005$) and the associated contingency table (Table 4.3) corroborated the above findings. According to Table 4.3, 63.5 percent respondents in the Central corridor indicated they were within 60 minutes from their preferred market. In the Western corridor, however, 66.7 percent respondents noted they were over an hour away from their preferred market therefore, making it the least accessible sub-division per the respondents.

Table 4.3: Relationship between major divisions and respondents' estimated travel time to their preferred market

		Estimated time for a travel experience		Total
		Within 60 minutes	*Over 60 minutes*	
Major division	Central	40 (63.5%)	23 (36.5%)	63
	East	32 (49.2%)	33 (50.8%)	65
	West	18 (33.3%)	36 (66.7%)	54
Total		**90 (49.5%)**	**92 (50.5%)**	**182 (100%)**

As noted already, the test results for modeled spatial accessibility similarly confirmed that spatial accessibility varied across the area (Kruskal-Wallis H: $\chi^2 = 30.704$, df = 2, $p < 0.001$ and Chi Square: $\chi^2 = 14.138$, df = 2, $p = 0.001$). The post-hoc analysis (under Kruskal Wallis H) though showed that, the differences existed between two pairings: Central-Eastern ($p < 0.001$) and Central-Western ($p = 0.002$). Regarding the associated contingency table (Table 4.4), though there were obvious differences (hence, corroborated the chi-square results), it generally differed from the perceived case. Unlike the previous case, over 50 percent of all respondents as well as in each of the three sub-divisions were within an hour's journey from a preferred market.

Table 4.4: Relationship between major divisions and modeled travel time to respondent's preferred market

		Travel Time to Preferred Market		Total
		Within 60 minutes	*Over 60 minutes*	
Major division	Central	37 (56.9%)	28 (43.1%)	65
	East	41 (60.3%)	27 (39.7%)	68
	West	47 (87.0%)	7 (13.0%)	54
Total		**125 (66.8%)**	**62 (33.2%)**	**187 (100%)**

Also, the Western corridor, in contrast with the previous case, recorded the most people (87 percent) within an hour from a preferred market. A similar situation occurred under Central corridor: recorded most people (43.1 percent) who were over an hour from a preferred market. The above contrast was further highlighted under the associated mean rank results (Table 4.5). The mean rank travel times to market (121.14 minutes for the Central corridor, 89.04 minutes for the Eastern corridor and 67.58 minutes for the Western corridor) were essentially, the reverse of their equivalents under perceived spatial accessibility. So, in essence, the findings for modeled and perceived spatial accessibility covertly contrasted each other despite both affirming that spatial accessibility varied across the area.

Table 4.5: Comparing mean ranks of perceived and modeled travel times to respondent's preferred market

Major division	Perceived Travel Time		Modeled Travel Time	
	N	*Mean Rank*	*N*	*Mean Rank*
Central	63	78.06	65	121.14
East	65	90.88	68	89.04
West	54	107.92	54	67.58
Total	**182**	**-**	**187**	**-**

To examine any difference between perceived and modeled spatial accessibility, with mean travel time of 117.0 minutes and 76.5 minutes respectively, the Wilcoxon Signed Ranks test was conducted and it affirmed the above proposition (Z = -2.515, p = 0.012). In addition, a Spearman correlation test showed a significant but weak negative correlation between the two measures (r_s = -0.184, p = 0.014). This outcome, although quite odd, was not surprising. The reason being that, local perceptions are often susceptible to inaccuracies; a direct result of poor judgment associated with overestimation or underestimation of distance measures on the part of respondents (Leach and Mearns, 1996; Briggs, 2005). Nevertheless, this result could also be indicative some factors that might be influencing local perception of spatial accessibility that were not fully accounted for in the modeled spatial accessibility. Despite such uncertainty, the results still revealed an interesting paradoxical pattern.

4.4 Controlling Factors of Spatial Accessibility in Afram Plains

4.4.1 Travel Distance / Travel Time

Distance is widely known as a key factor that influences spatial accessibility. In view of that, the author sought to find out how important distance was to the residents in their journey to market. The two main questions were: how did distance affect the decision to choose a market as well as the visiting frequency to a particular market?

Regarding the first question, distance was found to be a major factor in determining which market respondents chose. A crosstab/chi square analysis revealed that there was a strong significant association ($\chi^2 = 148.4$; df 8; $p < 0.001$) between residents' choice of market and their location (Table 4.6). Majority of the respondents selected the nearest market or one within their vicinity. For instance, residents within the Eastern corridor massively patronized the Donkorkrom market (87 percent) which is located in the north-eastern part of the study area. A similar trend was seen in the case of the Western corridor where most the respondents (84.7 percent) showed they visited the markets in Maame Krobo (57.6 percent) and Ekye Amanfrom (27.1) which are in the Western corridor. Maame Krobo is the largest market in the Western corridor (in terms of size and traders), and thus is considered as more attractive.

Table 4.6: Relationship between major divisions and respondent's preferred market

		Preferred choice of market					Total
		Donkorkrom	*Ekye Amanfrom*	*Maame Krobo*	*Tease*	*Other*	
Major division	Central	22 (31.9%)	3 (4.3%)	12 (17.4%)	19 (27.5%)	13 (18.8%)	69
	East	60 (87.0%)	1 (1.4%)	4 (5.8%)	1 (1.4%)	3 (4.3%)	69
	West	1 (1.7%)	16 (27.1%)	34 (57.6%)	3 (5.1%)	5 (8.5%)	59
Total		**83 (42.1%)**	**20 (10.2%)**	**50 (25.4%)**	**23 (11.7%)**	**21 (10.7%)**	**197 (100.0%)**

In the case of the Central corridor, the association was not as apparent as was in the previous situation. Even though, Tease market is the main market in the Central corridor, it was the second preferred market (27.5 percent). This could be attributed to the centrality of the area thus, giving the residents the liberty to also choose from markets in the adjoining sub-divisions; including Donkorkrom market (31.9 percent) in the East and Maame Krobo market (17.4 percent) in the West. In fact, the average travel time by tractor (the second preferred means of transport to market) was less than an hour from both Donkorkrom and Maame Krobo markets.

Notwithstanding, distance came up short to have any influence on resident's frequency of visit to market. A correlation analysis ($r = -0.056$, $N = 172$, $p = 0.469$) revealed that there was no significant relationship between the average frequency of market visits in a week and the travel time to their preferred market location. This result reflected the popular view from the field interview that the residents usually travelled to market only during the harvest season when they had some produce to sell. Some market travels also occurred during the planting season when they visited the market to get farm tools and agro-chemicals for their farms. According to them, regular visit to market was not a common practice. It could therefore be asserted that improvements in road systems might not necessary increase the number of times farmers/residents visit the market. Nevertheless, it could create new opportunities for people to diversify their economic activities and investments in other areas due to possible reduction in transportation cost.

4.4.2 Consumer Preference: Market

Consumer preference or choice is also widely acknowledged as a vital controlling factor in people's access to social facilities. Its impact, for example, was clearly seen in the Multi-MODAM spatial accessibility model introduced in this research. In this section, the author reports the survey respondents' choice of market and their associated reasons.

Table 4.6 above actually, also provides insight into respondents' preference for market. As noted already, Donkorkrom was respondents' most patronized market (42.1 percent). In a descending order, the other preferences were as following: Maame Krobo (25.4 percent), Tease (11.7 percent), Other Markets (10.7 percent), and Ekye Amanfrom

(10.2 percent). The associated chi square result (χ^2 = 148.442, df = 8, $p < 0.001$) similarly confirmed that, there was a significant spatial association regarding residents' market preference. In other words, residents in the separate sub-divisions had a spatial bias for market for their trading activities. This finding here however, could be seen as pertaining more to the distance or travel time factor discussed already in the previous sub-section.

Nonetheless, an analysis of the level of preference (on a scale of 1 to 5; 1 being rarely patronize and 5 being often patronize) of a market, provided a better understanding of resident's preference for markets in the area. A Kruskal-Wallis H test showed that the preference for the top two large markets, Maame Krobo and Donkorkrom, varied significantly among the major sub-divisions (χ^2 = 14.574, df = 2, $p < 0.01$ and χ^2 = 21.629, df = 2, $p < 0.001$ respectively). A post-hoc analysis showed that, for Maame Krobo, the differences were only significant between the Eastern versus Central corridors ($p < 0.01$) and Eastern versus Western corridors ($p < 0.001$). But in the case of Donkorkrom, significant differences existed between all sub-divisions ($p < 0.05$). The other markets preference levels did not differ significantly among the major sub-divisions. The results implied that, in terms of the top two markets, preference for them varied significantly in the area.

Furthermore, gender was also found to have a significant association with the choice of market (χ^2 = 12.427, df = 4, $p = 0.014$), indicating that, males and females had different preferences for market in the study area. The associated contingency table (Table 4.7), showed that, males in general, preferred Donkorkrom (35.7 percent) and Maame Krobo (32.5) markets to the rest of the markets. Females on the other hand, preferred Donkorkrom (53.6 percent) to the rest. This pattern could be linked to the major produce cultivated and sold by the different sex groups (Table 4.8). Males primarily produced tuber crops (54.8 percent), which were mainly sold at the Maame Krobo market whereas, females mainly produced grains (44.1 percent), the major commodity sold at Donkorkrom.

Table 4.7: Relationship between gender and preferred choice of market

		Preferred choice of market					Total
		Donkorkrom	Ekye Amanfrom	Maame Krobo	Tease	Other	
Sex	Male	45 (35.7%)	10 (7.9%)	41 (32.5%)	15 (11.9%)	15 (11.9%)	126
	Female	37 (53.6%)	10 (14.5%)	9 (13.0%)	7 (10.1%)	6 (8.7%)	69
Total		**82 (42.1%)**	**20 (10.3%)**	**50 (25.6%)**	**22 (11.3%)**	**21 (10.8%)**	**195 (100%)**

Table 4.8: Relationship between gender and major crops cultivated

		Major crop grown			Total
		Tuber (*Yam / Cassava / Cocoyam*)	Grain (*Maize / Millet*)	Other	
Sex	Male	69 (54.8%)	51 (40.5%)	6 (4.8%)	126
	Female	28 (41.2%)	30 (44.1%)	10 (14.7%)	68
Total		**97 (50.0%)**	**81 (41.8%)**	**16 (8.2%)**	**194 (100.0%)**

In terms of reasons for preferring a particular market over the others, "proximity" was found to be the dominant reason (48.7 percent) across all major sub-divisions. This finding also supported the earlier finding and conclusion that, distance was a major factor that influenced residents' choice of market. The second reason was "availability of buyers" (33.9 percent); a factor closely associated with the size or attractiveness of the market but not the subdivisions. These observations affirmed existing theories of consumer behavior: proximity and attraction of a facility or service influence people's decision to patronize it not (Hotelling, 1929; Huff, 1964; Church and Murray, 2009). The reasons were also highly associated with the major sub-divisions ($\chi^2 = 26.206$, df = 6, $p < 0.001$). According to the contingency table (Table 4.9), "proximity" primarily influenced the decision among majority of residents in the Eastern (69.1 percent) and Western (46.3 percent) corridors. In the Central corridor, “availability of buyers” was the main reason (47.8 percent).

Furthermore, comparing respondents’ preferred market choice to reasons for choosing a market, over 59 percent of the respondents suggested that “proximity” was the main reason for choosing any markets except Maame Krobo, where 57.8 percent respondents attributed it to the “availability of buyers” (Table 4.10).

Table 4.9: Relationship between major divisions and main reason for preferred choice of market

		No. 1 reason for preferred choice of market				Total
		Good sale price	Availability of buyers	Proximity	Other	
Major division	Central	7 (10.4%)	32 (47.8%)	20 (29.9%)	8 (11.9%)	67
	East	8 (11.8%)	11 (16.2%)	47 (69.1%)	2 (2.9%)	68
	West	3 (5.6%)	21 (38.9%)	25 (46.3%)	5 (9.3%)	54
Total		**18 (9.5%)**	**64 (33.9%)**	**92 (48.7%)**	**15 (7.9%)**	**189 (100%)**

Table 4.10: Relationship between preferred choice of market and main reason for choosing such market

		No. 1 reason for preferred choice of market				Total
		Good sale price	*Availability of buyers*	*Proximity*	*Other*	
Preferred choice of market	Donkorkrom	3 (3.7%)	20 (24.7%)	55 (67.9%)	3 (3.7%)	81
	Ekye Amanfrom	2 (10.0%)	3 (15.0%)	13 (65.0%)	2 (10.0%)	20
	Maame Krobo	7 (15.6%)	26 (57.8%)	8 (17.8%)	4 (8.9%)	45
	Tease	1 (4.5%)	6 (27.3%)	13 (59.1%)	2 (9.1%)	22
	Other	5 (25.0%)	8 (40.0%)	3 (15.0%)	4 (20.0%)	20
Total		**18 (9.6%)**	**63 (33.5%)**	**92 (48.9%)**	**15 (8.0%)**	**188 (100.0%)**

The exception of Maame Krobo might be due to its size and specific function (center for specific produce like tubers), making it appealing to many traders and buyers from all over Afram Plains and even other parts of Ghana. Although gender was previously seen as having influence over preference for a market, this time, it had no significant association with the main reason for choosing a particular market (Table 4.11). In other words, both males and females had similar reasons for choosing a market.

Table 4.11: Relationship between gender and reason for choosing a preferred market

		No. 1 reason for preferred choice of market				Total
		Good sale price	*Availability of buyers*	*Proximity*	*Other*	
Sex	Male	14 (11.9%)	38 (32.2%)	57 (48.3%)	9 (7.6%)	118
	Female	4 (5.8%)	24 (34.8%)	35 (50.7%)	6 (8.7%)	69
Total		**18 (9.6%)**	**62 (33.2%)**	**92 (49.2%)**	**15 (8.0%)**	**187 (100.0%)**

4.4.3 Consumer Preference: Mode of Transportation

As noted already, six main modes of transportation were identified from the survey, with "walking" (also called headloading; 39 percent) being the most popular choice followed by tractor (34.1 percent) (Table 4.2). Similar to choice of market, residents' choice of transportation mode also varied across the study area. In fact, preferred mode of transportation was significantly associated with the major sub-divisions ($\chi^2 = 35.443$, df = 10, $p < 0.001$). Notwithstanding, the chi-square analysis violated one assumption; 55.6 percent of the cells had expected count less than 5 instead of the maximum bar of 20 percent. Thus, this result could not be firmly used to make a claim. Nevertheless, walking was clearly popular among residents in the Central (47.6 percent) and Eastern corridors (43.5 percent) while in the West, it was mainly tractor (38 percent) (Table 4.12).

Table 4.12: Relationship between major division and preferred choice of transportation

		Preferred choice of transportation to market						Total
		Car/Taxi	*Tractor*	*Truck*	*Motorbike*	*Bicycle*	*Walking*	
Major division	Central	3 (4.8%)	23 (36.5%)	7 (11.1%)	0 (0%)	0 (0%)	30 (47.6%)	63
	East	6 (8.7%)	20 (29.0%)	4 (5.8%)	1 (1.4%)	8 (11.6%)	30 (43.5%)	69
	West	3 (6.0%)	19 (38.0%)	1 (2.0%)	7 (14.0%)	9 (18.0%)	11 (22.0%)	50
Total		**12 (6.6%)**	**62 (34.1%)**	**12 (6.6%)**	**8 (4.4%)**	**17 (9.3%)**	**71 (39.0%)**	**182 (100.0%)**

Again, gender was significantly associated with respondents' preferred choice of transportation ($\chi^2 = 15.048$, df = 5, $p = 0.010$). But, like the case under the major sub-division comparison, the chi-square analysis violated one assumption; over 20 percent of the cells had expected count less than 5. As a result, this result similarly, could not be used to firmly make a claim. Yet, the contingency table (Table 4.13) provided useful insight about the relationship between the two variables. For instance, males preferred tractor (34.5 percent) over walking (30.1 percent) and the rest (<14 percent each), whereas females mostly relied on walking (54.4 percent).

Table 4.13: Relationship between gender and preferred choice of transportation

		Preferred choice of transportation to market						Total
		Car/Taxi	*Tractor*	*Truck*	*Motorbike*	*Bicycle*	*Walking*	
Sex	Male	9 (8.0%)	39 (34.5%)	9 (8.0%)	7 (6.2%)	15 (13.3%)	34 (30.1%)	113
	Female	3 (4.4%)	22 (32.4%)	3 (4.4%)	1 (1.5%)	2 (2.9%)	37 (54.4%)	68
Total		**12 (6.6%)**	**61 (33.7%)**	**12 (6.6%)**	**8 (4.4%)**	**17 (9.4%)**	**71 (39.2%)**	**181 (100.0%)**

Table 4.13 result indirectly corroborated findings from previous research which noted that, due to lack of general technical/operational skills, poverty, and cultural bias

against women, females are generally disadvantaged socially. Thus, they tend to resort to non-motorized forms of transportation than their male counterparts (Porter, 2002(a); 2008; 2011; Lloyd et al., 2010; Porter et al., 2013).

Concerning the reason(s) for choosing a particular mode of transportation, they comprised space/convenience (61.7 percent), affordability (17.7 percent); availability (12 percent) and other (8.6 percent) (Table 4.14). This showed that space/convenience (ability to carry more as well as the expediency in carting the produce) was cherished the most by many residents. This factor was considered as helpful in reducing cost by minimizing the number of trips to market as well as reducing losses due to vehicular breakdowns or accidents. Again, these reasons were observed to have high spatial association with the major sub-divisions (χ^2 = 23.371, df = 6, p = 0.001) and confirmed by Table 4.14. Table 4.14 shows that, while space/convenience was overwhelmingly the deciding factor in both the Eastern (64.2 percent) and Western (78.7 percent) corridors, it was comparatively mild in the Central corridor (45.9 percent). A similar trend was observed with regards to the second important reason, affordability: in both Eastern (23.9 percent) and Western (10.6 percent) corridors. However, availability was ranked second most important reason (24.6 percent) in the Central corridor, whereas it was less and least important in the Eastern (7.5 percent) and Western corridors (2.1 percent) respectively.

Table 4.14: Relationship between major division and main reason for choosing a preferred mode of transportation

		No. 1 reason for preferred choice of transportation				Total
		Availability	Affordability	Space /Convenience	Other	
Major division	Central	15 (24.6%)	10 (16.4%)	28 (45.9%)	8 (13.1%)	61
	East	5 (7.5%)	16 (23.9%)	43 (64.2%)	3 (4.5%)	67
	West	1 (2.1%)	5 (10.6%)	37 (78.7%)	4 (8.5%)	47
Total		**21 (12.0%)**	**31 (17.7%)**	**108 (61.7%)**	**15 (8.6%)**	**175 (100.0%)**

Contrary to the above, there was no significant association ($p > 0.05$) between gender and the reasons for choosing a particular mode of transportation when traveling to a market. This signified that both males and females provided similar reasons for choosing a mode of transportation when traveling to a market. This was corroborated by Table 4.15.

Table 4.15: Relationship between gender and main reason for choosing a preferred mode of transportation

		No. 1 reason for preferred choice of transportation				Total
		Availability	Affordability	Space / Convenience	Other	
Sex	Male	13 (11.6%)	21 (18.8%)	67 (59.8%)	11 (9.8%)	112
	Female	8 (12.9%)	10 (16.1%)	40 (64.5%)	4 (6.5%)	62
Total		21 (12.1%)	31 (17.8%)	107 (61.5%)	15 (8.6%)	174 (100.0%)

5. DEVELOPING NEW ROAD NETWORKS IN AFRAM PLAINS

This chapter presents the results for research questions 2: "*Based on the level of spatial accessibility and economic potential, where are the areas of greatest need (i.e. poor access but high economic potential)?"* and 3a: "*If new roads are to be developed, which network model (intensive or extensive) is suitable and where should the roads be constructed to better improve spatial accessibility within the area?".* It also presents the results from the survey regarding residents' views on how to solve the problem of poor spatial accessibility in the area.

5.1 Resident's Views about Constraining Factors for Rural Road Networks

As part of the mixed method approach adopted in this study, the author sought inputs from the residents with regards to the best solution to improve spatial accessibility to market in the area. Possible solutions included "need for new roads", "need to improve existing roads", "need for new markets", "need to improve existing market" and "other". In general, the results showed that 39.8 percent of the respondents, favored building "new roads" as the best solution for improving spatial accessibility in the area. Other options, "improve existing roads", "improve existing market", "build new market" and "other" followed with 26.7 percent, 13.1 percent, 12.6 percent and 7.9 percent respectively (Table 5.1a, **bold** fonts).

The above results showed that, the need for new roads or improvement in existing ones clearly ranked high for improving spatial accessibility to market in the area. A follow-up question was to find out if the suggestions had any significant spatial associations with the major sub-divisions. The chi square test result however, proved otherwise ($p > 0.05$). In fact, the need for “new roads”, unlike the rest of the solutions, was quite evenly distributed among all the subdivisions, which suggested a ubiquitous need in the region (Table 5.1b). On the other hand, the option “improve existing roads” had some obvious variations. The responses were comparatively more emphatic in the Central (41.2 percent) and Eastern (39.2 percent) corridors than in the Western corridor (19.6 percent). This confirmed field observations where the Western corridor accounted for majority (55 percent) of all the paved (motorable) roads as well as some of the best roads in the area (Figures 3.2 and 3.5). This finding was crucial as it could help planners to apportion projects appropriately and fairly.

Table 5.1a: Relationship between major divisions and suggestion for improving spatial accessibility to market

		Suggestion for improving accessibility					Total
		Need for new roads	Need to improve existing road	Need for new market	Need to improve existing market	Other	
Major division	Central	24 (34.3%)	21 (30.0%)	15 (21.4%)	5 (7.1%)	5 (7.1%)	70
	East	29 (42.6%)	20 (29.4%)	5 (7.4%)	10 (14.7%)	4 (5.9%)	68
	West	23 (43.4%)	10 (18.9%)	4 (7.5%)	10 (18.9%)	6 (11.3%)	53
Total		**76 (39.8%)**	**51 (26.7%)**	**24 (12.6%)**	**25 (13.1%)**	**15 (7.9%)**	**191 (100.0%)**

Table 5.1b: Relationship between suggestion for improving spatial accessibility to market and major divisions

		Major division			Total
		Central	East	West	
Suggestion for improving accessibility	Need for new roads	24 (31.6%)	29 (38.2%)	23 (30.3%)	76
	Need to improve existing road	21 (41.2%)	20 (39.2%)	10 (19.6%)	51
	Need for new market	15 (62.5%)	5 (20.8%)	4 (16.7%)	24
	Need to improve existing market	5 (20.0%)	10 (40.0%)	10 (40.0%)	25
	Other	5 (33.3%)	4 (26.7%)	6 (40.0%)	15
Total		**70 (36.6%)**	**68 (35.6%)**	**53 (27.7%)**	**191 (100.0%)**

Since the need for new roads is critical in Afram Plains, the next step was to identify factors to be considered prior to building new roads. This question was posed to the respondents in the survey. The top results revealed by NVivo word frequency analysis is as shown in Table 5.2. Table 5.2 shows that, bridges must be included in the master plan of new roads. This finding also clearly affirmed the observation that there were many streams in the area without any bridges on them; the most probable hindrance to residents' daily activities. Hence, in accounting for cost of road construction, proximity to water bodies would certainly be critical. Other factors included terrain features and characteristics.

Table 5.2: Factors to consider before new road construction

Factor	Count	Weighted Percentage
Big bridges on streams	63	27.2
Fill potholes	6	3.0
Coat surface with asphalt /gravels	3	1.3
Avoid hills / cut it down	3	1.3

With regards to upgrading the existing roads, the top factors identified by the respondents included the following (Table 5.3):

Table 5.3: Factors to consider for road improvement

Factor	Count	Weighted Percentage
Big bridges on streams	43	19.7
Coat surface with asphalt /gravels	11	5.1
Build side gutters / drains	6	2.8
Increase road width and thickness	3	1.4

Among the above factors, building durable and sizeable bridges or culverts along the streams (both permanent and intermittent) was the top priority for the residents. However, building a new bridge is expensive and involves constructional design factors that are normally only considered after finding the ideal path for a new road. This factor was thus, taken into consideration (albeit indirectly) when developing the cost surface for improvement of existing roads. The study accounted for the "bridge factor" in developing new roads by way of avoiding or limiting the number of river crossings in the final cost surface.

5.2 Accounting for Economic Potential

Road construction can be very expensive hence, it is necessary to build roads in areas that need them the most (e.g. deprived and isolated communities) especially where funding is limited. Besides initial construction cost, roads also require periodic maintenance, which is likewise costly and could totally be neglected if beneficiary communities do not have the capacity (population and sufficient funds) to support and sustain it. To minimize the risk of road deterioration due to poor maintenance, some experts advocate for rural roads to be developed in such that they link major hubs of economic activity. Proponents of such idea argue that, the beneficiary areas would likely be able to generate enough funding to ensure such roads' maintenance. Thus, this study modelled economic potential across Afram Plains by implementing Equation 3.3 in GIS (Figure 5.1).

Figure 5.1 shows a north-south disparity of economic potential in the Afram Plains. In general, the north has higher economic potential than the southern region. It can also be inferred from the map that, economic potential was higher near major towns like Donkorkrom and Maame Krobo. In terms of agro-zones, Adeemra ($\bar{x}$ = 4.71; sd = 0.26) and Donkorkrom (m = 4.69; sd = 0.36) had the highest level of economic potential.

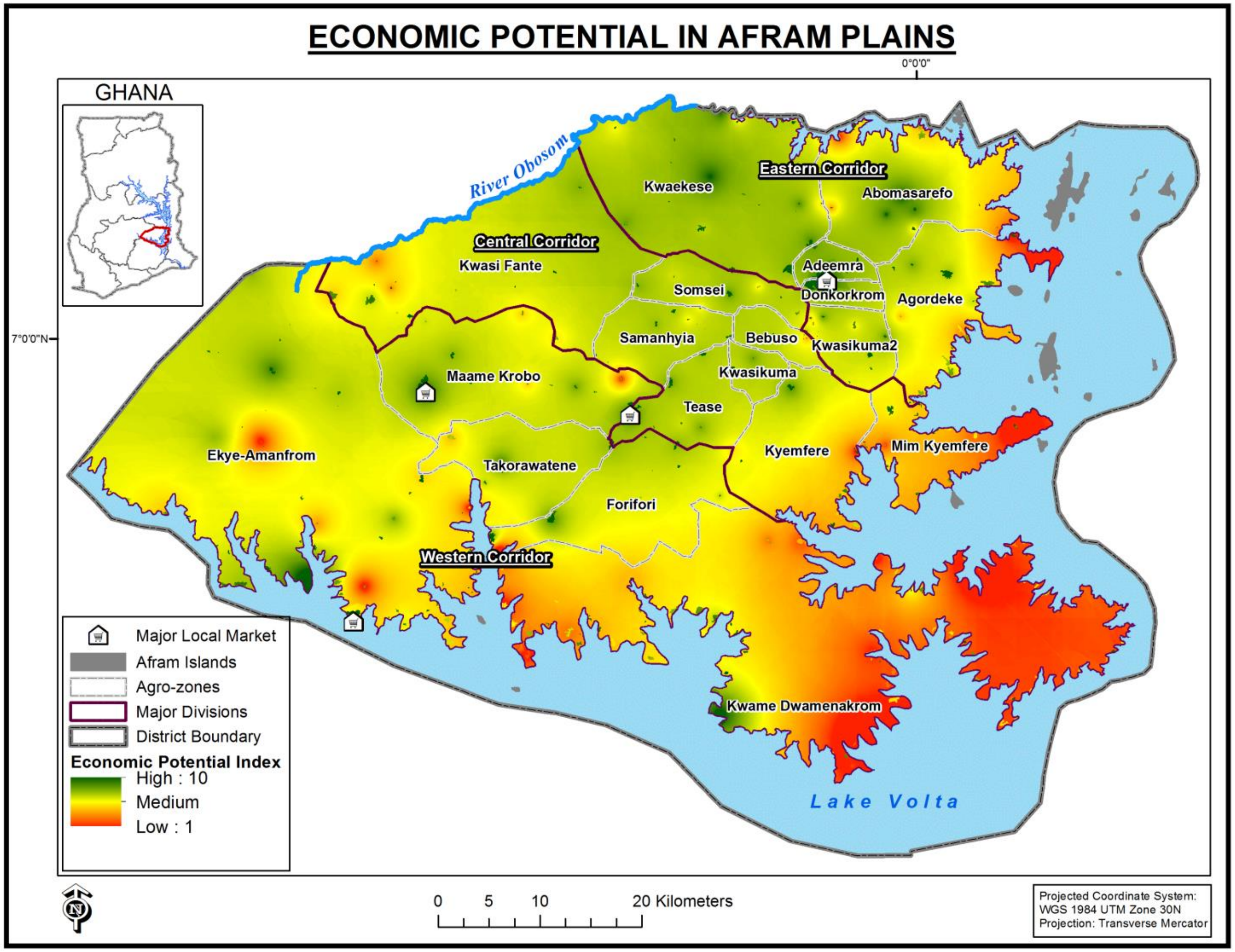

Figure 5.1: Economic Potential in Afram Plains

On the other hand, Kwame Dwamenakrom ($\bar{x}$ = 3.78; sd = 0.37) and Mim Kyemfere ($\bar{x}$ = 3.8; sd = 0.36) agro-zones have the lowest level of economic potential. In Kwame Dwamenakrom, an area best known for its high yield of tubers and grains, some communities (e.g. Sakabu No. 2, Tailorkope, Kwame Dwamenakrom and Kwabena Kwao) suffered from low yields during 2013 (the year used in the model) due to insufficient rains (Mensah, 2016). This low yield in 2013 reflected in the low economic potential recorded in that part of Afram Plains in Figure 5.1

5.3 Areas of Need

Based on the overall potential spatial accessibility and economic potential outputs, areas with the greatest need were identified. The areas of greatest need were defined as: places with low spatial accessibility but have high economic potential to sustain an intervention. Fuzzy modelling was used for this analysis (Figure 5.2).

The general pattern in Figure 5.2 showed that, the eastern half had a greater need than the western half; the higher the values, the greater the need and vice versa. In the west, Maame Krobo ($\bar{x}$ = 4.3; sd = 0.46) and Takoratwene ($\bar{x}$ = 4.48; sd = 0.37) agro-zones came out as the areas with the least need. This was not very surprising as these areas had the highest level of overall potential spatial accessibility and comparatively decent levels of economic potential. Contrary, Kwame Dwamenakrom ($\bar{x}$ = 6.05; sd = 0.57) and Kyemfere ($\bar{x}$ = 5.97; sd = 0.23), in the eastern half, recorded the lowest values. These two zones also had the lowest levels of overall potential spatial accessibility and economic potential. Per the fuzzy consequence rules, areas with such conditions were ascribed a value of 5 or greater which signified moderate to greatest needs. It was therefore not very surprising these zones came out as areas with the greatest need.

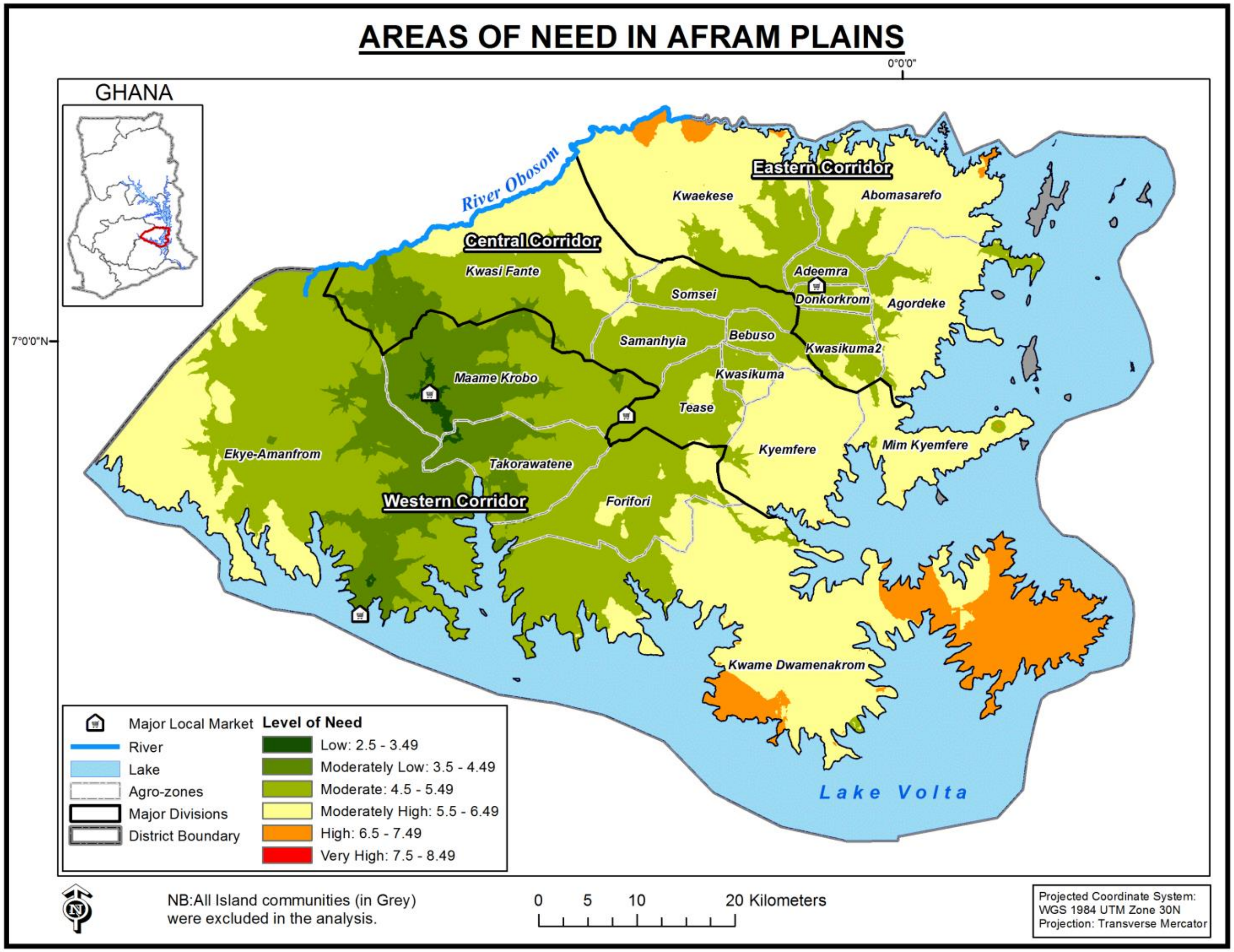

Figure 5.2: Areas of Need in Afram Plains

The above finding would enable planners to make meaningful decisions regarding where facilities need to be located. For example, the author combined the output with other factors to determine suitable areas to build new road networks or new market centers. The results and discussion regarding building new road networks follow below.

5.4 Determining New Roads Using a Step-wise LCP Approach

5.4.1 Modelling New Roads

The ultimate objective here was to improve spatial accessibility to market in Afram Plains. To achieve this objective, the author focused on ensuring that most communities (if not all) in the area could reach a market within sixty minutes of traveling. As discussed in the methodology, there were 152 communities which were not directly connected to a market via a paved or feeder road. The step-wise LCP approach effectively predicted new roads that linked the identified communities to the existing roads and ultimately to a market. The result is presented in Figure 5.3 below.

According to Figure 5.3, majority of the communities that got connected for the first time, were all located in the south-eastern peninsula. The new roads totaled 341.3 kilometers meaning, the overall length of Afram road networks (trunk and feeder roads) increased from 1124 kilometers to 1465.3 kilometers; showing a 23.3 percent increase in road networks. In addition, with the expansion of the road network, average travel time to the nearest market reduced from 71.33 minutes to 49.2 minutes. Yet, there were still some communities that were beyond the preferred sixty-minute travel time to a market. The farthest community for instance, was 100.7 minutes away from the nearest market. Though, in comparison with the current maximum of 261.52 minutes or 4 hours 21.5 minutes, it was an improvement.

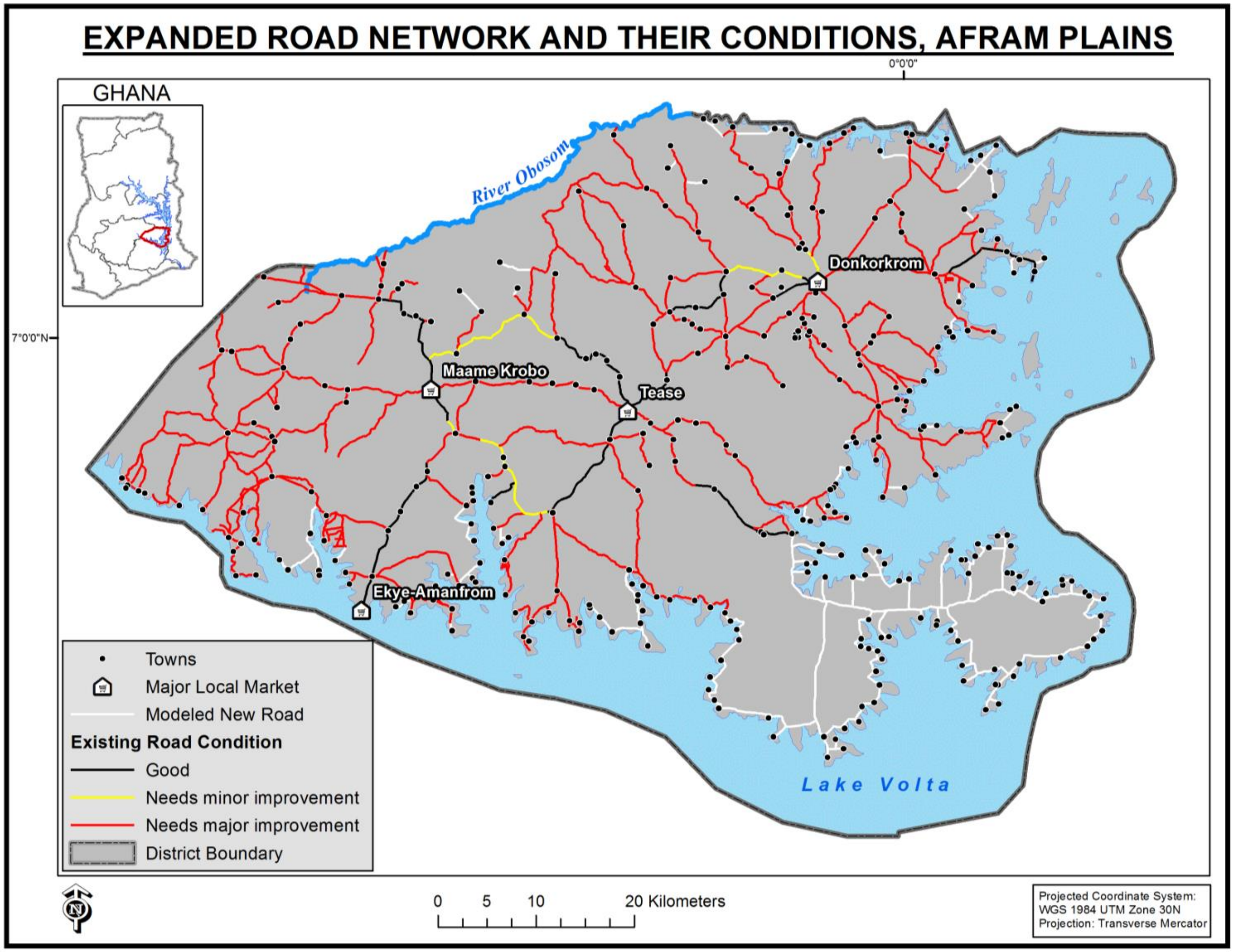

Figure 5.3: Expanded road network and their conditions

The failure to attain the preferable sixty-minute travel time target, was partly due to the deplorable conditions of some of the existing roads as shown in Figure 5.3.

In view of the above, a new scenario was modeled to assess how an improvement in road conditions would affect travel time to markets in the area. To account for improvement in road condition, all existing roads with speed limits less than 50 km/hour were increased to 50 kilometers (the normal speed for tractor on a newly built feeder road). The new scenario yielded an average travel time of 32 minutes and a maximum of 84.8 minutes. Table 5.4 shows a comparison between the two expanded road network scenarios. The new result still could not yield a ≤ 60-minute travel time to a market. This possibly was indicative of the need for faster vehicles, improvement of road surface to asphalt/concrete or additional market facilities. The last option was explored in this study and the results are presented in chapter six.

Table 5.4: Comparing road improvement scenarios

LCP Scenario	**Total Coverage (Towns)**	**Travel Time (in km)**	
		Average	*Maximum*
After New Roads Only	378	49.2	100.7
After New + Improved Roads	378	32.0	84.8

5.4.2 Prioritizing Development of Expanded Road Network

As noted already, budgetary constraints tend to hinder major developments like road construction or improvements for many governments, particularly in developing countries. So, for a proposed network to be considered as meaningful and worthy of implementation by policy makers, it was important to prioritize parts of the network. Prioritizing might also motivate policy makers to act about the project. Against this backdrop, some routes of the proposed expanded network in this study were prioritized

(Figure 5.4). The following included the criteria used for the prioritization:

1. Routes that connected towns currently not linked to the existing network.
2. Routes that connected several towns with large population; ≥ 500.

It is clear from Figure 5.4 that, the priority roads connected most of the large populated towns and towns that previously were not connected to the existing road network. Overall, a total of 164,440 persons (about 73.4 percent of Afram Plains' 2013 population) lived in the connected towns or were within 0.5 kilometers (equivalent to a 20-minute walking distance) of a priority road. Regarding newly connected towns, most of them were in the south-eastern peninsula. The priority roads summed up to 611.8 kilometers in length and formed about 42 percent of the entire expanded road network (1,124 kilometers). Out of that number, only 155.2 kilometers (25.4 percent) were to be constructed. The remainder were in either good condition or required minor to major renovations (Table 5.5).

Table 5.5: Conditions of priority roads

Road Condition	**Total Length (in km)**	**% of Total**
Good	98.7	16.1
Fair - Needing minor improvement	26.1	4.3
Poor – Needing major improvement	331.9	54.2
New - To be constructed	155.2	25.4
Total priority roads	**611.8**	**100.0**
Total marked for improvement only	358.0	58.5
Total marked for improvement or construction	513.2	83.9

The author acknowledges that, the above results may not necessarily be fully adopted and implemented in the area. Yet, the ideas presented here could serve as a guideline to planners in ensuring that they utilize scarce fiscal resources designated for development in the area in a more efficient way to benefit residents in the local area.

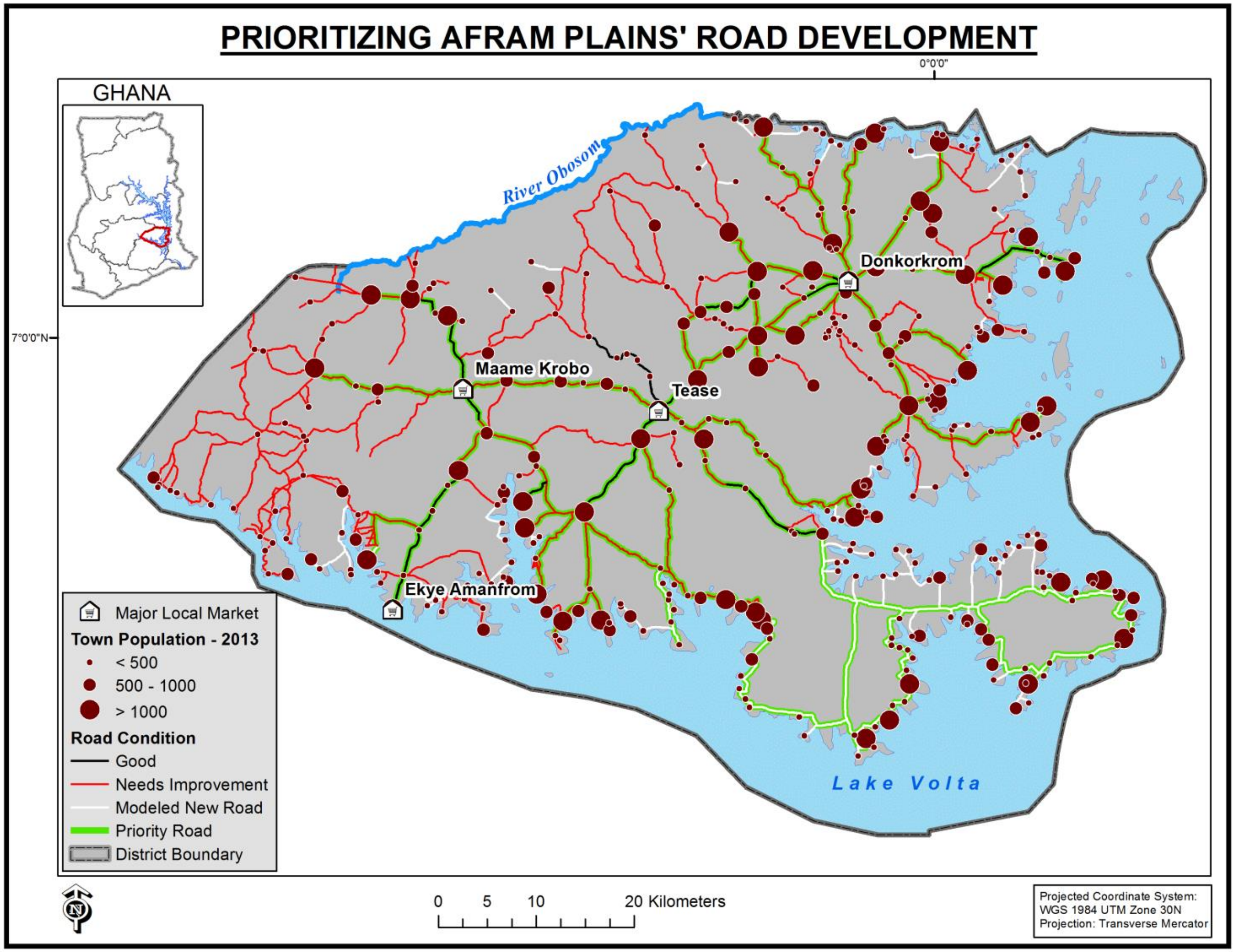

Figure 5.4: Prioritized routes of expanded road network

6. LOCATING NEW MARKET CENTERS USING A HYBRID LOCATION-ALLOCATION MODEL

In this chapter, the author presents the results regarding locating new markets in the Afram Plains based on the survey and Location-Allocation model. The results were directly in response to research question 3b: *If new markets are to be developed, where should they be located?*

6.1 Suitable Locations for New Markets

6.1.1 Proposals from Survey Respondents

Table 5.1a in chapter 5 provided a summary of the responses from survey participants regarding solution(s) to improving spatial accessibility to market in the area. The results showed that, many respondents (39.8 percent) favored "new roads" as the best solution for improving spatial accessibility in the area. "Need to improve existing market" (13.1 percent) and "Need for a new market" (12.6 percent) came up third and fourth respectively based on the responses (Table 5.1).

The results indicated that, in general, very few residents actually saw the need for a new market as a necessary means to improve spatial accessibility in the area. Could the opinions be place-specific though? According to the chi square analysis, there was no significant association ($p > 0.05$) between the major sub-divisions and their opinions. Nevertheless, the contingency table (Table 5.1b) suggested that the option "need for new market" had clear variations among the major sub-divisions in the area. Comparing the three sub-divisions, most the advocates for a new market (62.5 percent) were from the Central corridor. This finding suggested that, the option for a new market was more favored in the Central corridor than in the other corridors. Since the sub-divisions and even agro-zones were quite big in size with many communities, the survey provided the respondents the opportunity to identify specific locations ideal for a new market to be built. The top results from word frequency analysis were as following (Table 6.1):

Table 6.1: Factors/locations to consider before new market

Factor/Location	Count[11]	Weighted Percentage (%)
Forifori	5	16.1
Road side	4	12.9
Mmradan	4	12.9
Dedeso	3	9.7

The locations listed in the above table (except road side), are all located in the Central corridor. Among the towns, it was Mmradan that the respondents particularly stressed that a market was critically needed there. They noted that the nodal nature of the town (located at a point where several roads converge) made it ideal for a market; residents from surrounding villages could easily travel there to trade. Again, the projected population of the town in 2013 was 598, (representing 0.24 percent of Afram Plains' population) was sizeable enough to sustain trading. In the case of Forifori, the residents indicated that a new market had been built but was not yet opened for operation. Thus, they were hoping a new market could be opened soon to help boost their trading activities and also reduce their travel time to market. Regarding Dedeso, the respondents cited its location (along the main road) as an ideal location for a new market. In any of those locations, the respondents indicated that, locating the market by the road side would be ideal since such location will ensure visibility and easy access to potential traders.

[11] The total word/phrase count (N) was 31.

On the other hand, market improvement was the most popular factor among the respondents in the Eastern and Western corridors (40 percent each). This might indicate a general expectation to upgrade the markets at Donkorkrom and Maame Krobo. The top three factors they identified for consideration in the upgrade process are captured in Table 6.2. Other factors included improving the level of security and coating the market ground with concrete. The above findings guided the author to select relevant criteria for modelling suitable locations for new markets in the area. The results from the suitability analysis are presented in the section below.

Table 6.2: Factors to consider before market upgrade

Word	Count[12]	Weighted Percentage (%)
Storage facilities	7	10.1
Expand size	6	8.7
Guest houses	4	5.8

6.1.2 Suitability Analysis for Potential New Market Locations

A suitability analysis was conducted using WLC (Figure 6.1) prior to the LA modelling. In the suitability analysis, the Afram Islands were excluded to ensure that, only land-based transport systems (i.e. no ferry) were considered. Accounting for the off-shore communities would have required the inclusion of water transport systems; which was outside the scope of this research.

Figure 6.1 shows that, the areas suitable for a new market were mainly concentrated in the fringe areas like the south-eastern peninsula, the north-central and western areas.

[12] The total word/phrase count (N) was 69.

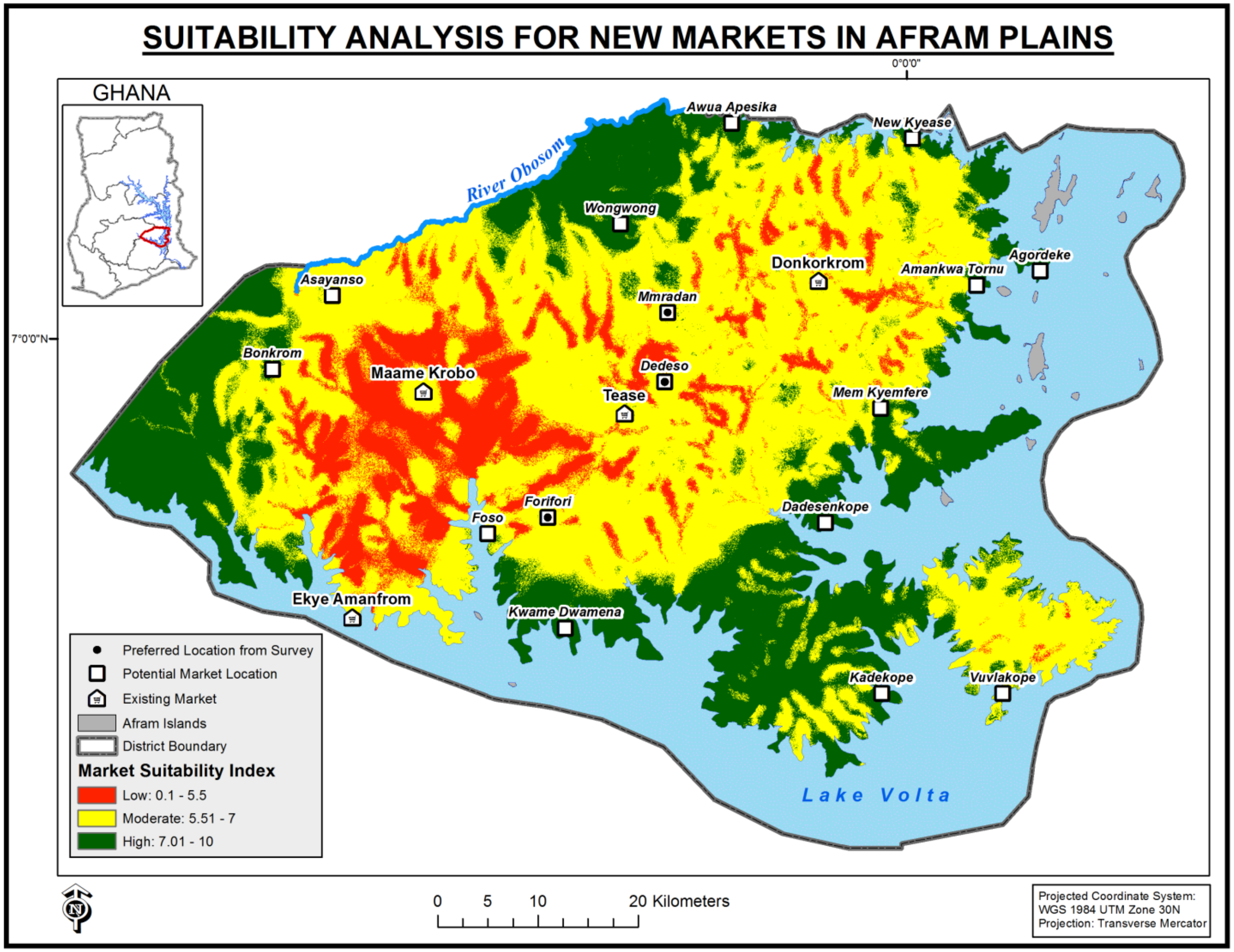

Figure 6.1: Suitability analysis of new market in Afram Plains

Unlike the western area, the southern peninsula and north-central areas had many communities particularly, the south-eastern peninsula (Figures 1.5 and 3.2).

Though the analysis was based on multiple factors (including distance from lake, rivers, and existing markets, proximity to populated areas and existing roads, and location in an Area of Need), the resultant pattern aligned relatively well with the pattern found in the Areas of Need (AON) map (Figure 5.2) in the sense that high suitability areas corresponded with moderately high to high level areas of need. This could be partly due to the relatively high weight (0.2 out of 1) assigned to the AON factor.

Besides the emphatic impact of AON, distance from existing market was another important factor. Its objective was to ensure that, each market could achieve a threshold; the minimum population or income required to ensure meaningful trading). In fact, this factor was weighted equally as AON in the suitability analysis. The resultant map revealed potential locations for new markets which were sufficiently far from existing markets.

A total of 16 suitable towns ultimately were selected. They included 13 towns that met the criteria for both the spatial query (within a high suitability class) and attribute query (have a population ≥ 500); the remaining 3 were added by virtue of being strongly recommended by the respondents in the survey. As shown in Figure 6.1, the latter included Mmradan, Forifori and Dedeso. None of the latter 3 towns was within a high suitability class but, each of them had population greater than 500 as seen in Table 3.21.

6.2 Locating New Markets Based on Total Coverage P-Median Problem

As noted in the methodology, the goal of TCPMP was to locate facilities such that the ratio of total coverage (demand allocated to a facility) to that of total weighted impedances (sum of square of the travel time to each located facility multiplied by the cost of building a facility) is maximized (Equation 3.9). Its conceptualization was necessitated by the need for a model that could reasonably account for coverage, travel impedance and cost of construction at the same time.

There were four separate scenarios modeled to assess how different conditions would influence the location of additional markets. The scenarios included the following: *new markets only*, *new markets with improved roads*, *new markets with new roads* and *new markets with new roads plus improved roads*. In each scenario, the median or market set that obtained the maximum TCPMP value was chosen as ideal for development. Table 6.3 provides some details about the chosen medians while Figure 6.2 show their locations and how the local communities were allocated to them.

Table 6.3: Top medians from LA Scenarios

Scenario		**Chosen Median**[13]	**Coverage**		**Total Market Cost**	**TCPMP**
No.	*Description*		*No. of Towns*	*Population*		
1	New Markets Only	Awua Apesika, Bonkrom, Mem Kyemfere, New Kyease & Wongwong	226	170,405	$783,310.45	0.164
2	New Markets + Improved Roads	Asayanso, Awua Apesika, Bonkrom, New Kyease & Wongwong	226	170,405	$748,138.09	0.202
3	New Markets + New Roads	Awua Apesika, Bonkrom, Kadekope, New Kyease, & Mem Kyemfere	378	223,915	$859,613.11	0.170
4	New Markets, New and Improved Roads	Awua Apesika, Bonkrom, Kadekope, New Kyease, Wongwong	378	223,915	$810,371.73	0.214

[13] The list here includes only the new or additional markets. The entire set however, includes the existing markets (Donkorkorkrom, Ekye Amanfrom, Maame Krobo and Tease) as well.

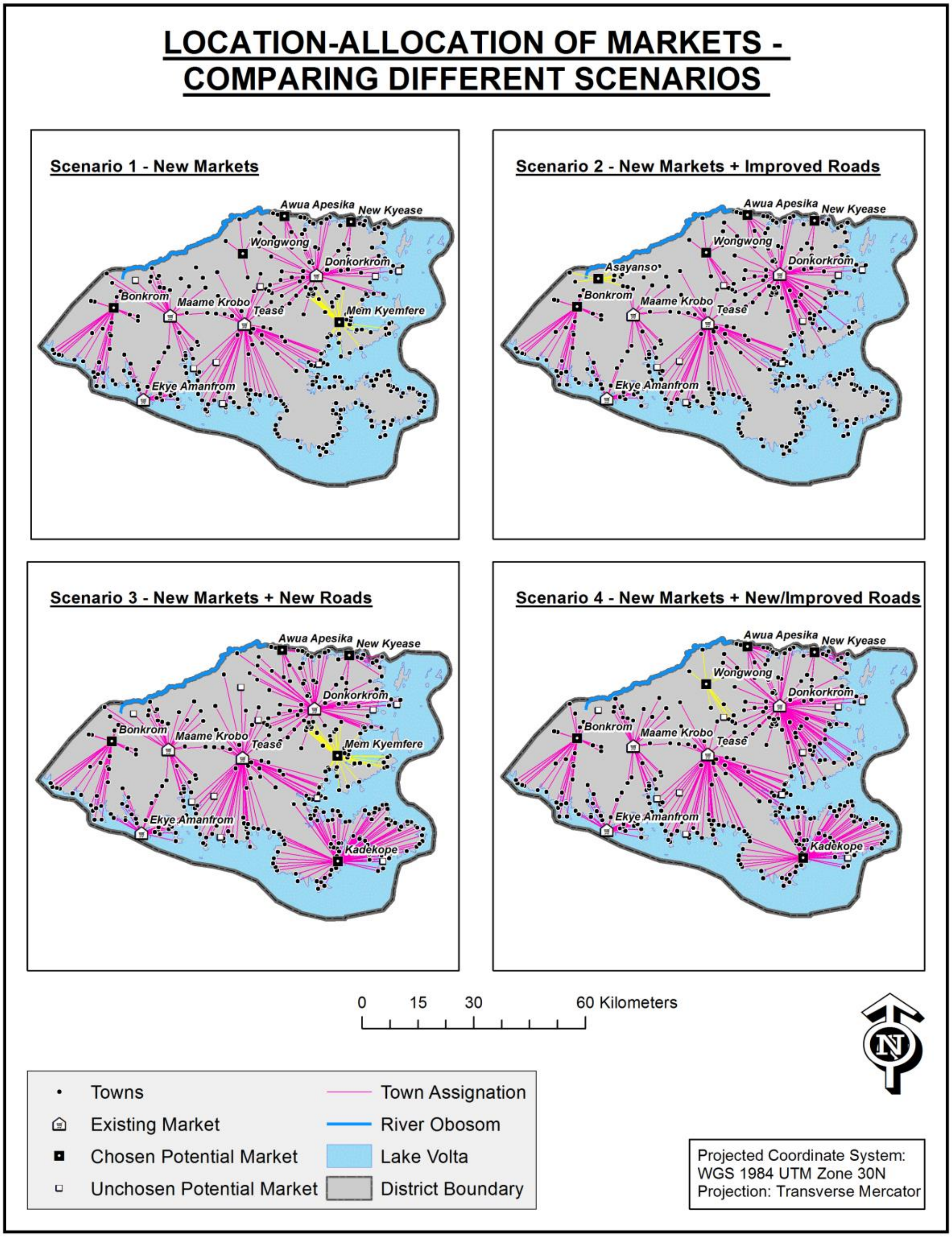

Figure 6.2: Location-Allocation[14] of markets using TCPMP in Afram Plains

[14] The town assignations were represented as straight lines for the sake of mapping but were based on network impedance, and not Euclidean distance.

According to Table 6.3 and Figure 6.2, each of the scenarios produced different outcomes. In scenarios 1 and 2 for instance, due to the absence of roads connecting some of the towns (especially, in the south-eastern peninsula), no market was allocated to them. As a result, the two scenarios covered only 226 communities (about 60 percent of communities in the study area). The other two scenarios on the other hand, were based on the expanded road network, hence, all 378 communities in the area were allocated to a market. Again, different combinations of the potential markets were located in each scenario. Those markets that did not "appear" in any scenarios were colored yellow in Figure 6.2. However, some of the chosen markets appeared in all four scenarios. These included: Awua Apesika, Bonkrom, and New Kyease. Besides all that, one surprising discovery was made; none of the three towns recommended by the survey respondents was included in any of the chosen medians among the four scenarios. This suggested that, though they might be ideal as potential new markets as perceived by the locals, their location in relation with the other centers, did not contribute meaningfully towards an efficient market configuration for the area.

The above chosen medians for each scenario were further analyzed to assess their potential impact on travel time in the area if implemented (Table 6.4). According to Table 6.4, Scenario 2 best improved travel time to the closest market; average of 17.8 minutes and maximum of 38.7 minutes. But, it is important to remember that, the coverage of the scenarios differed due to the different road networks they were based on (Table 6.3). Scenarios 1 and 2 covered fewer towns while Scenarios 3 and 4 covered all towns. This was likely the reason why Scenario 2 in particular had comparatively lower values for both average and maximum travel times. There were fewer towns allocated to the markets as compared to the cases under Scenarios 3 and 4.

Table 6.4: Impact of LA Scenarios on travel time

Scenario		Travel Time (in minutes)	
No.	*Description*	*Average*	*Maximum*
1	New Markets	28.4	78.7
2	New Markets + Improved Roads	17.8	38.7
3	New Markets + New Roads	30.5	78.7
4	New Markets + New/Improved Roads	22.1	53.7

Notwithstanding the varying circumstances under each scenario, it was obvious from the table that, each of them improved travel time to the closest market in comparison to the average travel time of the current situation; 71.33 minutes. The maximum travel times in each scenario showed a drastic reduction from a current high of 4 hours 21.5 minutes (261.5 minutes) to a range of 38.7 – 78.7 minutes. These values undoubtedly provide some indicators that, expanding the number of facilities or improving infrastructure could actually enhance spatial accessibility to markets or social facilities in the area.

Evidently, the question about which of the four scenarios should be considered for implementation arose. Considering coverage and reduced travel cost as the goals, the answer to such question would largely depend on the fiscal strength of a local government. Dependent on available resources ranging from scarce to unlimited, actual implementation would also likely range from scenario 1 to scenario 4.

Moreover, the scenarios were further examined to understand their impact on spatial allocation of Afram Plains towns to each market center (Table 6.5). According to Table 6.5, under each scenario, the distribution of the towns was unequal.

Table 6.5: Summary of towns and population served by each market under each LA Scenario

LA Scenario		Markets	Coverage				Average Travel Time (in minutes)	Maximum Travel Time (in minutes)
No.	*Description*		*Allocated Towns*	*Average Population*	*Total Population*	*% of Total Population*		
1	New Markets	Awua Apesika	6	497	2,983	2%	27.9	46.6
		Bonkrom	28	279	7,803	5%	39.3	75.4
		Donkorkrom	43	1,149	49,388	29%	28.1	54.9
		Ekye Amanfrom	17	995	16,917	10%	19.4	35.6
		Maame Krobo	25	1,066	26,651	16%	20.6	45.2
		Mem Kyemfere	36	411	14,811	9%	23.3	40.4
		New Kyease	9	653	5,877	3%	11.0	26.1
		Tease	57	779	44,380	26%	35.1	78.7
		Wongwong	5	319	1,593	1%	31.5	56.2
2	New Markets + Improved Roads	Asayanso	9	620	5,581	3%	7.2	9.7
		Awua Apesika	8	400	3,201	2%	14.1	23.6
		Bonkrom	28	279	7,803	5%	19.4	37.6
		Donkorkrom	74	851	63,004	37%	20.6	36.4
		Ekye Amanfrom	16	1,043	16,681	10%	12.8	22.9
		Maame Krobo	17	1,253	21,307	13%	13.0	21.5
		New Kyease	9	653	5,877	3%	5.5	13.1
		Tease	54	805	43,447	25%	21.0	38.7
		Wongwong	11	318	3,503	2%	16.3	25.7
3	New Markets + New Roads	Awua Apesika	11	404	4,445	2%	18.7	46.6
		Bonkrom	28	279	7,803	3%	39.3	75.4
		Donkorkrom	57	939	5,3548	24%	31.5	61.7
		Ekye Amanfrom	30	749	22,477	10%	25.7	43.5
		Kadekope	90	386	34,742	16%	30.8	55.4
		Maame Krobo	32	894	28,600	13%	23.5	45.2
		Mem Kyemfere	43	427	18,340	8%	24.6	40.7
		New Kyease	15	467	7,012	3%	15.9	28.6
		Tease	72	652	46,949	21%	39.3	78.7
4	New Markets + New / Improved Roads	Awua Apesika	15	335	5,021	2%	12.1	23.6
		Bonkrom	31	332	10,301	5%	19.3	37.6
		Donkorkrom	91	770	70,034	31%	22.0	39.5
		Ekye Amanfrom	29	767	22,240	10%	17.3	33.0
		Kadekope	81	377	30,499	14%	29.8	53.7
		Maame Krobo	30	878	26,338	12%	16.2	28.5
		New Kyease	15	467	7,012	3%	9.2	18.9
		Tease	75	653	48,968	22%	24.6	40.7
		Wongwong	11	318	3,503	2%	16.3	25.7

Such inequality became severe as one moved from scenario 1 to 4. Regarding population allocation, the distinction was based on whether the scenarios included a road upgrade (scenarios 1 and 3) or not (scenarios 2 and 4). Inequality under the former was less acute than the latter. The market centers that got the large share of the towns included Donkorkrom and Tease. Together, the two centers served 44.5 percent and 56.6 percent of the towns under scenarios 1 and 2 respectively. Again, they represented the market for well over half of the population; 55 percent and 62 percent under scenarios 1 and 2 respectively. Under scenarios 3 and 4 though, another center, Kadekope, entered the competition. Yet, Donkorkrom and Tease remained competitive. In fact, the two markets still served the most people (53 percent).

Aside the above, Table 6.5 also revealed that, generally, the new markets in comparison with the existing markets were allocated fewer towns and population. The only exception was Kadekope. One such town that consistently had low numbers was Awua Apesika, one of the northern towns. Despite the low numbers, such towns could still serve a vital purpose by providing market services to many other communities located on the north side of the river and lake which were not accounted for in this study.

As already pointed out, Tease market was seen in Table 6.5 as one of the dominant markets in terms of town and population allocation. This observation was quite fascinating particularly, when one related it to the current situation in Afram Plains. Currently, Tease, is the least popular market while Maame Krobo is the most popular. Nonetheless, the finding pointed out that, if any of the scenarios was implemented, it would have resulted in a reallocation of towns to markets in the area such that Tease would have ended up becoming one of the popular market destinations in the area. This was likely due to the location of Tease; being at a nodal point of roads, it was accessible via the networks to many towns. This finding suggested that, Tease provided a greater potential for enhancing spatial access to market to many communities and people in the area. Hence, if an attempt is made to improve facilities at Tease, it would benefit many residents.

In terms of average travel time, all the market towns could be reached within one hour under each scenario. However, considering the maximum travel time, under scenarios 1 and 3, there were some towns allocated to markets like Bonkrom and Tease that would have to travel for over 60 minutes to get to a market. This was likely due to the lack of road improvement in those two scenarios. This observation provided a solid evidence that, developing new roads alone might not be enough to reduce travel time to market in the area. Some consideration must also be given to improving existing roads which were in deplorable state.

7. EVALUATION OF SPATIAL ACCESSIBILITY INTERVENTIONS

This chapter presents the findings for part of research question 3a and the entirety of research question 3c. Research question 3a states: *“If new roads are to be developed, which network model (intensive or extensive) is suitable and where should the roads be constructed to better improve spatial accessibility within the area?”.* This chapter focused on how the new road network (discussed in chapter 5) improved travel time to market in the area (or not). This also included results from the connectivity measures which tested the overall efficacy of the new road network. Research question 3c, on the other hand states: *“If the interventions* (new road network and new markets discussed in Chapters 5 and 6) *produce any changes in spatial accessibility: i. Is there any significant difference between them after their implementation? ii. How is spatial accessibility affected when both are applied together?*

7.1 Efficiency of Expanded Road Network based on Connectivity Measures

The overall efficiency of the new road network was evaluated by connectivity measures. For the entire Afram Plains mainland, the results for Street Density (SD), Normalized Street Density (NSD), Gamma Index (GI) and Detour Index (DI) were 0.404, 0.199, 0.352 and 0.951 respectively. The values of SD, NSD and GI were all low (< 0.5), indicating a poor connectivity with fewer networks as opposed to a potential higher number that could be developed in the area. The result of the DI on the other hand, was very high. It signified that, on average, all the road segments effectively minimized travel distance. This also implied a potential reduction in travel time and cost which would be beneficial to residents and the local economy.

Regarding the results for the agro-zones, they were all relatively similar to that of the entire mainland (Table 7.1). Based on NSD, Kwasikuma2 had the highest level of connectivity while Kyemfere had the lowest. Apart from Kwaskuma2, seven other agro-zones also had values exceeding that of the entire area.

Table 7.1: Results from connectivity measures

Zone Name	Street Density	Normalized Street Density	Gamma Index	Detour Index
Abomasarefo	0.383	0.189	0.292	0.966
Adeemra	0.560	0.273	0.278	0.984
Agordeke	0.553	0.270	0.317	0.967
Bebuso	0.356	0.176	0.300	0.982
Donkorkrom	0.583	0.283	0.292	0.979
Ekye-Amanfrom	0.458	0.225	0.356	0.955
Forifori	0.327	0.162	0.300	0.950
Kwaekese	0.342	0.170	0.286	0.961
Kwame Dwamenakrom	0.446	0.219	0.315	0.947
Kwasi Fante	0.279	0.139	0.293	0.949
Kwasikuma	0.392	0.193	0.444	0.920
Kwasikuma2	0.638	0.309	0.333	0.972
Kyemfere	0.198	0.099	0.293	0.945
Maame Krobo	0.321	0.159	0.314	0.944
Mim Kyemfere	0.621	0.301	0.328	0.957
Samanhyia	0.358	0.177	0.293	0.971
Somsei	0.468	0.230	0.278	0.975
Takorawatene	0.356	0.176	0.347	0.963
Tease	0.389	0.192	0.319	0.958

Green fonts – highest; Red fonts - lowest

In terms of GI (which tests the relationship between the number of observed links in the network to the number of maximum possible links between nodes), Kwasikuma had the highest. Here, it was Somsei that scored lowest among the agro-zones. Concerning detour index, all the agro-zones recorded very high values. In fact, except for six zones, all of them improved upon the value of the entire area.

The above indices provided essential information in gauging the relative efficiency of the road networks; the density of connections and the directness of links between nodes. Generally, the higher the connectivity, the shorter the travel distance and time (MDT, 2014). Ultimately, a higher connectivity encourages community interaction and stimulates economic growth. However, the results obtained in this study, except for DI, were not high (both NSD and GI). This suggested that the new network was poorly connected. Despite the seemingly unfavorable result, some experts have argued that the desired levels of connectivity tend to differ with location, and thus it is "counter-productive to insist on a rigid connectivity principle applicable" to every place (MDT, 2014). Instead, the goal should aim at connecting most residents in a variety of ways such that their access to basic facilities and services were enhanced. Considering this, it was argued that the essential goal of connectivity for the new road networks in this research had been achieved; each community had been directly or indirectly connected to a market facility in the Afram Plains. Moreover, the conditions in Afram Plain (such as hydrography, terrain, wildlife conservation, and relatively sparse population distribution) would not permit or even encourage the development of a highly dense road network. Therefore, the values obtained above essentially present a practical solution to address the current need of improving spatial access to local markets.

With the expanded road network evaluated, the question that remained to be answered was, what network model (intensive or extensive) was it? This was associated with research question 3a but mainly focused on how the expanded road network impacted travel time to market in the area. Regarding the entire network, the low values from the connectivity measures (NSD and GI) suggested that, the road network was more extensive in nature than intensive. Specifically, it resembled the *Least-cost network to the builder* (Figure 2.6 and Table 2.4). This was supported by the fact that, there was no centrality and also, majority of the towns were not connected directly to all their neighbors except the closest one. Even though, this type of network does not foster sustained interaction as compared to an intensive network like *Delauney Triangulation*, it still offers a lot of benefits like lower construction cost and efficiency (eliminates redundancy). Also, considering its suitability for areas with sparse and scattered population, the network suited the conditions of Afram Plains.

Focusing on just the modeled new roads particularly in the south-eastern peninsula, the network could best be described as *Dendritic*, a type of extensive network (Figure 2.6 and Table 2.4). This was so because, the network was built around a main central road; roads developed from the central road in more less right angles to connect the towns. This network shares similar advantages and limitations as the previous one. The unique configuration of towns in this section of Afram Plains however, arguably, made this network ideal for the area.

7.2 Impact of Interventions (Scenarios) on Travel Time

As noted in the methodology chapter (chapter 3, sub-section 3.2.3.7), the methods applied in this study could be used to assess different scenarios. Under expanded road network, two scenarios were modeled while under location-allocation of markets, four were modeled. An assessment of these scenarios revealed that, the implementation of any of them would lead to a substantial reduction in average travel time in Afram Plains; over -30 percentage change (Table 7.2). Among the scenarios that covered all the towns (LCP 1 and 2 and LA 3 and 4), LA 4 was the best. LA 4 had an average travel time of 22.1

minutes and a maximum of 53.7 minutes. The average travel time of LA 4 also represented a -69 percentage change over the current situation, making it the scenario that would best reduce travel time to market in the Afram Plains.

Table 7.2: Comparing travel times among scenarios

Intervention	Scenario		Total Coverage		Travel Time (min)		% Change (vs. current)
	No.	*Description*	*Towns*	*Population*	*Mean*	*Max.*	
	-	-	378	223,915	71.33	261.52	-
Current Situation	-	-	378	223,915	71.33	261.52	-
LCP	1	New Roads	378	223,915	49.2	100.7	-31.0
	2	New + Improved Roads	378	223,915	32.0	84.8	-55.1
LA	1	New Markets	226[15]	170,405	28.4	78.7	-60.2
	2	New Markets + Improved Roads	226	170,405	17.8	38.7	-75.0
	3	New Markets + New Roads	378	223,915	30.5	78.7	-57.3
	4	New Markets + New/Improved Roads	378	223,915	22.1	53.7	-69.0

Notwithstanding, one must bear in mind that, comparatively, LA 4 would require more funding to implement. This was because, it comprised of building new roads and new markets as well as improving some existing roads. In areas where budgetary constraints are a concern, LA 4 might not be feasible. In such cases, LCP 2 or LA 3 might be considered. The difference between them, in terms of travel time were marginal. LA 1 and LA 2 on the other hand, also provided improvements in travel time to market. But, due to their limited coverage (only 226 towns; about 60 percent of the towns), they

[15] LA 1 and LA 2 recorded reduced coverage in towns and population only because some towns had no road connecting them to existing road network. As a result, they were excluded by the algorithm. The results thus, represent towns that were directly or indirectly connected to a market via a road network.

were considered as flawed since they fell short of the goal of covering or connecting all towns to a market. Figures 7.1 and 7.2 show travel times to nearest market for both LCP and LA scenarios respectively and maps corroborated the findings in Table 7.2.

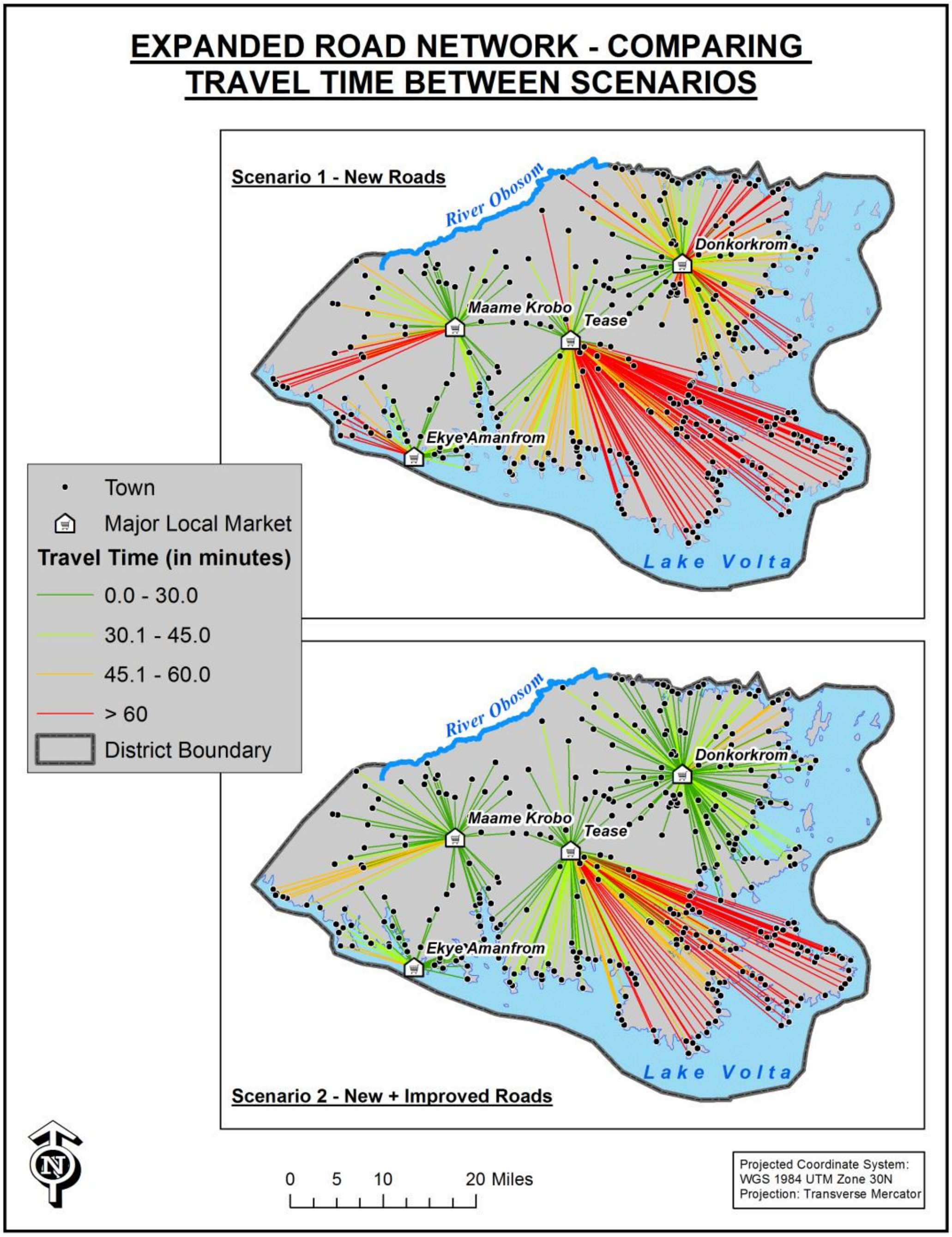

Figure 7.1: Comparing travel times[16] to market under different LCP scenarios

[16] The resulting routes are represented as straight lines for the sake of mapping but are based on network impedance, and not Euclidean distance. This applies to Figure 7.2 as well.

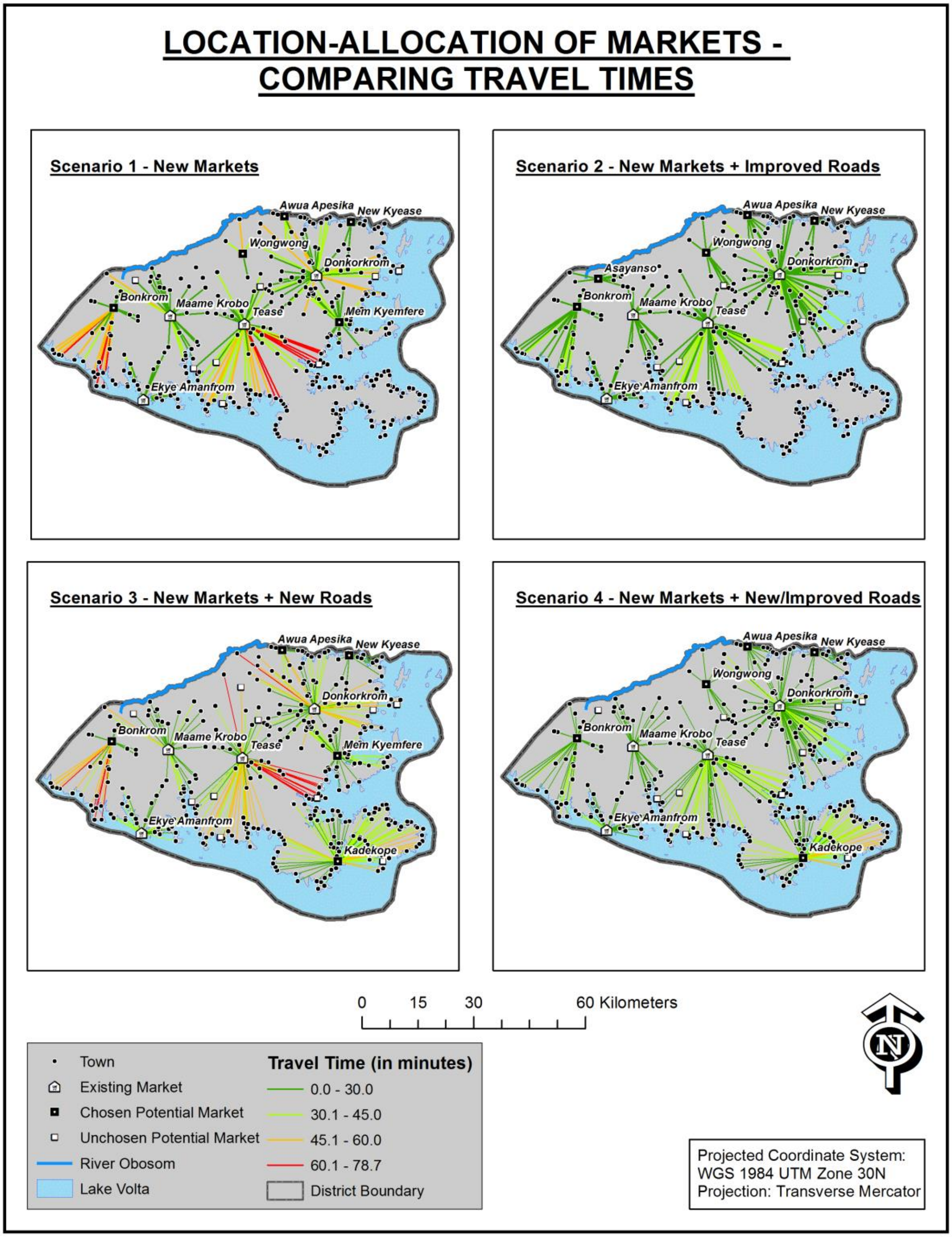

Figure 7.2: Comparing travel times to market under different LA scenarios

Based on the above analysis, the ideal scenario for improving travel time to market (within 60 minutes) would involve construction of some new roads and markets as well as some minor to major improvements in some of the existing roads. This showed that, implementing just a single intervention like: build new roads, build new markets or just improve some existing roads, would not be enough to effectively improve travel time to market in the area. As shown above, a holistic approach would best serve that purpose.

7.3 Impact of All Interventions on Overall Potential Spatial Accessibility

This section assesses the impact of some of the modeled scenarios discussed in chapters 5 and 6 on overall potential spatial accessibility (OPSA) in the study area. Specific scenarios considered here were identified in Table 3.22 in chapter 3. Each of the solutions was subjected to the Multi-MODAM model (Equations 3.1 and 3.2). Figure 7.3 shows the resulting OPSAs in comparison with the current situation. It is worthy to note that, this assessment was based on residents' opinion about their current preferred mode of transportation as revealed in the survey. No anticipated change in residents' preference due to potential future infrastructural development was considered. Thus, the weighting of separate modes in the Multi-MODAM equation was biased towards present conditions.

According to Figure 7.3, in general, all the interventions improved on the current situation. While some showed marginal changes, others showed drastic changes. For example, the addition of new roads (LCP: New Roads) improved upon the current situation but mostly in the south-eastern peninsula. But with improvement in existing roads, the level of accessibility increased generally (LCP: New Roads + Improved Roads). Yet, comparing these two interventions to the others, their level of improvement was relatively marginal.

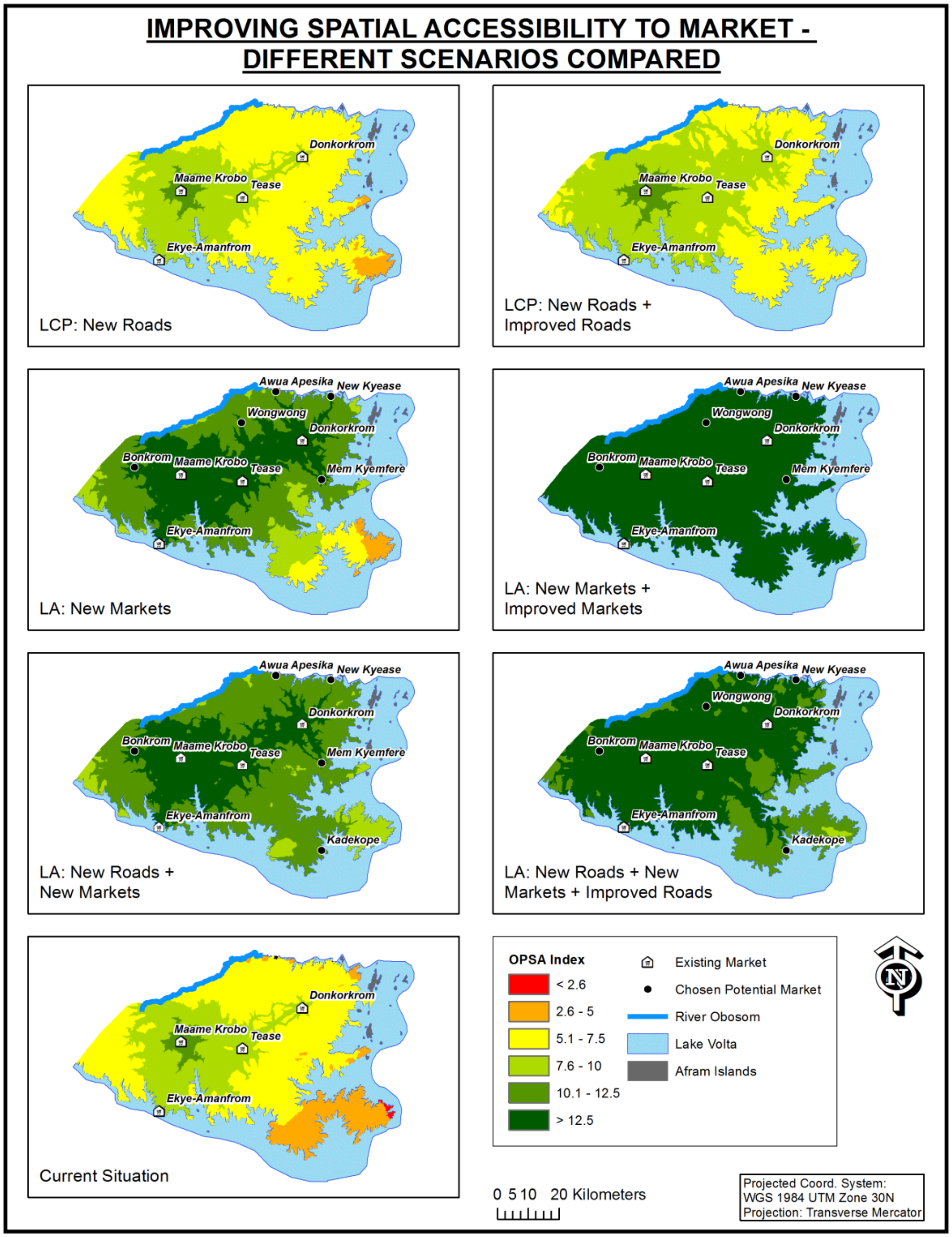

Figure 7.3 Comparing all OPSA surfaces for the interventions

Based on Figure 7.3, the top two scenarios that recorded major improvement in spatial accessibility included the addition of new markets plus improvements in existing markets (LA: New Markets + Improved Markets) and the combination of new roads, new markets and improvements in existing roads (LA: New Roads + New Markets + Improved Roads). Both recorded OPSA values above 7.5 across the entire area.

To establish whether any of the interventions statistically improved upon the current situation, the cell values in each scenario were compared against the ones in the current situation using ANOVA with repeated measures. This assessment was in direct relationship with answering this hypothesis question:

> H_o3: *There is no significant difference in the mean overall potential spatial accessibility among the scenarios indicating* $OPSA_{Current} = OPSA_{New\ Roads} = \ldots OPSA_{New\ Roads\ +\ New\ Markets\ +\ Improved\ Roads}$.

The test result based on Greenhouse-Geisser correction indicated that, the mean OPSAs differed significantly between each intervention scenario and the current situation ($F = 28141948.95$, $df = 1.047$, $p < 0.001$). The Greenhouse-Geisser correction was necessary because Mauchly's test (test of sphericity) showed that the assumption of sphericity had been violated; $\chi^2 = 29794511.56$, $df = 20$, $p < 0.001$). Hence, Greenhouse-Geisser's estimate of sphericity ($\varepsilon = 0.175$) was applied to correct the degrees of freedom. Post-hoc test based on Bonferroni correction revealed that, in a pair-wise comparison, each of the intervention scenarios differed significantly from the current situation and from each other as well ($p < 0.001$) (Table 7.3).

Table 7.3: Post-hoc analysis of the spatial accessibility interventions

Scenarios (I)	Scenarios (J)					
	New Roads	*New Roads + Improved Roads*	*New Markets*	*New Markets + Improved Markets*	*New Roads + New Markets*	*New Roads + New Markets + Improved Roads*
Current Situation	-0.25	-1.06	-4.81	-25.53	-5.17	-6.84
New Roads	-	-0.81	-4.55	-25.28	-4.92	-6.59
New Roads + Improved Roads		-	-3.75	-24.47	-4.11	-5.78
New Markets			-	-20.72	-0.37	-2.03
New Markets + Improved Markets				-	20.36	18.69
New Roads + New Markets					-	-1.67

The values represent mean difference (I-J) with each having a p-value < 0.001.

In addition, Table 7.3 showed that, each of the scenarios improved upon the OPSA of the current situation since the former had higher values than the latter (under mean difference). Among the scenarios, New Markets + Improved Markets and New Roads + New Markets + Improved Roads represented the greatest improvement. This confirmed the output in Figure 7.3. Comparing the scenarios with each other, the two best scenarios once more performed better. This suggested that, 1. developing new markets alongside improving existing markets or 2. developing new roads and new market facilities alongside improving existing roads represent the best option for improving overall potential spatial accessibility in Afram Plains. Figure 7.4 below shows the difference in OPSA between the current situation and each intervention scenario. Based on Figure 7.4, it is apparent that, the interventions indeed improved upon the current situation.

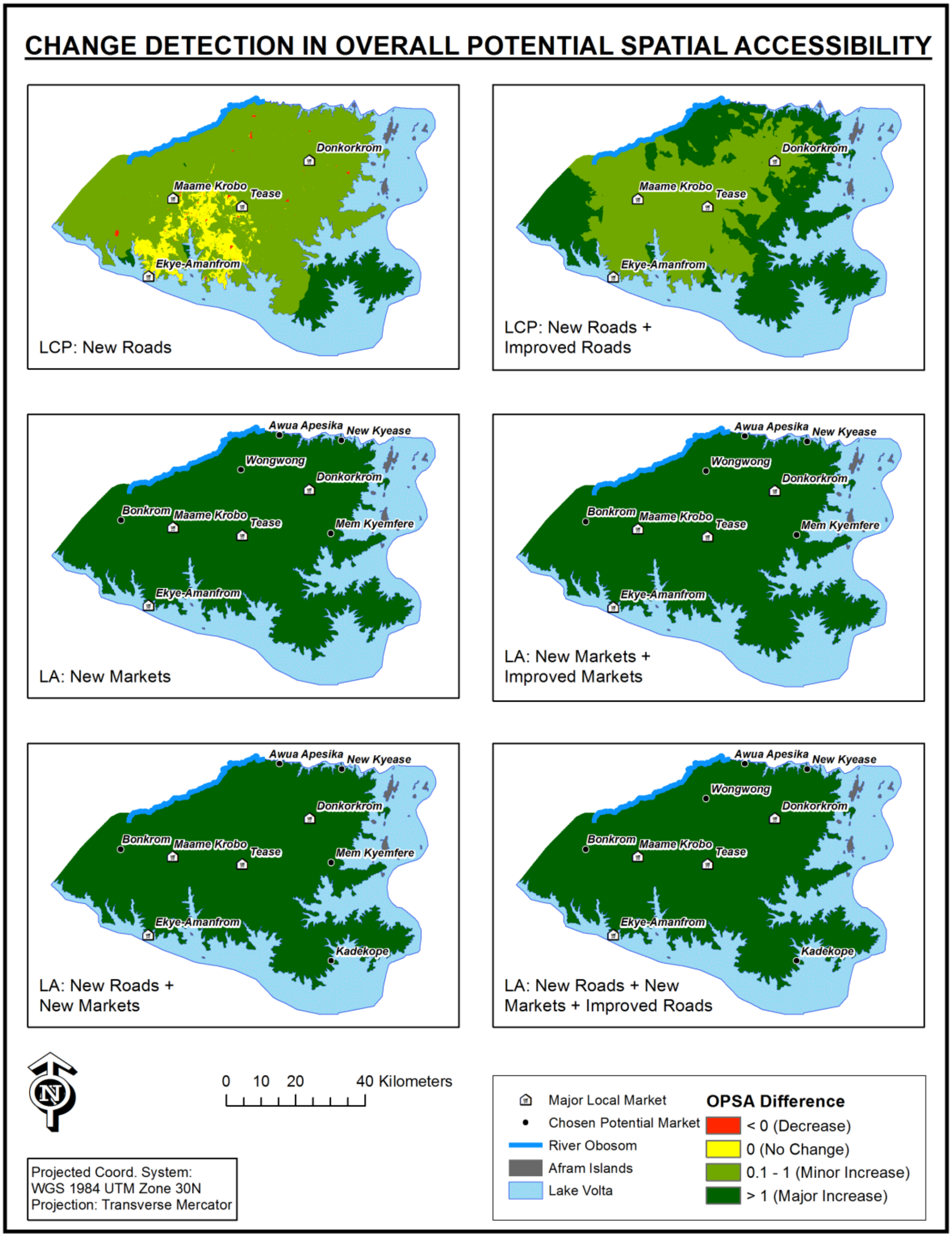

Figure 7.4: Change in OPSA between intervention and current scenarios

After establishing that *New Markets + Improved Markets* and *New Roads + New Markets + Improved Roads* interventions were the best options for improving spatial accessibility in the area, they were both subjected to ANOVA test to examine any geographic disparity among the agro-zones. It was based on this hypothesis:

H_o4: *There is no significant difference in the mean overall potential spatial accessibility among the different agricultural zones, so that* $OPSA_1 = OPSA_2 = \ldots = OPSAn$

Like the current situation, the interventions also varied significantly among the agro-zones ($p < 0.001$). One reason for this could be, like the current situation, the interventions also applied the same weights in modelling OPSA. Besides, the differences in land cover among the agro-zones obviously contributed to such geographic disparities. Nevertheless, the new interventions evidently, produced positive changes in spatial accessibility in the entire area.

Finally, a correlation analysis between OPSA index ($OPSA_i$) for each of the interventions (new roads only, new roads + improved roads, new markets only, new markets + improved markets, new roads + new markets and new roads + improved roads + new market) and connectivity indices (*NSD*, *GI*, and *RI*) was conducted using Spearman's Rank-Order correlation coefficients to examine the following null hypothesis:

H_o5: *There is no correlation between all* $OPSA_i$*, NSD, GI & RI indices* $(\rho = 0)$.

The results showed, only one pairing was significant; New Markets + Improved Markets versus Detour Index ($p < 0.05$). The correlation coefficient indicated a moderately strong positive relationship between the two variables. This implied, as road directness improved, potential spatial accessibility under this scenario likewise improved. The remaining pairings however, were not significant implying, in this research, there was no relationship between the OPSA indices and the connectivity indices (Table 7.4 and Figure 7.5). Based on this result, the null hypothesis could not be rejected completely, implying, the data did not provide enough evidence to suggest the null hypothesis was completely false.

Table 7.4: Spearman correlation analysis

Scenario	Statistic	NSD	GI	DI
Current Situation	Coefficient	-0.223	0.072	0.091
	Sig. (2-tailed)	0.359	0.770	0.710
New Roads	Coefficient	-0.256	0.063	0.053
	Sig. (2-tailed)	0.290	0.797	0.831
New Roads + Improved Roads	Coefficient	-0.186	0.056	0.109
	Sig. (2-tailed)	0.446	0.819	0.658
New Markets	Coefficient	0.028	-0.097	0.418
	Sig. (2-tailed)	0.909	0.691	0.075
New Markets + Improved Markets	Coefficient	0.295	-0.318	0.709
	Sig. (2-tailed)	0.221	0.185	**0.001**
New Roads + New Market	Coefficient	-0.023	-0.119	0.418
	Sig. (2-tailed)	0.926	0.629	0.075
New Roads + Improved Roads + New Markets	Coefficient	-0.075	-0.133	0.321
	Sig. (2-tailed)	0.759	0.588	0.180

N = 19

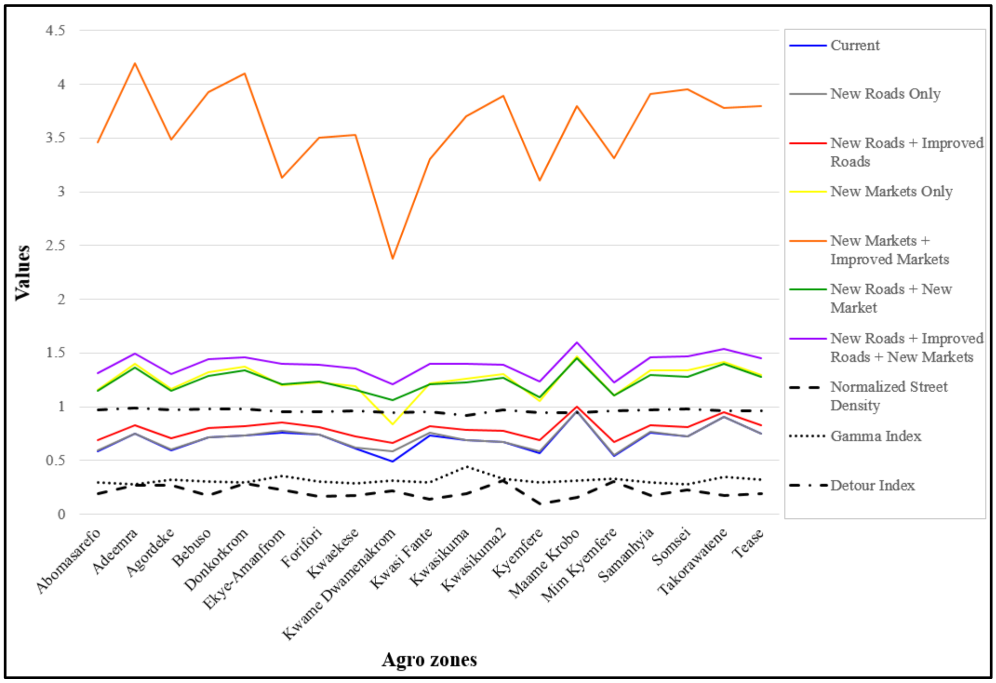

Figure 7.5: Comparing OPSA indices[17] of scenarios and connectivity measure indices

[17] OPSA indices values = $n*10^{-1}$; values were divided by 10 to allow for easy presentation in the chart.

8. SUMMARY, CONCLUSION AND RECOMMENDATIONS

This chapter provides a summary of the major findings from this study. It also discusses key limitations encountered in the study and makes recommendations for future research. Moreover, some suggestions for policy making and implementation in Ghana concerning rural planning and development have also been suggested in this chapter.

8.1 Summary

The goal of this research was basically two-fold: (i) understand and quantify the problem of poor spatial accessibility to agricultural markets in the Afram Plains, and (ii) explore effective ways to improve it. The goal was addressed by posing three main questions. These questions and their associated answers are summarized below.

The first research question with its sub questions is as following: *What is the spatial accessibility of the inhabitants to market centers based on a multi-mode transportation system?*

a. Is there any geographic disparity of spatial accessibility to market centers in the area among the agricultural zones?

b. Is there any significant difference in the spatial accessibility to market centers by various modes of transportation across the agricultural zones?

From the survey conducted, six main modes of transportation were identified, with walking (also called headloading; 39 percent) and tractor (34.1 percent) being the top two means of traveling to local market in the area. Space or convenience was the main reason cited by majority of respondents (61.7 percent), for choosing a particular mode of transportation when traveling to a market. Among the four major local markets, Donkorkrom was the preferred or most patronized market (42.1 percent). Nonetheless, preference for a particular market differed significantly among the major sub-divisions in the area. Proximity was found to be the main factor influencing respondents' decision in choosing a market to visit. This showed that, respondents' preferences indeed differed but, the primary reasons for the choices they made largely coincided. Observing proximity as the main reason for choosing a market here, was not surprising as it conformed to existing knowledge of consumer behavior (Hotelling, 1929; Huff, 1964; Church and Murray, 2009).

To quantify the current state of spatial accessibility to market based on the six identified modes of transportation in the area, a new potential accessibility model called Multi-Mode Accessibility Model or Multi-MODAM was developed. After applying the model, the results indicated that, potential spatial accessibility (PSA) to market generally, depreciated as one moved away from the market centers or from the road networks. This was observed in both individual PSA (per transportation mode) and overall PSA outputs. Overall, the western part of Afram Plains (with comparatively better roads especially in Maame Krobo agro-zone) had better potential spatial accessibility than the other areas. The south-eastern peninsula (or Kwame Dwamenakrom agro-zone) had the worse level of OPSA. This was not surprising, as this area had virtually no existing road infrastructure.

The Multi-MODAM findings were corroborated by results from the survey. From the survey, over half of the respondents (over 70 percent; N =190) perceived their travel experience to market (frequently visited market) as "extremely difficult". Many of them attributed the difficulty to deteriorated roads (80.9 percent; N = 141). Other major factors included lack of vehicles and lack of roads. These same factors were identified in the literature as some of the main causes of poor spatial accessibility in the developing world (Riverson et al., 1991; Guimarfies and Uhl, 1997; Porter, 2002(b); Gwilliam, 2011). The issue about lack of vehicles is crucial as it has implication on any future intervention. It can be argued that, since there is acute shortage of vehicles in the area, technically, a major improvement in road infrastructure may still not enhance spatial accessibility in the area. However, many scholars acknowledge that new infrastructural developments tend to attract economic growth and investment (Naude et al., 1999; Olsson, J. 2009). Hence, it can be expected that, improvements in road infrastructure in the area would encourage individuals or firms to invest in the transport business in the area. In fact, the current lack of vehicles situation in the area could be attributed to the poor road infrastructure in the area. Prospective investors might have considered it too risky to invest in transport services in the area as their vehicles would certainly wear out quickly (due to bad roads) and thus, result in losses. Confidence to invest could be induced if efforts were made towards improving the current situation. Without such intervention, even government incentives would do very little to sustainably boost number of vehicles in the area.

The two sub-questions of research question 1, were answered based on two respective null hypotheses:

H_o1: *There is no significant difference in the mean overall potential spatial accessibility among different agricultural zones, so that* $OPSA_1 = OPSA_2 = \ldots = OPASA_n$

H_o2: *There is no significant difference in the mean potential spatial accessibility among various modes of transportation, so that* $P_{i,\alpha} = P_{i,\beta} = \ldots = P_{i,n}$

Both null hypotheses were rejected at the 0.05 level, indicating that, mean overall potential spatial accessibility varied significantly across the different agricultural zones. Similarly, the individual potential spatial accessibility surfaces (representing the modes of transportation) varied significantly from each other. The significant difference among the modes of transportation was expected as each mode had different travel speed and resistance to terrain conditions. These factors influenced their resultant travel time surfaces and ultimately their potential spatial accessibility outputs.

Concerning the second research question: "*Based on the level of spatial accessibility and economic potential, where are the areas of greatest need (i.e. poor access but high economic potential)?"*, a fuzzy analysis provided a practical way of modelling the "level of need" in Afram Plains. The goal was to ensure that new developments were allotted appropriately to meet local needs. The results showed that the eastern half of Afram Plains had a greater need than the west especially in the Kwame Dwamenakrom, Kwaekese and Kyemfere agro-zones. However, it must be pointed out that, some areas in the south-east, experienced poor harvest during the target year of 2013 and therefore reflected in the economic potential output. So, it is possible that, a different outcome could be obtained if the data was based on a normal season's harvest. The "Area of Need" output also served as one of the cost factors for modelling new road networks and new market locations.

The third research question: "*How best can spatial accessibility be improved*?" focused on finding a solution to the problem of poor spatial accessibility in the Afram Plains. In this study, three main interventions were explored: developing new roads, locating new markets and a combination of new roads and new markets. From the survey, most respondents (39.8 percent) favored “developing new roads”. However, after subjecting the different interventions to modelling under different scenarios, the results revealed that, a combination of both new roads and new markets along with improvement in existing road networks provided the best solution to the problem in the area. Under the “best scenario”, all communities were connected by a road network while mean travel time reduced by 69 percent (from 71.3 minutes to 22.1 minutes). Awua Apesika, Bonkrom, Kadekope, New Kyease, and Wonwong included the set of towns identified as ideal locations to build five additional markets. The primary challenge of this proposed solution though was that, it would be costly to implement due to the major constructions it entails. But, certain cities could be prioritized to ensure efficient use of limited funds.

Notwithstanding the above, under situations where the interventions were considered separately, locating new markets proved to be a better option for mitigating the problem than simply developing new roads. Mean travel time for example reduced by 60.2 percent (from 71.3 minutes to 28.4 minutes). Yet, this option only had a section of the communities (226; ≈ 60 percent) connected by a road network. This is problematic since the absence of roads tend to negatively affect other local activities like school attendance and health care. Hence, it cannot be considered as a convincing solution. The five set of towns identified as ideal locations for new markets under the “new markets” scenario included Awua Apesika, Bonkrom, Mem Kyemfere, New Kyease, and Wonwong.

Finally, since developing new roads was eventually found to be crucial in helping improve spatial accessibility, the resultant expanded network was subjected to connectivity assessment. The results (based on Normalized Street Density [NSD] and

Gamma Index [GI]) showed low values, indicating the expanded road network ws not well-connected or had fewer options regarding connections to a destination. However, concerning the directness of the network (based on Detour Index [DI]), the result was high indicating the routes of the new network were more direct. This implied a potential reduction in travel distance if the expanded road network is implemented. Considering the agro-zones separately, the results for the connectivity assessment were about the same, except for a few selected cases where the values for the agro-zones were better than the entire area. With connectivity measures known to be controlled by location and project goals (MDT, 2014), the low values recorded for the NSD and GI, would not necessarily imply the expanded road network was inefficient. In fact, they could be justified in view of the geographic context of Afram Plains and conservative goal of the new road network: a rural area with scattered population enclaves and connecting all communities to at least a market in the Afram Plains.

Finally, based on the connectivity measure metrics and the physical configuration of the resultant expanded network, it was concluded that the network was extensive model. The entire network conformed to a *Least-cost network to the builder* while the modeled new roads only conformed to a *Dendritic* network.

8.2 Research Limitations

This research, like many other research, encountered some challenges that to some extent could have influenced parts of the findings. This section highlights some of these limitations for the benefit of the reader.

1. In modelling potential spatial accessibility, new road network and location allocation of new markets, some simplifications or assumptions were incorporated. For example, factors like traffic congestion, time of the day, weather conditions, driver characteristics, and vehicular conditions were not accounted for in the analysis.
2. A default distance decay of 2 was utilized in this research. Even though this value was generally considered as adequate, many scholars admit that an empirically determined value helps yield a better and more realistic outcome (Haynes et al., 2003; Geurs and van Wee, 2004; Wan et al., 2011). An attempt was made to determine this value in this research based on survey data. Unfortunately, due to mild response rate which resulted in a relatively small data size, a statistically significant result could not be attained, hence, the decision to resort to the default value of 2.
3. In analyzing the geographic disparity of overall potential spatial accessibility among the agro-zones, a fishnet with a cell size of 50 meters was used to extract the raster values from the 15-meter resolution raster output. This became necessary as the raster to point conversion yielded millions of point records which could not be further processed due to limited computer processing capacity. While the aggregation made further processing possible, it made the subsequent spatial analysis susceptible to the Modifiable Area Unit Problem (MAUP) (Fotheringham and Wong, 1991).

4. Subjectivity in the weight assignments could possibly have introduced some personal bias or prejudice into the model while accounting for the relative importance of certain factors over others.
5. Also, an initial attempt was made at using a stochastic/heuristic approach (specifically Genetic Algorithm) in modelling both new routes and new market locations. However, the approach failed in both cases primarily due to challenges encountered at the encoding stage. Alphanumeric coding instead of binary coding was considered ideal for the encoding. Yet, it proved problematic during the application of genetic operators such as crossover and mutation; obtaining a set of offspring that were uniquely different from their parents was impossible. The offspring kept assuming the same genes as the parents. Meanwhile, each offspring was expected to be unique in order to prevent reaching local optima quickly than planned. So, the inability to solve this problem led to the adoption of a deterministic approach to addressing the research questions. However, a stochastic approach would have generally provided a more robust way of addressing the problem by allowing multiple scenarios to be explored.
6. Finally, the lack of data coupled with data uncertainty was a common dilemma encountered throughout the research. Thus, some important data (e.g. roads, land cover, interpolated agricultural data etc.) needed for this research were generated from scratch. These datasets were prone to some errors and thus, might have propagated into the final analysis. For example, the agricultural data derived from spatial interpolation were acceptable but unverified.

8.3 Conclusion

As noted throughout this dissertation, the primary motivation for this research was to understand and quantify the problem of poor spatial accessibility to agricultural markets in the Afram Plains and explore effective ways to improve it. In line with such motivation, this study devised new approaches within a mixed methods framework that helped answer the research questions. The methods also helped revealed several significant findings.

Combining both quantitative (including geospatial and geocomputational techniques) and qualitative approaches provided the platform to critically analyze and understand the problem at stake. The qualitative data, including opinions of residents and local stakeholders, supplemented the complex geospatial modelling techniques implemented. Without the former for example, the research would have been limited in selecting relevant cost factors, ascribing weights to cost factors and explaining some of the results from the modelling processes.

The quantitative portion also led to the development of new modelling procedures which would contribute to existing body of knowledge. These included Multi-MODAM, Economic Potential Model, TCPMP and Stepwise LCP. Multi-MODAM's multi-mode approach towards modelling potential spatial accessibility for example, fill some gaps in existing literature regarding spatial accessibility modelling. In areas where usage of varied transport systems is common practice, failure to account for each transport system would likely result in an error-laden assessment of spatial accessibility. By addressing this problem, Multi-MODAM, thus provided a practical alternative to modelling potential spatial accessibility.

Similarly, *TCPMP* also provided a novel approach towards location allocation where both coverage and impedance/cost were accounted for at the same time. Existing models mainly focus on just one factor. Although existing approaches have sufficed for some time now, their failure to account for both coverage and cost simultaneously, render them deficient for making comprehensive planning decisions. This is because, both coverage and cost are critical factors in local planning and are often considered together (Sanders, 2007). So, having successfully modeled them together in this research was really assuring especially, knowing that it would provide a new paradigm for location allocation modelling. The stepwise LCP on the other hand, showed how an existing road network could be expanded while ensuring efficiency by limiting the occurrence of redundant routes.

It is worthy to note here that, even though this research only applied the above described models to address a rural development issue, they could be applied in other fields, such as rail routing, location analysis, planning, health geography and social and environmental justice. For instance, TCPMP's emphasis on total/maximum coverage and minimum cost, ensures that new social developments are both socially equitable and financially prudent; a key element in social and environmental justice.

Besides the above, the study realized some other interesting phenomena: some discrepancy between survey participants' responses and results from geospatial modelling. One such discrepancy was observed between respondents' estimated (perceived) travel time and modeled travel time. The two estimates were negatively correlated albeit very weak (r_s = -0.184,). Another case was observed about "locating new markets". There was a mismatch between modeled results and suggested locations from survey respondents. The survey participants suggested three towns: Dedeso, Forifori and Mmradan for locating new markets. These were included in the TCPMP model. Yet none of them was picked by the model among the five final locations. Such discrepancies obviously raised concerns about the practicality of the methods used and results in this study. This was so because local knowledge is generally considered as pragmatic and tested, thus relatively reliable (Mcconchie and Mckinnon, 2002; Briggs, 2005).

Nevertheless, local knowledge has been critiqued as not always practical; it is sometimes prone to false claims, people's biases and prejudices and populism rather than feasible ideas (Leach and Mearns, 1996; Briggs, 2005). For example, local knowledge of time or distance (perceived time or distance) tend to vary directly with road congestion and inversely with respondents' level of comfort and security on the road (Wener et al., 2006). This was likely the case in this study. For instance, in expressing how dire travel conditions were, some respondents overestimated travel distance and time. Besides, it was noted that, some suggestions were biased to respondent's location or hometown. Most respondents were more concerned about their comfort and town pride rather than the broader picture of improving spatial access to market in the entire area. Some of these human factors could explain why such discrepancies occurred. Moreover, some scholars have argued that, local knowledge must not be seen as a rigid or static form of knowledge. Rather, it must be seen as fluid and adaptable to new ideas (Briggs, 2005). In a field study in Tanzania, Briggs (2005) observed that, local farmers were open to utilizing any knowledge that would help solve their problem, and not necessarily maintaining the status quo. In that sense, the pragmatic solutions identified in this study, may likely appeal to the locals despite the solutions' conflicting stance with their opinions.

Despite the above issues, this study still utilized some local knowledge. The local opinions solicited through the survey provided crucial help in identifying cost factors for new roads and market development. Also, in an attempt not to bias the results, survey suggestions (as in the case of locating new markets) were incorporated in the model.

To sum it up, the approaches adopted in this research would influence both theoretical and practical knowledge about the problems addressed: spatial accessibility, modelling new road networks, and location allocation. In addition, they could have broad implications in both developing and developed countries in diverse fields. Considering these potential impacts, it was worth undertaking this research.

8.4 Recommendations

8.4.1 Suggestions for Policy Makers

Some key findings in this research deserve attention from policy makers. These are outlined below:

1. There is a dire need for transportation development in several parts of Afram Plains especially in the south-eastern peninsula. Currently, there are virtually no motorable road networks connecting many communities to a major market in the sub-area. This has compelled many residents to travel across the lake to trade instead. The journey across the lake is very risky due to the unreliable and poor conditions of the transportation infrastructures - old canoes equipped with no life jackets. Due to the scarcity of such canoes along with their limited schedule, canoe operations are characterized by cases of overloading and occasional fatal

accidents. Therefore, it is recommended that, at least some new feeder roads should be constructed to enhance spatial interaction and trade relations in this area. There are also some parts of Afram Plains with poor spatial access to market but, needing just an improvement in existing roads to solve it. These areas include Abomasarefo, Agordeke, Kwaekese, and Mem Kyemfere agro-zones.

2. Regarding both new road development and road improvements, the locals (as revealed in the survey) resoundingly demanded for the construction of stronger and larger bridges along the major road-stream intersections. Some residents explained that, with such bridges in place, they would be able to travel to market uninterrupted all year round even if their road surfaces remain in bad condition. But without the bridges, their movement is drastically impeded anytime the streams flood. In view of this, reliable bridge construction should be prioritized when considering new road development or improvements.

3. Besides new road constructions and road improvements, there is also a need for more vehicles in the area. The lack of vehicles was identified as the second most challenging factor limiting spatial accessibility of facilities within Afram Plains. Although, a future improvement in road infrastructure is expected to attract investment in transport services, the government could enhance such process. The government could provide incentives like reduced import duties on imported cars especially, for people interested in investing in the area. This would encourage prospective private investors to invest in transport business in the area. The government could also prioritize major farming areas for the allocation of state-owned tractors. This could be put under the charge of various recognized farmers'

associations in the area to ensure proper care and safety of such property. These steps could relieve the locals of some of their transport burdens.

4. There is the need for introduction of efficient forms of transportation and training in their usage especially for women. The findings from the survey showed that women are greatly disadvantaged in the area due to poor accessibility to market. Many of them rely on inefficient means of transportation such as walking (headloading) in carting their produce to market as compared to their male counterparts. Introducing affordable but durable transport systems coupled with some training that focuses on women in the area would be very beneficial to the women.
5. Ferry transportation is the main form of transportation in the area that needs major improvement. With increasing population in the area, demand for ferry services have also increased over the years. The few ferries available presently coupled with their limited time of operation (10:00 AM – 5:00 PM) constrains movement to and from the area. Expanding ferry services in the area would provide additional improvement in spatial accessibility to and from the area.
6. Tease township, by virtue of its central location and road connectivity, makes it a prime candidate for development of essential social facilities, such as a high-order market, a hospital, a fire station, and a library in Afram Plains. Comparatively, it is the most reachable major town in the area. Unfortunately, Tease currently hosts the least patronized major market in the area. This is partly due to the poorly resourced state of the market. It lacks basic facilities like restrooms, security controls, storage facilities, sheds, and rest houses which are all disincentives to

many prospective traders. In fact, these facilities were identified by survey respondents as needed in any new market that is developed. So, improving Tease market with these facilities will likely boost trading there. Besides, locating other facilities in the town will also be beneficial to majority of Afram Plains' locals as it will help cut down on their transport cost. Hence, it is recommended that, Tease should be considered for future developments of social facilities aimed at serving the entire area.

7. Finally, the farmers need to unite to form cooperatives to enhance their lobbying capacity. With such as united front, they could petition the government to attend to their needs by building new roads, bridges or fixing existing broken ones. Also, they could have the power to implement fair prices for their produce.

8.4.2 Future Research Direction

It is acknowledged that the methods and findings from this research are not conclusive, and can benefit from further research efforts. To extend the research agenda from this study, possible ideas worthy of pursuing include (but not limited to) the following.

1. First, is to explore a stochastic optimization algorithm for modelling new road networks and locating facilities. This would then be compared to the deterministic approach adopted in this study to see which one is more efficient. The stochastic approach would allow for more scenarios to be explored thus, providing further insights and understanding into the problem.
2. Second, is to empirically determine a distance decay function regarding spatial accessibility for Afram Plains. Alongside, is to explore how the function would

influence the Multi-MODAM. The function, since it would be based on local experience might cause a change in the final outputs. Hence, it is relevant to look at it in a future research.

3. Third, is to explore the impact of an impedance threshold in the TCPMP model. Imposing such constraint (be it maximum time or distance) would justify the medians used to maximize the coverage. In this case, some towns or demand centers might not be covered or allocated to a market. But the model would show the ideal sets of markets or facilities that both minimizes impedance/cost and maximizes coverage within a stipulated time frame or distance.
4. Fourth, is to determine if there is any edge effect, and its impact on overall potential spatial accessibility in the Afram Plains. Also, how could it be mitigated? This issue was a concern because it was discovered that, due to absence of motorable roads to the nearest major market in the south-eastern peninsula, some residents travel by water to the adjoining district to trade. This was not accounted for in this study as the author did not know prior to the research so it would be beneficial to look at this aspect in a future research.
5. Fifth, is to compare modeled results from models like OPSA with surveyed opinions (or local knowledge) and explore for points of agreement and disagreements. Where some significant patterns are observed, further analysis could be done to understand the reasons behind them.
6. Sixth, it would be helpful to explore the impact of spatio-temporal distribution of periodic markets in a location-allocation model. Some specific questions that could be asked include:

   a. *Is there an inverse relationship between the temporal interval (assignment of periodic days) and location of periodic markets?*
   b. *Are markets which are close in time also close in space?*

7. Last, undertaking a thorough cost-benefit analysis of the interventions identified in this study by assigning monetary values will be very helpful in persuading policymakers in adopting the solutions in this study. With such analysis, a very strong case could be made for the need to pay attention to the poor spatial accessibility situation in Afram Plains.

APPENDIX SECTION

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APPENDIX A: SURVEY INSTRUMENT AND INTERVIEW GUIDE

Introduction: This survey is solely for academic purpose and all information collected shall be kept confidential. The survey is soliciting for your views and experiences with regards to accessibility in your town of residence / electoral area to a market. Your priceless time offered to answer the questions is much appreciated.

Name of Town/Village:……………………….. Electoral Area:……………………..

Accessibility in the area

1. Are you the head of this household? ☐ Yes ☐ No. If no, please indicate your status in the household …………………………………..
2. On average, how many times in a week do you or a member of your household travel to a location outside this town but within this district? ……………………….
3. What is the purpose of your travel (check all that apply) ☐ To sell ☐ To shop/buy

   ☐ To farm ☐ To visit ☐ Other (please specify)…………………………
4. On average, how many times do you travel to a market in a week? …………………
5. On a scale from 1 to 5, where **"1"** means "Rarely" and **"5"** means "Often", please indicate your **first choice** of a market for this household.

Name of market	Rank
Ekye Amanfrom	
Donkorkrom	
Maame Krobo	
Tease	
Other (please specify)……………………………	

6. On a scale from 1 to 10, where **"1"** means "least important" and **"10"** means "very important", please rank the following reasons as they apply to your **most frequently visited** market in #5 above.

   "least important" 1 2 3 4 5 6 7 8 9 10 **"very important"**

   Good sale pricing ……..Availability of buyers….…..Goodwill with customers….…

   Proximity ……… Safety / Security…………Other (please identify).. ……………...

7. On a scale from 1 to 10, where **"1"** means "least important" and **"10"** means "very important", please rank the following reasons as they apply to your **second most frequently visited** market in #5 above.

   "least important" 1 2 3 4 5 6 7 8 9 10 **"very important"**

   Good sale pricing ……..Availability of buyers….…..Goodwill with customers….…

   Proximity ……… Safety / Security…………Other (please identify).. ……………...

8. On a scale from 1 to 5, where **"1"** means "very rare /never" and **"5"** means "very often / always", please rank the following as your preferred modes of transport to your **most frequently visited** market.

   "very rare / never" 1 2 3 4 5 **"very often / always"**

   Car/Taxi ………..Tractor………Truck……Tricycle (Aboboyaa)…………….
   Motor Bike …….. Bicycle……… Walking…….. Other (please identify)…………

9. On a scale from 1 to 10, where **"1"** means "least important" and **"10"** means "very important", please rank the following reasons as they apply to your answer in #8 above

   "least important" 1 2 3 4 5 6 7 8 9 10 **"very important"**

   Availability ……… Affordability….………Space / Convenience………………….

   Safety……………Other (please identify)……………………………………...….

10. What is your main reason for patronizing your **most frequently visited** market? (check all that apply)

    ☐ To sell ☐ To shop/buy ☐ Other (please specify)……………………

11. What is the estimated time for a travel experience to your **most frequently visited** market (**one way**)? ………..…………minutes / hours.

12. What is the estimated cost (money) for each travel experience to your **most frequently visited market** (one way **without goods**)? GH¢..………………………

13. Do you often travel with goods to your **most frequently visited market**?

    ☐ Yes ☐ No.

14. If you checked yes in #13 above, please identify the item. ☐Tubers ☐ Grains

    ☐ Vegetables Other (please specify)…………………......................................

15. What is the estimated weight / quantity of goods you usually carry with you to the market in each visit? ……...…………………Kg / Olonka / Rubber / Bags / Tubers.
16. What is the estimated cost (money) for each travel experience to your **most frequently visited market** (one way **with goods**)? GH¢..…………………………
17. On a scale from 1 to 10, where **"1"** means "extremely easy" to get to market, and **"10",** means "extremely difficult" to get to market, please indicate (circle) your perception of your travel to your **most frequently visited market** .

    "extremely easy" 1 2 3 4 5 6 7 8 9 10 **"extremely difficult"**
18. On a scale from 1 to 10, where **"1"** means "least critical" and **"10"** means "very critical", please indicate the challenges to accessibility to your **most frequently visited market** area by ranking the following factors

    "least critical" 1 2 3 4 5 6 7 8 9 10 **"very critical"**

    Poor nature of existing roads…….……....… Lack of paved roads………...……….
    Lack of vehicles………… Other (please specify)……………………………………

19. Please give a brief description of your journey to your **most frequently visited market** (including point of origin, nature of roads or paths, challenges or hazard(s) and how they affect your entire trip etc.) …………………...………………………

    ……………………………………….….…………………………………………

    …………………………………………………………………………………..…….

<u>Estimating Economic Potential of towns (please skip if you do not practice any farming)</u>

20. What is the estimated size of your farm?..……………………… acre / lines / $m^{2.}$
21. What type of crop(s) do you grow? (check all that apply)

    □Tuber (Yam / Cassava / Cocoyam) □ Grain (Maize / Millet) □ Legume (Beans / Peanuts) □ Vegetable (Local / Exotic) □Other (please specify)…………
22. In a peak season, what is your usual yield? ..…………………Kg / Olonka / Rubber / Bags / Tubers.
23. What is the average selling price of your produce this season? GH¢……..…….. per ………………...
24. What percentage of your products are you usually able to sell in a season?...……..%

25. If your answer in #24 above is <100%, what is the primary reason (check all that apply) □ Poor access to market □ Lack of buyers □ Feed my family □ Other (please specify)..
26. If accessibility to market **remains the same** in this area, will you do something different than farming? □ Yes □ No □ No but will add another job □ Not sure
27. If accessibility to market **is improved** in this area, will you do something different than farming? □ Yes □ No □ No but will add another job □ Not sure

<u>Improving Accessibility</u>

28. What is currently being done to improve accessibility in general in this area? (check all that apply). □ New feeder roads being constructed □ Existing feeder roads being tarred □ Proper road maintenance being done □ Temporary road maintenance being done □ New markets being created / constructed □ Existing market being improved □ Nothing □ Other (please specify)…………..
29. What would be your suggestion for improving accessibility in general in this area? □ Need for new roads □ Need to improve existing roads □ Need for new market □ Need to improve existing market □ Other (please specify)………….
30. What is / are the reason(s) for your answer in #29 above? □ Will reduce travel time □ Will reduce transport cost □ Will attract more buyers □ Other (please specify)……………….
31. If you indicated new roads, please suggest factors to be considered before construction begins? ………..…………………………………………………..
………..………………………………………………………………………….
32. What is/are the reason (s) for your answer above? …………………………..…..
…………………………………………………………………………….....…
33. If you indicated road improvement, please suggest or indicate things that must be considered or need improvement before construction begins?……………………….
……………………………………………………………………………….....
34. What is/are the reasons for your answer above? ………….......................................
....……………………………………………………..…

35. If you indicated new market, please suggest where the market should be located?
……………………………………………………………………………………………...

36. What is/are the reasons for your answer above?.....…………………….……………
………………………………………………...

37. If you indicated market improvement, please suggest or indicate things that must be considered or need improvement before construction begins?…………………..…..
………………………………………………...

38. What is/are the reasons for your answer above?.....………..…………………………
………………………………………………...

39. Any other comment(s)? ..……………………………………..………………………
………………………………………………...

<u>Demographic & Socio-economic data</u>

40. Sex: □ Male □ Female

41. Age: □ 18-25 □ 26-35 □ 36-45 □ 45-60 □ Over 60

42. Education (Please check the **highest** year of school completed)
□ Basic/Primary □ Secondary/High School □ Technical/Vocational
□ Tertiary/Polytechnic □ None Other (please specify)…………….….……….

43. Size of household (number of people in this household) ……………………………

44. Ethnic origin (check **one**):
□ Akan □ Ewe □ Northern Tribe □ Other (please specify)…………………….

45. Current primary occupation (check all that apply).
□Farming □ Trading □ Artisanal □ Unemployed □ Other (please specify)……………

46. Average household income:
Monthly: □ < GH¢100 □ GH¢100-200 □ GH¢200.1-300 □ GH¢300.1-400 □ GH¢400.1-500 □ >GH¢500

Seasonal: □ < GH¢1000 □ GH¢1000-2000 □ GH¢2000.1-3000 □ GH¢3000.1-4000 □ GH¢4000.1-5000 □ >GH¢5000

Interview with Drivers Guide

Accessibility in the area

Speed limits (km/hr) on Afram Roads						
Mode of Transport	**Trunk Roads**			**Feeder Roads**		
	Good	*Fair*	*Poor*	*Good*	*Fair*	*Poor*
Car / Van / Motorbike						
Tractor						
Bicycle						
Animal						
Walking						

Travel cost for different modes of transport			
Rule	**Outcome / Cost (GHC / $)**		
	Car / Motorbike	*Tractors*	*Animal*
If network is **good**, for every *X length*, assign			
If network is **fairly good**, for every *X length*, assign			
If network is **poor**, for every *X length*, assign			

What would be your suggestion for improving accessibility in general in this area and why? ……………………………………………………………………………….………….

..………..………………………………………………………………………...……….

Please suggest factors to be considered before construction begins?

………...……………………………………………………………………………………….

..………..………………………………………………………………………...……….

APPENDIX B: IRB APPROVAL CERTIFICATE AND OTHER COVER LETTERS

TEXAS STATE UNIVERSITY
SAN MARCOS
The rising STAR of Texas

Institutional Review Board Application

Certificate of Approval

Applicant: Nathaniel Dede-Bamfo

Application Number : 2012Q1825

Project Title: Modeling Spatial Accessibility to market in the Afram Plains, Ghana

Date of Approval: 07/09/13 09:02:18

Expiration Date: None(Application Approved - Exempt)

Assistant Vice President for Research and Federal Relations

Chair, Institutional Review Board

COVER LETTER

Modelling Spatial Accessibility to Market in the Afram Plains, Ghana

I am Nathaniel Dede-Bamfo, a doctoral student in the Doctorate in Geographic Information Science program at the Department of Geography, Texas State University – San Marcos, Texas. I am currently in the process of writing my doctoral dissertation and I am collecting data for that purpose. My doctoral dissertation research focuses on **modelling spatial accessibility to markets in the Afram Plains of Ghana.** I am conducting this research under the supervision of my doctoral advisor, Dr. Edwin Chow, a faculty member at the Department of Geography at Texas State University – San Marcos, Texas.

The primary objective of this study is to understand how spatial accessibility influences economic development in the study area and explore how the situation can be improved.

The purpose of this letter is to seek for your permission to be a participant in this study. Please ask any questions that you have about participating in this study at any time. I want you to have the information you need to make a decision that is best for you. All information collected through this survey will remain anonymous and confidential. Names, agencies and organizations will not be identified. You do not have to answer any questions that make you feel uncomfortable in any way.

If you have any other questions, comments, or concerns please contact me, or my advisor, Dr. Edwin Chow. Thank you for taking the time to participate in this research. Please e-mail me or Dr. Edwin Chow if you would like a copy of the final report, due out summer of 2014.
Questions, comments, or concerns contact:

Nathaniel Dede-Bamfo or Dr. Edwin Chow
nd1115@.txstate.edu chow@txstate.edu
+1 (512) 245-1937

Mailing address:
Texas State University-San Marcos
Department of Geography
601 University Dr.
San Marcos, Texas 78666-4684

________________________ Participant

________________________ Principal Investigator

CONSENT FORM

Research Title
Modelling Spatial Accessibility to market in the Afram Plains, Ghana.

Introduction
This study is part of a research focused on collecting and analyzing information concerning views and experiences with regards to spatial accessibility in your town of residence to market(s) in this district. It is being conducted by **Nathaniel Dede-Bamfo** (nd1115@txstate.edu) of the Department of Geography, Texas State University-San Marcos, Texas, U.S.A. This study is primarily being sponsored by the principal investigator but is also partly being supported by a travel grant from West African Research Center (WARC), Dakar, Senegal. Your priceless time offered to answer the questions is much appreciated. Please do not hesitate to contact the investigator in case you have any with regards to the survey.

Participation
Participation in this research study is totally voluntary. You may disregard any question you consider inappropriate or uncomfortable to you. You may also at any point choose to terminate your participation. Nonetheless, your precious time devoted to this survey is duly appreciated.

Procedures
The investigator seeks your personal views regarding the questions presented in the questionnaire. This survey is expected to take not more than 20 minutes of your time. Please do not hesitate to stop and ask for clarification if you do not understand the meaning of any question or part of the survey.

Confidentiality
This survey is solely for academic purpose and strictly anonymous. Any personal data collected shall be kept confidential and will only be reported in an aggregated format. In addition, all data shall be concealed and kept only by the principal investigator. If a participant shows interest in the results, they will be provided but only after the completion of the entire research. Please do contact the investigator with regards to this issue.

Risks/Benefits/Compensation
There is very minimal risk involved in this research. This is because, the questions do not solicit for very sensitive and confidential details from a participant which might be used to identify him or her. There is also just a minimal direct benefit for participants. This is offered to appreciate you for your time spent in this survey. However, the principal investigator expects that the eventual presentation and publishing of the final results at a conference and in a reputable journal will create awareness and educate the public about the problem being investigated.

Questions about your Rights as Research Participants
If at any time you have questions concerning your rights as a research subject, you may call the Chair of the Institutional Review Board at 001(512) 245-2314.

I, ……………………………………………… have read and understood the purpose and procedure for the proposed study. Also, any question I have, have fully been answered. My signature below indicates that I have agreed to willingly participate in this study.

____________________________	_______________	___________
Name of Researcher	Signature	Date
____________________________	_____________	___________
Name of Participant	Signature	Date

A copy of this form will be given to you upon your agreement to participate in this study.

APPENDIX C: CODES FOR PYTHON SCRIPTING

Item 1

```
# Step-wise Least Cost Path Modelling
#
# This script determines the optimal or cost effective path for each town in Afram Plains
# to its associated market center based on a path distance and path backlink/direction surfaces.
# Unlike, conventional LCP, this script generates the best single path for each location among
# numerous locations.
# Author: Nathaniel Dede-Bamfo
# Date: Originally written in Spring, 2012; last modification September 28, 2016.
# ------------------------------------------------------------------------

# Import modules
import arcpy
from arcpy import env
from arcpy.sa import*

def clearWSLocks(inputWS):
  '''Attempts to clear locks on a workspace, returns stupid message.'''
  if all([arcpy.Exists(inputWS), arcpy.Compact_management(inputWS), arcpy.Exists(inputWS)]):
    return 'Workspace (%s) clear to continue...' % inputWS
  else:
    return '!!!!!!!! ERROR WITH WORKSPACE %s !!!!!!!!' % inputWS

# Environment settings
path =  r"C:\Scenario2_post_processing\Default.gdb" # The workspace where the output will be saved
arcpy.env.workspace = path
arcpy.env.scratchWorkspace = r"C:\Scenario2_post_processing\Default.gdb"
arcpy.env.cellSize = 15
arcpy.env.extent = "landcov13"
arcpy.env.mask = "landcov13"
# Also, make sure you set the path or workspace in the environment section in the tool.
arcpy.env.overwriteOutput = True

# Make a layer from the feature class
arcpy.MakeFeatureLayer_management("Towns_250m_from_rd_distance2mkt_sorted",
"Sorted_Afram_towns") # The feature class upon which the cursor will be based

# Introduce a Cursor
cur = arcpy.SearchCursor("Sorted_Afram_towns")

y = 0
for row in cur:
    fidField = row.getValue("OBJECTID") # The field to be used by the SQL
    #townName = "Name"# The name field to be used in naming each town
    townName = row.getValue("Name") # The name field to be used in naming each town
    print townName

    # Define local variables for select tool
    myInput = "Sorted_Afram_towns" # The feature class used by the select tool
    myOutput = townName # The resultant feature layer after the select function

    # SQL for selecting attributes
    sQL = "OBJECTID = %s" % (fidField)
```

```
# Execute Select function
myOutput2 = arcpy.MakeFeatureLayer_management(myInput, myOutput, sQL)

# Enable ArcGIS extension license
arcpy.CheckOutExtension("spatial")

# Define local variables 1
mySource = myOutput2 # The source feature class name
inElev = "afram_dem"
#inMask = "existn_Rds_rs"
#exTract = "extract_path"
pdOutput = "path_dis" # The output Cost Distance
myCostSurf = "weighte_cs" # The input raster or cost surface
pdcOutput = "path_d_cost" # The output Cost Distance
myBkLink = "pdc_bl" # The output Cost Backlink / Direction
myDest ="destination"
path_option = "BEST_SINGLE"
destn_Field = "VALUE" # A field in the destination feature class. It is an optional parameter
                # used to obtain values for the destination locations.
cP = "lcp"
cPfc = "lcp_fc"
rds = "Existing_RdsCopy1"
fieldMappings = ""
subtype = ""

# Polyline to Raster
rds2 = arcpy.PolylineToRaster_conversion(rds, "OBJECTID", "mask", "MAXIMUM_LENGTH", "NONE",
"15")
print "Done with existing road conversion"

# Execute Path Distance (PD)
myPD = PathDistance(mySource, "", inElev)
# Save the PD output
myPD.save(pdOutput)

# Extract by Mask
outExtract = ExtractByMask(pdOutput, rds2)
# Save the output
outExtract.save("extract_path")

# Get Raster Properties
proP = arcpy.GetRasterProperties_management(Raster("extract_path"), "MINIMUM")
myMIN = proP.getOutput(0)
print myMIN

# Reclassify path to get destination point
outCon = Con(Raster("extract_path") == float(myMIN), 1)
outCon.save("C:/Scenario2_post_processing/Default.gdb/min_pt")
print "Done with Reclassification"

# Raster to Point
#outC2 = Raster("F:/Scenario2_post_processing/min_pt")
#arcpy.RasterToPoint_conversion(outC2, myDest, "Value")

# Execute Path Distance with Cost (PDC)
myPDC = PathDistance(mySource, myCostSurf, inElev, "", "", "", "", "", myBkLink)

# Save the PDC output
myPDC.save(pdcOutput)
```

```
    # Execute CP
    outC2 = Raster("C:/Scenario2_post_processing/Default.gdb/min_pt")
    myCP = CostPath(outC2, pdcOutput, myBkLink, path_option, destn_Field)

    # Save the CP output
    myCP.save(cP) # The resultant Least Cost Path

    # Raster to Polyline
    arcpy.RasterToPolyline_conversion(cP, cPfc, "ZERO", "0", "SIMPLIFY", "VALUE")

    # Append
    arcpy.Append_management(cPfc, rds, "NO_TEST", fieldMappings, subtype)


y = y + 1

# Delete to remove locks
del cur

# My Compliment
print "Great job!"
```

Item 2

```
# Title: Composite_LocationAllocation_No_Impedance_Code.py
# Description:  This code has two main parts:
# Part One produces a set of 5 features called medians (a set of potential market locations) using
# factorial combinations. Part Two on the other hand determines which of the medians or proposed new
# would ensure that travel time from all demand centers market locations (Afram Plains communities)
# are minimized. For this scenario, a location-allocation analysis using minimize impedance or p-median
# problem type was used.
# Date: First written on February 17, 2016; Last modified on October 03, 2016
# Author: Nathaniel Dede-Bamfo with kind support from Dr. Edwin Chow and Guixing Wei
# Credit: Esri
# Requirements: Network Analyst Extension

# Import system modules
import itertools, random, os, math
import arcpy
from arcpy import env

def clearWSLocks(inputWS):
  '''Attempts to clear locks on a workspace, returns stupid message.'''
  if all([arcpy.Exists(inputWS), arcpy.Compact_management(inputWS), arcpy.Exists(inputWS)]):
    return 'Workspace (%s) clear to continue...' % inputWS
  else:
    return '!!!!!!!! ERROR WITH WORKSPACE %s !!!!!!!!' % inputWS

try:
    # Set environment parameters
    path = r"E:\Folder"
    arcpy.env.workspace = path # The workspace environment must always be set first before using any of
the List functions
    env.overwriteOutput = True # This ensures that previously run outputs can be written over

    # Part One: Generating medians or potential markets using Factorial Combination
    print "Generating the medians..."

    # Factorial combination parameters
    totalElements = 14 # "How many Potential_mkts are there in total?"
    desiredElements = 5 # "How many Potential_mkts to be included in a single solution?"

    def nCr(n,r):
        f = math.factorial
        return f(n) / f(r) / f(n-r)

    if __name__ == '__main__':
        n2 = nCr(totalElements,desiredElements)
        mktArray = []

        # Create an array to store the market indices
        for i in range(0, totalElements):
            mktArray.append(i)

        # Randomly sample the elements to initialize the population
        sLyrName = "LAlyr"
        file = open(path + "/medians.txt", "w")
        mediansArray = list(itertools.combinations(mktArray, desiredElements))
        strSQL = ""
        for i,item in enumerate(mediansArray):
            for j in item:
```

```
            file.write(str(j))
        file.write('\n')
        strSQL = """ "FID" = {0} OR "FID"={1} OR "FID"={2} OR "FID"={3} OR "FID"= {4} """.format(*item)
        arcpy.MakeFeatureLayer_management("All_Potential_Market_Locations.shp", sLyrName, strSQL)
        arcpy.CopyFeatures_management(sLyrName, "Potential_mkts_" + str(i)+ ".shp")
    file.close()

print "All medians created successfully. Now working on Location Allocation......"
```

 # Part Two: Running Location-Allocation

```
# Check out the Network Analyst extension license
arcpy.CheckOutExtension("Network")

x = 0
# List all median ("Potential_*") outputs
myMktslist = arcpy.ListFeatureClasses("Potential_*")
# print str(myMktslist)
for item in myMktslist:
    print "Processing ..." + " " + myMktslist[x] # [x] indicates pick just one item in myRaslist at a time

    # Set local variables
    inNetworkDataset = "Existing_Rds_plus_new_roads_Edited_planarized_ND.nd"
    outNALayerName = myMktslist[x][:-4] + "_LA" # [x] indicates pick just one item in myRaslist at a time
    impedanceAttribute = "Time_Trac_"
    inFacilities = myMktslist[x]
    requiredFacility = "Current_Market_Locations.shp"
    inDemandPoints = "Demand_Centers.shp"
    lines = outNALayerName + "\\Lines"
    outLineFile = "LA_for" + myMktslist[x][:-4] + ".shp"

    # Process: Summary Statistics
    mktSTATS = myMktslist[x][:-4] + "_Sum_Mkts_Cost.dbf"
    arcpy.Statistics_analysis(myMktslist[x], mktSTATS, "Mkt_Cost SUM", "")

    # Process: Add Field 4 - LA_NAME
    arcpy.AddField_management(mktSTATS, "LA_NAME", "TEXT", "", "", "", "","NULLABLE",
    "NON_REQUIRED", "")

    # Process: Calculate Field 1 - LA_NAME using names of the Potential market centers shapefile
    names1 = str(myMktslist[x][:-4])
    expression = '"'+ names1 +'"'
    arcpy.CalculateField_management(mktSTATS, "LA_NAME", expression,"PYTHON_9.3", "")

    # Process: Ceate a new location-allocation layer. In this case the demand travels to
    # the facility. The goal is to find 5 potential market locations out of all the candidate market
    # centers in addition to 4 existing locations using the minimize impedance model. Since all 5 potential
    # market centers will be located, the procedure here will be finding nearest facility.
    arcpy.na.MakeLocationAllocationLayer(inNetworkDataset, outNALayerName,
    impedanceAttribute,"DEMAND_TO_FACILITY", "MINIMIZE_IMPEDANCE","9", "",
    "LINEAR","1", "10", "Length;Time_Trac_", "ALLOW_UTURNS","", "NO_HIERARCHY",
    "STRAIGHT_LINES", "1", "")

    # Process: Add Locations - Existing or Required Markets
    # Load the existing market centers as the required facility. Use the field mappings to set the facility
    # type to required. We need to append this required facility to existing facilities.
    arcpy.na.AddLocations(outNALayerName, "Facilities", requiredFacility, "Name Communit_1
#;FacilityType # 1;Weight # #",
                   "500 Meters", "Communit_1", "Existing_Rds_plus_new_roads_Edited_planarized
SHAPE;Existing_Rds_plus_new_roads_Edited_planarized_ND_Junctions NONE",
```

```
                "MATCH_TO_CLOSEST", "CLEAR", "NO_SNAP", "5 Meters",
"INCLUDE","Existing_Rds_plus_new_roads_Edited_planarized
#;Existing_Rds_plus_new_roads_Edited_planarized_ND_Junctions #")

    # Process: Add Locations 2 - Proposed or Candidate Markets
    # Load the candidate market centers as facilities using default search tolerance and field mappings.
    arcpy.AddLocations_na(outNALayerName, "Facilities", inFacilities, "Name Community #", "500 Meters",
                "Community", "Existing_Rds_plus_new_roads_Edited_planarized
SHAPE;Existing_Rds_plus_new_roads_Edited_planarized_ND_Junctions NONE",
                "MATCH_TO_CLOSEST", "APPEND", "NO_SNAP", "5 Meters",
"INCLUDE","Existing_Rds_plus_new_roads_Edited_planarized
#;Existing_Rds_plus_new_roads_Edited_planarized_ND_Junctions #")

    #Process: Add Locations 3 - Afram Communities or Demand Centers
    arcpy.na.AddLocations(outNALayerName,"Demand Points",inDemandPoints,"Weight Sum_PRJ1_1
#;Name Community #",
                "500 Meters", "Community", "Existing_Rds_plus_new_roads_Edited_planarized
SHAPE;Existing_Rds_plus_new_roads_Edited_planarized_ND_Junctions NONE",
                "MATCH_TO_CLOSEST", "CLEAR", "NO_SNAP", "5 Meters", "INCLUDE",
"Existing_Rds_plus_new_roads_Edited_planarized
#;Existing_Rds_plus_new_roads_Edited_planarized_ND_Junctions #")

    # Process: Solve the location-allocation layer
    arcpy.Solve_na(outNALayerName, "SKIP", "CONTINUE", "")

    # Process: Copy Features
    arcpy.CopyFeatures_management(lines, outLineFile, "", "0", "0", "0")

    # Process: Add Field 1 - Name2
    arcpy.AddField_management(outLineFile, "Name2", "TEXT", "", "", "", "","NULLABLE",
"NON_REQUIRED", "")

    # Process: Add Field 2 - Time_Sq
    arcpy.AddField_management(outLineFile, "Time_Sq", "DOUBLE", "", "", "", "","NULLABLE",
"NON_REQUIRED", "")

    # Process: Add Field 3 - Length_Sq
    arcpy.AddField_management(outLineFile, "Length_Sq", "DOUBLE", "", "", "", "", "NULLABLE",
"NON_REQUIRED", "")

    # Process: Calculate Field 1 - Name2
    arcpy.CalculateField_management(outLineFile, "Name2", "!Name!.split(\" -\")[0] ", "PYTHON_9.3", "")

    # Process: Calculate Field 2 - Time_Sq
    arcpy.CalculateField_management(outLineFile, "Time_Sq", "math.pow(!Total_Time!, 2)","PYTHON_9.3",
"")

    # Process: Calculate Field 3 - Length_Sq
    arcpy.CalculateField_management(outLineFile, "Length_Sq", "math.pow(!Total_Leng!, 2)",
"PYTHON_9.3", "")

    # Process: Summary Statistics
    laSTATS = myMktslist[x][:-4] + "_LA"+ "_Stats.dbf"
    arcpy.Statistics_analysis(outLineFile, laSTATS, "Weight SUM; Total_Leng SUM;Length_Sq
SUM;Total_Time SUM; Time_Sq SUM", "")

    # Process: Add Field 4 - LA_NAME
    arcpy.AddField_management(laSTATS, "LA_NAME", "TEXT", "", "", "", "","NULLABLE",
"NON_REQUIRED", "")
```

```
        # Process: Calculate Field 1 - LA_NAME using names of the Potential market centers shapefile
        names = str(myMktslist[x][:-4])
        expression = '"'+ names +'"'
        arcpy.CalculateField_management(laSTATS, "LA_NAME", expression,"PYTHON_9.3", "")

        if arcpy.Exists(outNALayerName):
            del outNALayerName

        if arcpy.Exists(outLineFile):
            del outLineFile

        if arcpy.Exists(mktSTATS):
            del mktSTATS

        if arcpy.Exists(laSTATS):
            del laSTATS

        x +=1 # Counter
    del x, item

    print "All LA functions completed successfully...Now executing merge of tables"

    # List all line stats tables
    myTablist = arcpy.ListFiles("*_Stats.dbf") # List all Table ("*_Stats.dbf") outputs
    #print myTablist
    # Use Merge tool to combine line stats tables into a single table
    outPut = "ALL_LA_SUMMARYSTATS.dbf"
    arcpy.Merge_management(myTablist, outPut)
    print "Merge of All LA Summary Stats completed successfully...Now creating a copy of that table"

    # Process: Copy Data
    outPut2 = "ALL_LA_STATS_MKT_COST.dbf"
    arcpy.Copy_management(outPut, outPut2)
    print "Copy of the table completed successfully...Now executing merge of Mkt cost tables"

    # List all summed cost of market tables
    myTablist2 = arcpy.ListFiles("*_Sum_Mkts_Cost.dbf") # List all Table ("*_Sum_Mkts_Cost.dbf") outputs
    #print myTablist2
    # Use Merge tool to combine tables into a single table
    outPut3 = "ALL_MKT_COSTS.dbf"
    arcpy.Merge_management(myTablist2, outPut3)
    print "Merge of Mkt cost tables completed successfully...Now executing join of the two tables"

    # Process: Join Field
    arcpy.JoinField_management(outPut2, "LA_NAME", outPut3, "LA_NAME")

    print "All functions executed; script completed successfully. Praise & Thanks be to God!!! :)"

except Exception as e:
    # If an error occurred, print line number and error message
    import traceback, sys
    tb = sys.exc_info()[2]
    print "An error occured on line %i" % tb.tb_lineno
    print str(e)
```

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