Original Research Article

Spatial distribution of telecom masts, accessibility and customer hotspots in the Greater Accra Metropolitan Area, Ghana

Abstract:

Geographical distribution of telecommunication masts, patronage, and provision of quality services, without unintended consequences, remain vital for telecommunication operators. The spatial distribution of telecommunication masts and services in Ghana are not uniformly distributed, resulting in the disparities of signal strengths in different locations. Bad signals directly or indirectly affect various forms of business transactions and communication activities. We assessed the spatial distribution of telecom masts and customer hotspots for the major telecommunication networks in Ghana using geospatial techniques. Findings revealed most of the telecom masts were highly concentrated in Accra Metropolis. Again, most of the enterprise business customers were clustered within the 4-km radii of sited masts. More investment is needed by telecommunication industries to boost patronage, particularly in La Dade Kotopon and Tema Metropolis. The area's prospect of attracting more customers increases sustainability concerns of telecommunication masts availability, accessibility, environmental health and management risks, among key industrial players.

Keywords: GIS, telecommunication industry; Enterprise Business customer hotspot; web-based application; Accra

1. Introduction

Advancement in telecommunications in recent years has intensified the flow of interactions and distribution of information among individual consumers and business organizations around the world via phone calls (voice) and over the internet (data). Consequently, the distribution and management of information by telecommunication companies have become crucial. The location of telecom mast may tend to pose both desirable and undesirable signal effects, especially where telecom customers are highly concentrated (Niles, 1994). In the fight against the COVID-19 pandemic, the telecommunication industry has played a crucial role. The human pattern of COVID-19 distribution has been studied using telecommunication data (Persson et al., 2021; Yeboah et al., 2021). 5G mobile technology connected households, hospitals, and ambulances, in order to improve healthcare delivery amid the pandemic (Ahmadi et al., 2020). For instance, a 5G network allows patients to connect with their doctors for medical care. Doctors in diverse ways provide visual and virtual guidance to ambulances on how to treat patients (Ahmadi et al., 2020).

Regions with high concentration of telecommunication customers, and limited masts experience poor signals. Since telecom operators have limited or no information about customer hotspots, they are unable to address challenges associated with low to no network signals. Telecommunication providers must examine a variety of elements that may have direct or indirect effects on various mobile signals of settlements and commercial sites when locating a telecom mast and offering services. The layout of telecom masts is being governed by the requirements of transmission and receiving conditions with the help of geospatial aided technology, especially when it comes to the spatial distribution of telecommunication masts to the customers' hotspot, elevation in which the mast is sited, and signal coverage. Africa has over 800 million mobile connections and almost 450 million unique customers, with a population of over 1.1 billion people where Sub-Saharan Africa alone accounts for 75% of the continent's unique customers (Kumar, 2014). However, in Africa, mobile network coverage is only 70 percent of the population, leaving about 300 million people without access to mobile communication infrastructure (Kumar, 2014). The coverage of mobile networks varies widely across Africa, ranging from 10 percent to nearly 99 percent. Africa's mobile industry is confronted with numerous problems, which are mainly infrastructural and operational. One of the primary obstacles in operating networks is the terrible grid electrical infrastructure, which adds a large cost to operations and unsuitable siting of telecom masts which results in poor signals. With only 43% of the population having access to grid energy, Africa has one of the lowest electrification rates in the world, leaving over 600 million people without power supplies. Electricity supply is highly unreliable, coupled with frequent and protracted outages causing fluctuations in telecom masts signals (Kumar, 2014). Furthermore, when grid energy infrastructure is available, there is often an occurrence of numerous customers taping from very limited mast. The present study draws on the tenets of United Nations Millennium Sustainable Development Goal (SDG) 3 which has one of its main objectives to ensure universal and even or equitable access basic services, information and so on. These tenets, coupled with the use geospatial technology will help identify, spatially analyse mast distributions and customer hotspots for the major telecommunication networks in Ghana. Studies of this nature could drive environmental and health-risks, associated with the siting of telecom masks.

Contextually, the Greater Accra Metropolitan Area (GAMA) of Ghana’s mobile signals are not evenly distributed spatially. Some areas enjoy smooth and good signals, whilst others have poor to no signal. In other to receive or make a call, the phone must be in proximity to a transmitter mast. When a call is received within a mast's range, the mast connects it to a switching center (typically through subterranean cable or microwave), which routes it to the appropriate area. (Fitch, 2011). That said, Ghana's government and telecommunication service providers are working together to expand network signals and internet access. The attempt to democratise digital participation in the country is being held back by limited coverage, technical know-how, and expensive budget (Endert, 2018). According to the recent population and housing census conducted by the Ghana Statistical Service (GSS), the population of the Greater Accra region currently stands at 5,446,237 (GSS, 2021). Interestingly, more than 80% own mobile phones (NCA and GSS, 2019). This triggers an improvement in service provision, and siting of mobile phone towers (cell sites and masts) across the Greater Accra Metropolis. Dowuona (2009) reported over 3,000 telecom towers serve more than 13 million mobile phone users, according to the National Communication Authority’s (NCA) report. Telecommunication experts argued that the number of towers is inadequate to ensure good signals or services to the various telecom customers (Dowuona, 2009). In as much as there are inadequate telecom masts (towers), the haphazard manner in which some telecom masts have been sited across the length and breadth of the Greater Accra Metropolis is a cause for concern. However, the NCA and the Environmental Protection Agency (EPA) have proposed that telecom network providers be required to co-locate telecommunication masts as a license condition (Osei-Owusu, 2015). This paper examines Dowuona's (2009) claim that more towers are needed to improve service delivery efficiency. As a result, the purpose of this paper is to evaluate the spatial distribution of telecom masts and to support the identification and monitoring of masts that are set up at random without regulation.

Moreover, one critical issue to consider entails telecom services, especially in the area of high concentration of their customers spatially (customer hotspots). Kyei and Bayoh (2017) reported that adequate information about the concentration of customers is essential in the provision of efficient telecom services. They further revealed this factor as a key component for customer retention and growing a sustainable business in a fairly competitive environment. According to Endert (2018), most telecommunication providers in Ghana have little to no information regarding the concentration of their clients in a certain area. This makes it a daunting task, in their quest to provide quality services or successfully enhance service patronage in these areas. Network signal usually goes down when there are numerous people tapping from very few masts (tower or cell sites) nearby. This normally causes huge network traffic and poor network signal in some areas in the GAMA, which slows down business transactions (Akakpo, 2008).

Boye et al. (2018) assessed telecommunication signals in Tarkwa in the Western Region of Ghana with emphasis on the signal strength available to customers of Airtel-Tigo, one of the telecos in the country. However, they did not consider the spatial distribution of the telecom masts and the customers' hotspots (the number of customers taping from each mast in the area) per the masts available in the area. In the Greater Accra region, no comprehensive study has been conducted on signal strengths and spatial distribution of telecom masts and customer hotspots. In a study that dwelt on the regional distribution of households with internet access in Ghana, Sasu (2021) revealed the Greater Accra had 37.7% of its households, having internet access as of 2018. This proportion was the highest among other households across the sixteen administrative regions in Ghana, followed by the Ashanti region (27.3%); Western region (24.1%); Central region (21.3%) among others (Sasu, 2021). Related studies in the study area and Ghana to a large extent have primarily focused on telecommunication management, determinants of internet usage and customer satisfaction (Kyei and Bayoh, 2017; Osei-Owusu, 2015; Gyasi Nimako and Azumah, 2009; Ayeh, 2007), coverage, challenges for connectivity and access to internet services (Endert, 2018; Akakpo, 2008). Determining the spatial distribution of telecommunication masts and customer hotspots in this study are timely and useful for addressing gaps in the extant literature. Geospatial technology has been instrumental in accomplishing the modern-day task of information management (Saikhom et al., 2016). The application of geospatial technology in Ghana remains pertinent, and elevate the nation to be ranked among the leading countries in Africa to promote telecommunication development. Geospatial techniques would also aid in identifying where telecom enterprises are highly concentrated to inform the decisions of telecommunication companies in the area of mast or cell site distribution. This paper seeks to assess the spatial distribution of telecom masts and telecom enterprise business customers' hotspots in the Greater Accra Metropolitan Area. We attempted to address the aforementioned knowledge gaps by (i) developing a web application showing the distribution of telecom masts and telecom Enterprise Business customer hotspots in Greater Accra Metropolitan Area (GAMA) (ii) determining Enterprise Business customer hotspots for the various telecom networks within the study area, and (iii) identifying the coverage of telecom mast signals within the study area. The rationale behind the study is to provide spatial information of masts and telecom services to customers, targeted to support baseline information to the public, as well as researchers who may wish to conduct or extend this study. This paper would enrich basic datasets to propel country-level studies, considering the few to no research conducted on the spatial distribution of masts and telecom customers in the area under study.

1.1 Description of the study area

The setting for this study is the Greater Accra Metropolitan Area (GAMA), which includes Ga South Municipal, Ga Central Municipal, Ga West Municipal, Ga East Municiapal, Ga North Municipal, Weija Gbawe Municipal, La Dade Kotopon Municipal, Ledzokuku Municipal, Ablekuma West Municipal, Ablekuma North Municipal, Ayawaso East Municipal, Ayawaso North Municipal, Ayawaso West Municipal, Adentan Municipal, Tema Metropolitan, Tema West Municipal, Ashaiman Municipal, La Nkwantanang Municipal, Krowor Municipal, Okaikwei North Municipal, and Kpone Katamanso Municipal Districts. GAMA is the smallest among Ghana's sixteen administrative regions in terms of area size. GAMA is bordered on the south by the Gulf of Guinea, in the north by the Eastern region, in the west by the Central region, and in the east by Volta Lake. It extends from latitude along the Atlantic coast in the south-eastern part of Ghana, covering a total area of 3,245 square kilometres representing 1.4% of the total land surface of Ghana. However, it is the second most urbanized area in Ghana, with a population of 5,446,237, accounting for 17.7% of Ghana's total population (GSS, 2021). According to a World Bank report, the area has a 90.5% urbanization level with urban population growth running at 4.2% per annum. Due to the continuous migration, data shows GAMA has a very high population density (103 people/sq.km) and growth rate (3.1%). Documented evidence suggests over the past years, rapid urbanization and unplanned urban growth in GAMA have relentlessly triggered dramatic changes in land-use, due to a lack of legally binding development control. The Greater Accra region houses the capital city of Ghana (ACCRA), major seaports (TEMA), the largest proportion of business establishments, and the majority of Ghana's industries. As a result, GAMA's population and infrastructure are constantly growing. Economic activities in GAMA include the financial and agricultural sectors, fishing, and the manufacturing of processed food, plywood, lumber, textiles, telecommunication activities, clothing, and pharmaceutical or chemical industries. GAMA was chosen as the area of interest because it hosts most of the Telecommunication enterprise customers, among other areas in Ghana. It hosts the majority of Ghana's network providers' masts or towers in terms of numbers. Again, the national headquarters of the various telecommunication network service providers are concentrated in GAMA, making it easier to accurately acquire relevant, reliable and valid spatial data on masts and customer information.

Fig 1. Map of the Greater Accra Metropolitan Area

2. Materials and Methods

2.1 Data collection and design

For the data collection, primary and secondary data were used. The primary data collection involved obtaining Enterprise Business Customers data (names and locations) from the various telecommunication companies (MTN, Vodafone, and Airtel-Tigo), as well as spatial data obtained from the various telecommunication masts using the Arc Collector. Secondary data collection was obtained from online sources, journals, articles, books, and magazines.

MTN, Vodafone, and Airtel-Tigo were the main telecommunication operators of interest due to the significant number of enterprise business customers (customer base) and masts distribution, as well as their reputation as the top three telecommunication operators in Ghana in terms of market shares.

Geographic Information System (GIS) was employed as the research design for this study, because of its enormous opportunities. GIS is a system that captures, processes, analyses, manages, and stores geographical data (Adegboyega et al., 2017; Shu et al., 2011; Hui et al., 2002). In recent years, GIS has become an indispensable technology in the telecommunication industry (Shu et al., 2011; Fry, 1999). The use of GIS in telecommunications aids telcos in determining client concentrations and the best transmission technique to use, as well as improving their advertising and network design skills (Fry, 1999). Moreover, GIS is cost effective, efficient, and enables telcos to store and manage spatial data of their customers (Narbaev et al., 2021; Shu et al., 2011).

2.2 Data Analysis

The study intensively utilized ArcMap and ArcGIS online for visualization, processing, and analyses, based on the data collected from the field. The study area was created using ArcMap, the spatial data collected on the field (masts and telecom enterprise customers) was visualized in ArcMap and published in ArcGIS online by logging on to ArcGIS online and linking the ArcMap to the ArcGIS online platform. Cold and hotspot analysis was also performed in the ArcMap (ArcGIS desktop) using point density tool in the spatial analyst (located in the Arc tool box) to show locations with high/low density or concentration of telecom customers to generate hotspot maps for the Telecommunication operators (MTN, Vodafone, and Airtel-Tigo) in the GAMA. It further examined the signal strength in terms of distance from the various masts and customer distributions in the study area using the multiple ring buffer tool in ArcMap for each of the Telecom operators. This was published and summarized in a form of web applications (interactive dashboards) using ArcGIS online. The interaction Dashboards were created using the various telecom customers, masts and buffer analysis, published on the ArcGIS online via the ArcGIS desktop (ArcMap). This was done by creating a web-based map for each of the published data (telecom customers, masts and buffer analysis), and creating a dashboard for each of the web-based maps by adding the various components (legends, number of districts, titles and map canvases, among others).

Fig 2. Work-flow designed for the study

Fig 2. presents the workflow on the acquisition of data for this study, and how the analysis was conducted to achieve the specific objectives set out in this study. The study's workflow involves field data collection of telecom masts and customers, which was visualized in ArcMap, published and analysed on ArcGIS online, and summarized using dashboards (Web-based applications). It further shows how geospatial technology can be applied to the spatial location of telecom masts, masts signal coverage, and business customers' hotspots in GAMA.

3. Results

3.1 Spatial Distribution of Telecom Masts and Telecom Enterprise Customers in GAMA

As of November 2022, about 503 telecom masts were mapped in the GAMA and out of this total, 208 masts belong to MTN Ghana, 176 masts for Vodafone Ghana, whereas 119 masts belong to Airtel-Tigo. Also, a sample of 130 telecom enterprise customers was mapped in the GAMA. Out of the 130 telecom enterprise customers, 50 were MTN Ghana subscribers, 50 belonged to Vodafone Ghana, whilst the remaining 30 were Airtel-Tigo customers. Airtel-Tigo had a smaller number of enterprise customers for this study due to the small number of business enterprises, subscribing to their services in the area. The spatial location of the various telecommunication operators' masts and enterprise business customers were mapped, visualized in ArcMap, and published on ArcGIS online. An interactive web-based application (Dashboard) was created out of the spatial location of masts and customers, and hosted online to show the distribution of the telecom masts and telecom enterprise business customers in the various districts under GAMA. Fig.3 shows the web application created to show the spatial distribution of telecom masts and telecom enterprise customers in GAMA.

Fig 3. Web-based Application of Telecom Masts and Enterprise Customers Distribution in GAMA

(Processed on: https://ugarc.maps.arcgis.com/apps/dashboards/7f02b9ff23134b89bc4d37145956692e)

3.2 Enterprise Customers Hotspot of the Telecom Operators in GAMA

3.2.1 MTN Enterprise Customers hotspot

Based on 50 enterprise customers mapped for MTN, a point density analysis was performed using ArcMap to reveal where MTN Enterprise Customers are highly concentrated. Per the illustration in Fig. 4, it is evident that Accra Metropolitan Area (AMA) has a high concentration of MTN Enterprise Customers, as compared to other districts. This is due to AMA having a significant number of businesses operating in its domain, and the area being a Central Business District (CBD). It is obvious for AMA to have numerous hotspots within its domain, even though LA Dade Kotopon houses limited MTN Enterprise Customer hotspots. A hotspot map of MTN Enterprise Customers in GAMA is illustrated in the figure below.

Fig 4. Map showing MTN Enterprise Customers Hotspot

3.2.2 Vodafone Enterprise Customers hotspot

Considering 50 enterprise customers mapped for Vodafone Ghana, a point density analysis was performed using ArcMap to identify areas where Vodafone Enterprise Customers are highly concentrated. Fig 5 gives a shred of clear evidence that AMA has the highest concentration of Vodafone Enterprise Customers, followed by LA Dade Kotopon, Tema Metropolitan Assembly (TMA), and Adenta. This can be attributed to AMA having a significant number of business operations in its domain, coupled with serving as a CBD.

Fig 5. Map showing Vodafone Enterprise Customers Hotspot

3.2.3 Airtel-Tigo Enterprise Customers hotspot

From the 30 enterprise customers mapped for Airtel-Tigo, similar analysis was conducted to reveal the localisation of the company's customers. Fig 6 indicated AMA having the highest concentration of Airtel-Tigo Enterprise Customers, followed by LA Dade Kotopon. This could similarly be attributed to reasons, highlighted for the other networks or service competitors.

Fig 6. Map showing Airtel-Tigo Enterprise Customers Hotspot

3.3 Telecom operator's masts signal coverages in GAMA

3.3.1 MTN mast signals coverage

Proximity analysis was performed using the multiple ring buffer tool to show MTN masts signal coverages with the spatial location of MTN Enterprise Customers. Statistics generated prove MTN Enterprise Customers are within 4 kilometres radii from the nearby masts. More so, few customers are within the 8-kilometre radii, with one business drifting 12 kilometres away from the nearby masts. Fig 7 presents MTN mast signal coverages in the GAMA.

Fig 7. Web application depicting MTN Mast Signal Coverages in GAMA

Web App Link: https://ugarc.maps.arcgis.com/apps/dashboards/df171a6917cb4e489a23685e66be19d4

3.3.2 Vodafone Ghana mast signals coverage

For Vodafone Ghana, most of Vodafone Ghana's enterprise customers are within the 4-kilometre radii from the nearby masts. The web application in Fig 8 shows Vodafone mast signal coverages in GAMA.

Fig 8. Web application depicting Vodafone Mast Signal Coverages in GAMA

Web App Link: https://ugarc.maps.arcgis.com/apps/dashboards/04a35f1ce860452db74912155181e690

3.3.3 Airtel-Tigo mast signals coverage

Similar proximity analysis was performed using the multiple ring buffer tool to show Airtel-Tigo masts signal coverages with the spatial location of Airtel-Tigo Enterprise Customers. Here, the company's enterprise customers fall within the 4-kilometre radii from a nearby masts, whilst some customers are within 8 kilometres from a nearby masts.

Fig 9. Web application depicting Airtel-Tigo Mast Signal Coverages in GAMA

Web App Link:
https://ugarc.maps.arcgis.com/apps/dashboards/ab978fd4eb8e49fb81d41fb20f3a3a8b

3.4 Discussion

The present study employed a novel approach through the use of GIS web-based application to spatially map, identify and analyze the distribution and coverage of telecom masts and enterprise business customer hotspots with the GAMA. The results section presented a thorough assessment of the location of telecom masts, identified telecom mast signal coverages, and identified telecom enterprise business customer hotspots which provide vital information to the general public, telecom operators, policy makers, development agencies and the research community.

Through this study, it was discovered that most of the masts in GAMA are located in Accra Metropolitan Area (AMA), due to the fact that the telecom operators (MTN, Vodafone, Airtel-Tigo) enterprise business customers are highly concentrated in AMA. It further revealed areas with high enterprise business hotspots, coupled with few telecom masts experience low network signals due to traffic on the signals, as a result of many customers tapping from few existing masts simultaneously. Our research also showed most of the telecom operators enterprise business customers are within four (4) kilometers radii closer to the nearby mast per the mast signal coverages. This aligns with the findings of Ubabudu (2013) and Omogunloye et al. (2013), who reported service providers are more interested in areas with a large population density, the state's commercial centers, and places with a high-income per capita head. Also, our study corroborated with the findings of Alade et al. (2011), who unveiled that 33% of masts are located in low-density residential regions, 26% in medium-density residential areas, and 41% in high-density residential areas. They further stated that they are neither clustered nor dispersed, but rather random in Lagos, Nigeria. This means that in Nigeria, telecom masts are highly concentrated in populated areas, as compared to moderate and low populated regions just like the case of the GAMA in Ghana.

Proximity analysis was performed using the multiple ring buffer tool to show MTN masts signal coverages with the spatial location of MTN Enterprise Customers. In terms of average signal coverage for the various telecommunication networks, MTN mast signal's coverage in the GAMA is within the 10 kilometres radii. The concentration of MTN enterprise customers in some parts of the Accra Metropolis and LA Dade Kotopon, per the number of masts in those areas account for the low network signals coverage. This is partly due to the assumption of traffic on the signals, due to multiple customers tapping from a single mast simultaneously. Illustration in Fig.8 show some customers are within the 8 kilometres radii from the nearby masts, whilst two businesses are within 12 kilometres radii away from the nearby masts. Interestingly, one business lies more than 16 kilometres away from a nearby mast. However, the average Vodafone mast signal in the area falls within 10 kilometres radii. The concentration of Vodafone enterprise customers in some parts of the Accra Metropolis, LA Dade Kotopon, Tema Metropolis, and Adenta per mast counts account for the low network signals in those respective areas. The average Airtel-Tigo mast signal coverage in GAMA is within 10 kilometres radii. The concentration of Airtel-Tigo enterprise customers in some parts of the Accra Metropolis and LA Dade Kotopon per the counts of masts in those areas account for the low network signals in those respective areas. Based on results presented, it is evident that low network signals identified in some regions of the study domain is primarily as a result of network congestion. It is worth noting that during the pandemic or lock down phase, the populace living in poor signal zones in GAMA were heavily affected. This was mainly due to their inability to communicate effectively with family and friends, co-workers or superiors, among others. This somewhat limited access to information, created emotional stress or frustration, limited productivity and workflow among the populace who mainly worked from home during this period.

3.4 Conclusion

The current study contributes to existing knowledge by developing a GIS web-based application that presents the distribution of telecom mast and enterprise business customer hotspots in the GAMA. Findings revealed that the Accra Metropolitan Area (AMA) has the highest Telecom Enterprise Business customers' concentration (hotspots) in GAMA. Again, our study further revealed LA Dade Kotopon has the second-highest Telecom Enterprise Business customer's concentration (hotspots) in GAMA. Through this study, it was discovered that most of the telecom masts in the GAMA are located in the AMA due to telecom operators' enterprise customers, highly concentrated in AMA. Besides, the study revealed areas with high enterprise hotspots, coupled with few masts experience low network signals due to traffic on the network signals. This is mainly as a result of multiple customers tapping from the few masts simultaneously.

Finally, the research showed most of the telecom operators' enterprise customers are within 4 kilometres radii closer to the nearby mast per the masts signal coverages. Therefore, this study suggests that more masts should be sited in areas like Ga South, Ga East, Ga West, Adenta, and Kpone Katamanso due to current growth and developments (developing at a faster pace). Additionally, these areas have telecom potential Enterprise customers to curtail the problem of poor network signals. Also, telecom operators should channel more resources (like masts) to areas like the Accra Metropolis, La Dade Kotopon, and Tema Metropolis because these areas have the potential of attracting more telecom enterprise business customers (customer hotspots). Telecom operators should enhance their business services in these areas by siting more masts and improving their marketing strategies to facilitate their publicity (corporate brand) and patronage for these areas. This is intended at gaining access to high network signals, irrespective of the customer concentration to boost socio-economic activities. Lastly, the telecom operators in the GAMA are encouraged to conduct periodic assessments and trends of the spatial distribution of their enterprise customers to identify emerging areas with high customer hotspots since GAMA is developing at a faster rate and as businesses grow in these areas, telecom service improvements constituting good network signals among others, must be considered and highly prioritized to address the problem of low to no network signals. The study's drawback was that, due to data confidentiality and privacy concerns, enterprise business clients were chosen over individual customers. Again, data on telecom mast height, transmission range among other parameters were impossible to obtain due to data confidentiality and privacy by the various telecom operators in the study domain. This was identified as a major limitation of this study, which future studies could explore once such data are made available and accessible.

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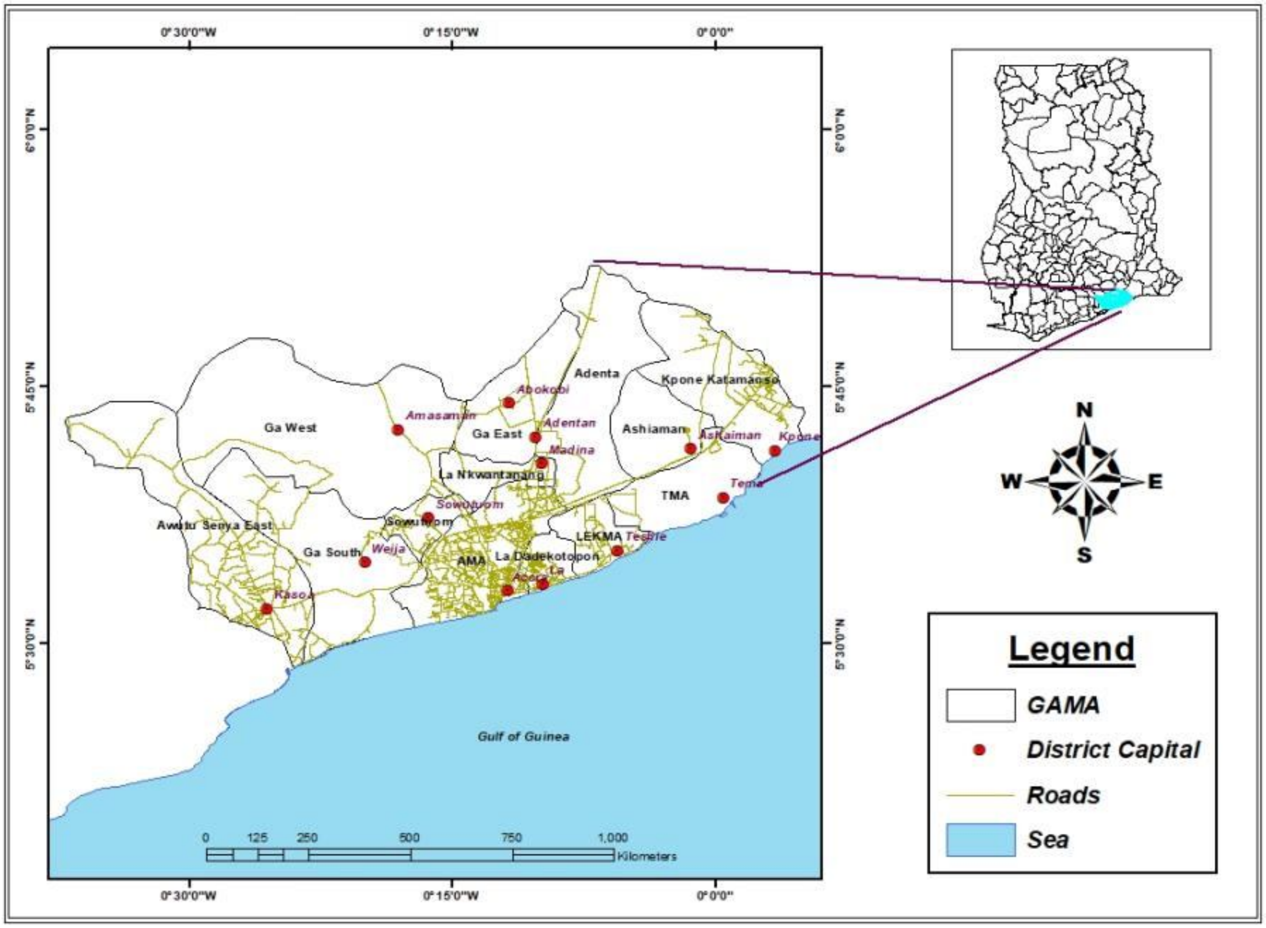

Fig 1. Map of the Greater Accra Metropolitan Area

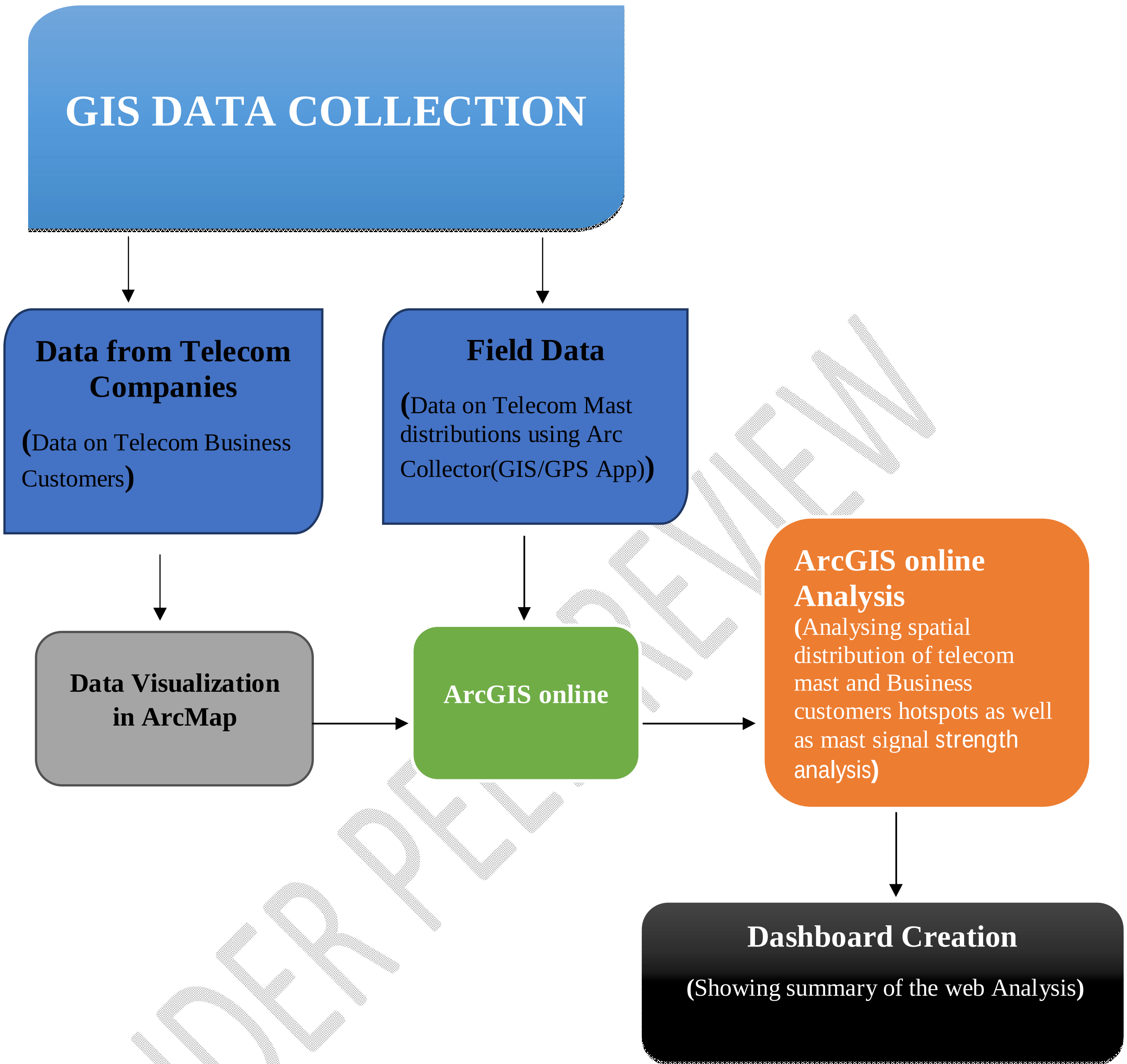

Fig 2. Work-flow designed for the study

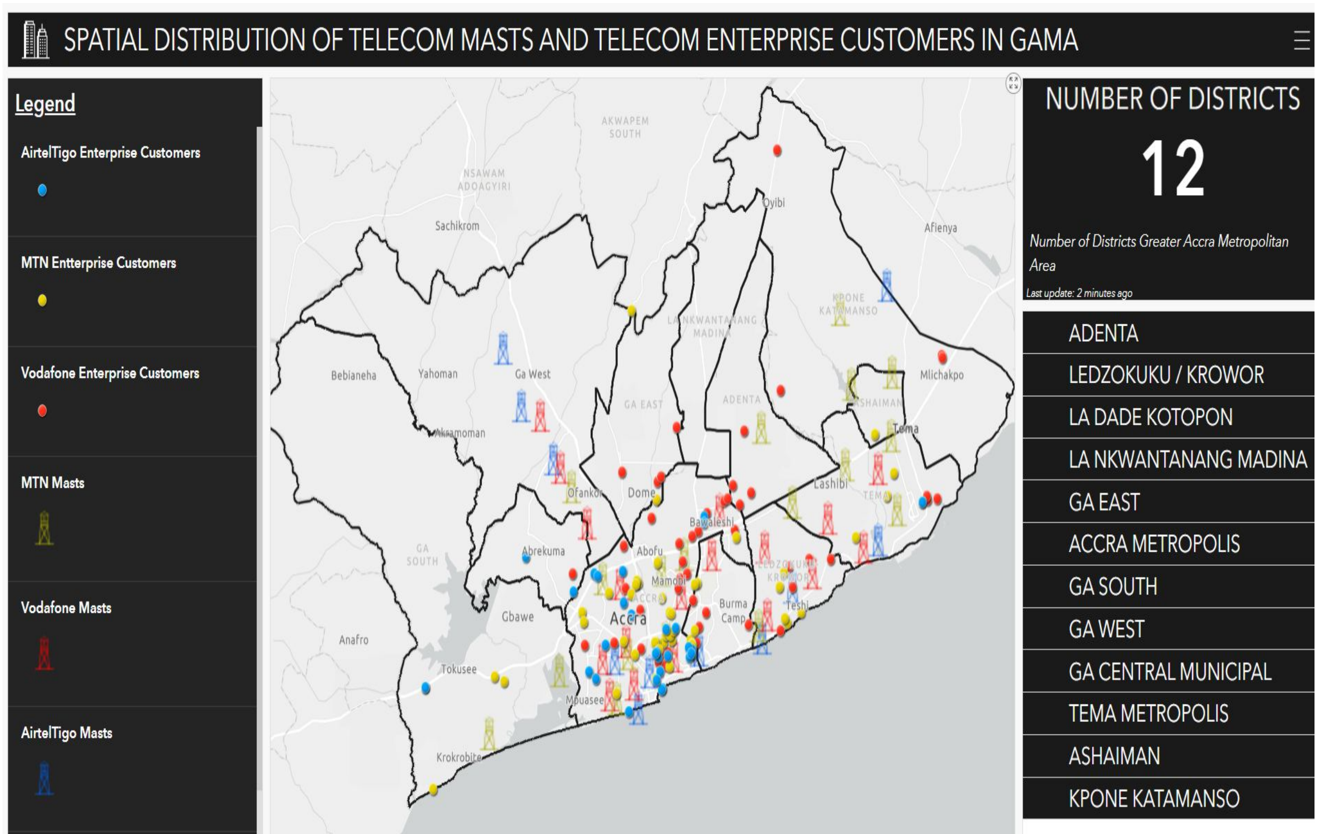

Fig 3. Web-based Application of Telecom Masts and Enterprise Customers Distribution in GAMA

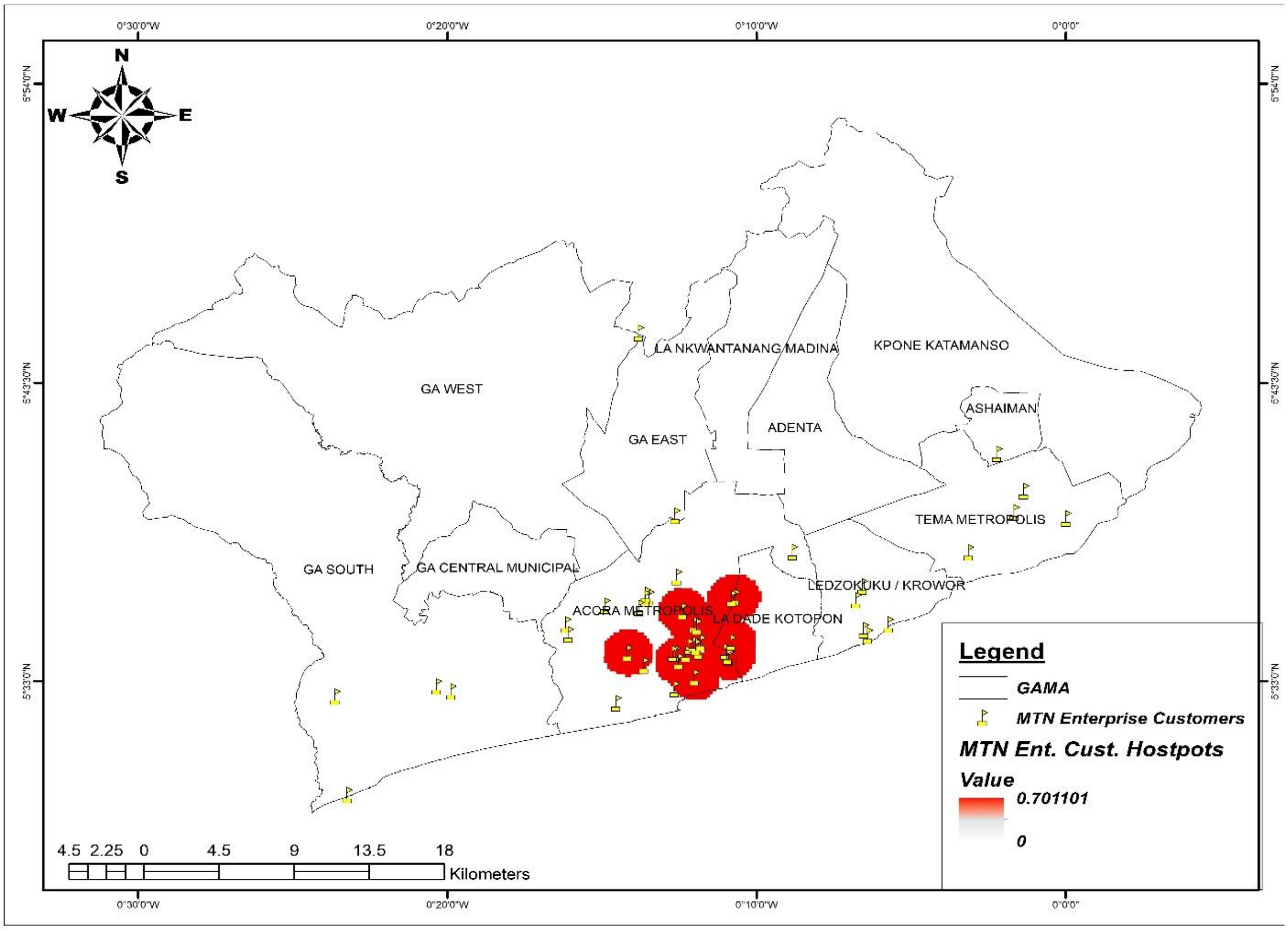

Fig 4. Map showing MTN Enterprise Customers Hotspot

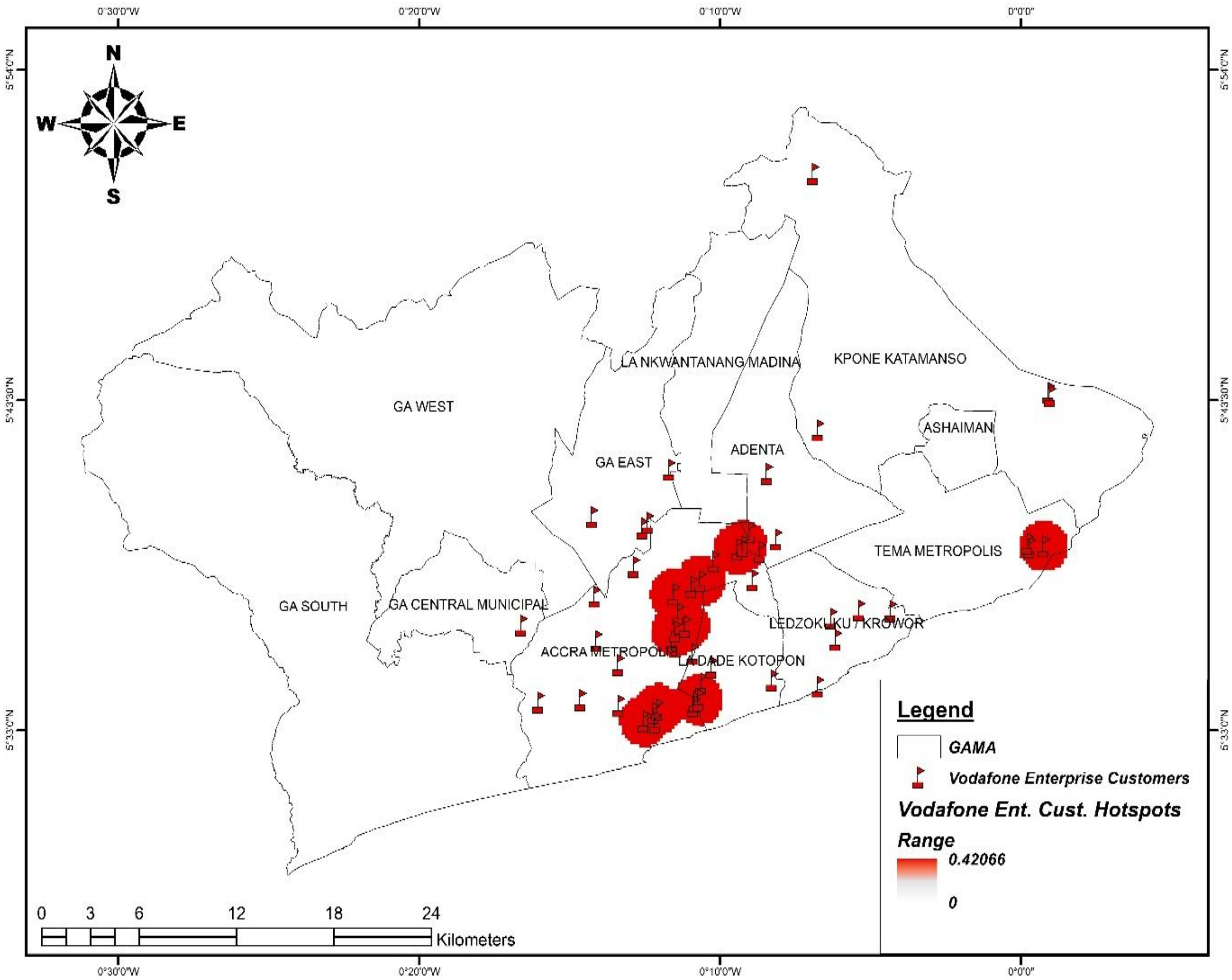

Fig 5. Map showing Vodafone Enterprise Customers Hotspot

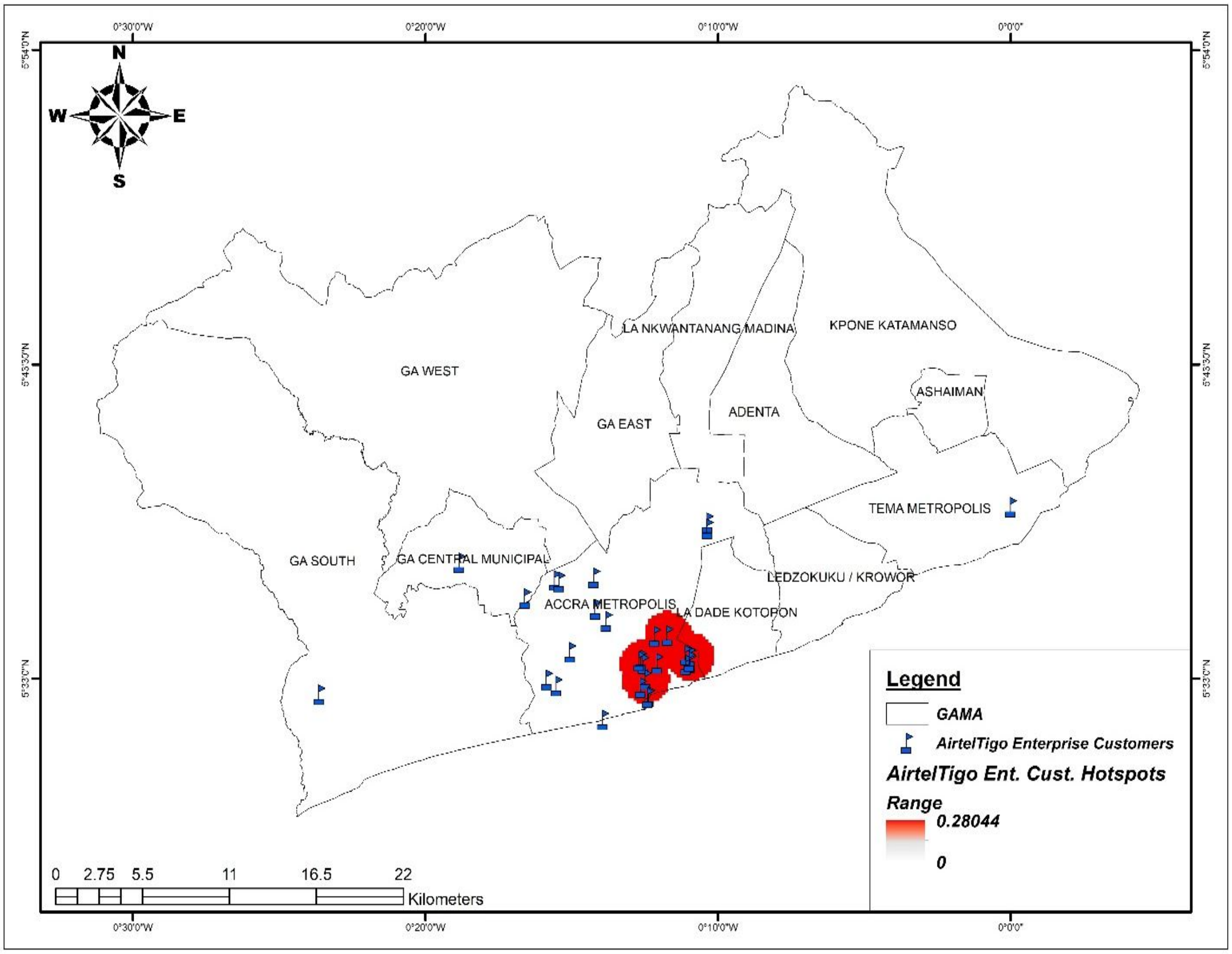

Fig 6. Map showing Airtel-Tigo Enterprise Customers Hotspot

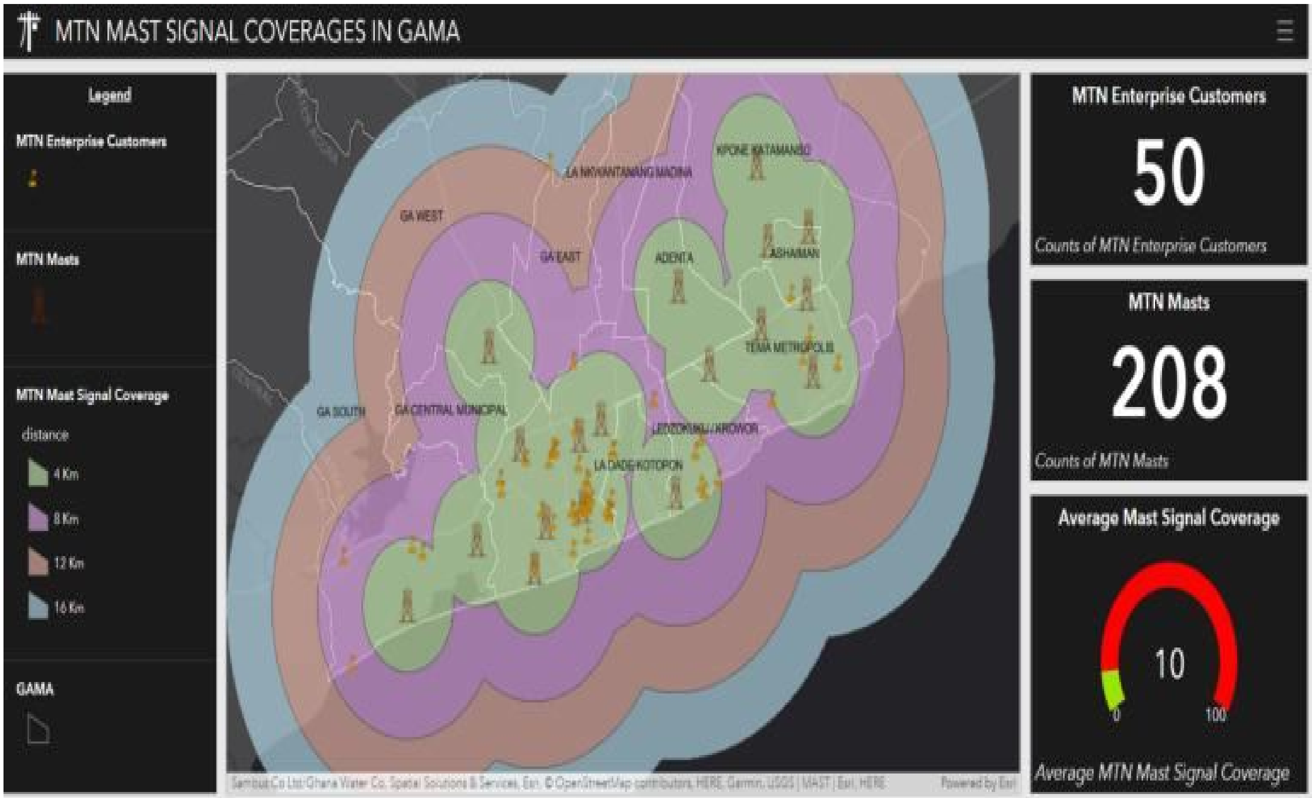

Fig 7. Web application depicting MTN Mast Signal Coverages in GAMA

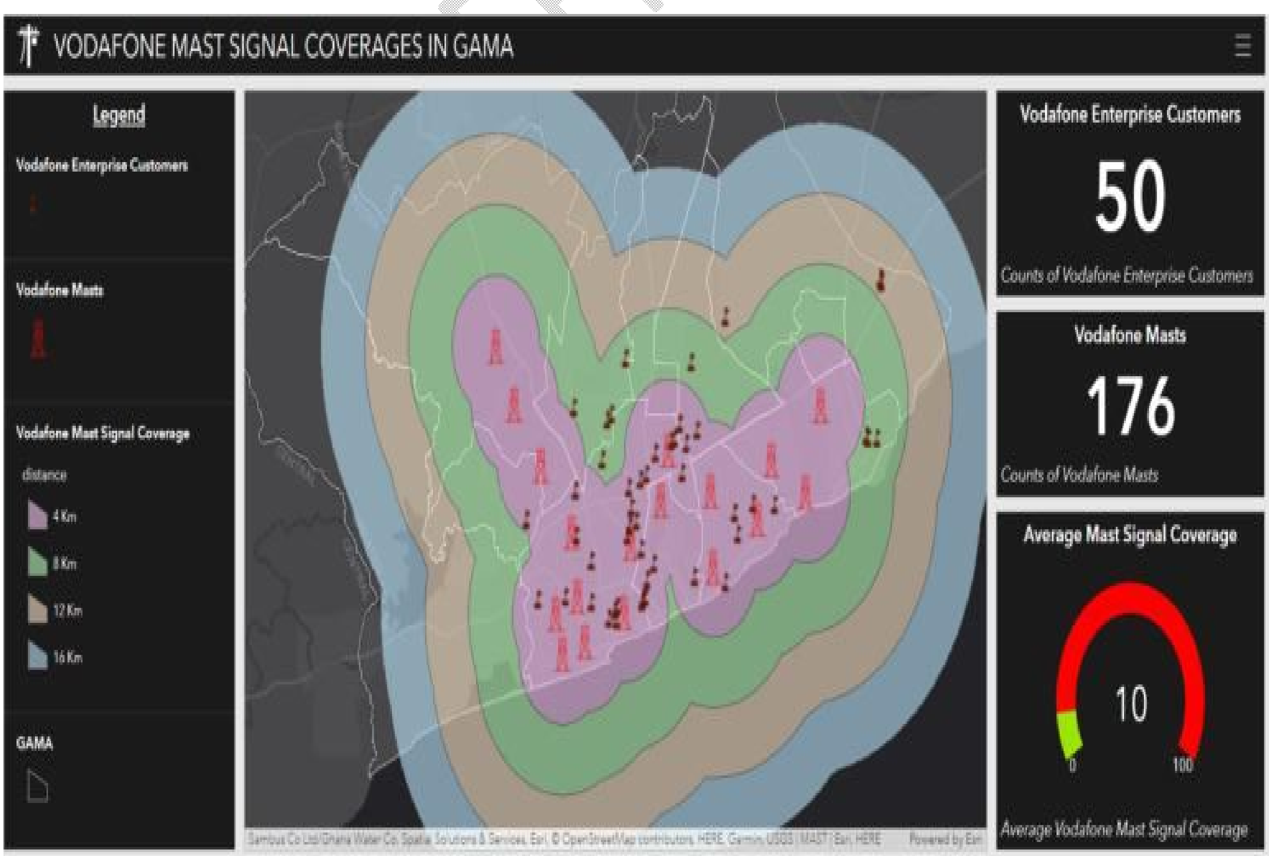

Fig 8. Web application depicting Vodafone Mast Signal Coverages in GAMA

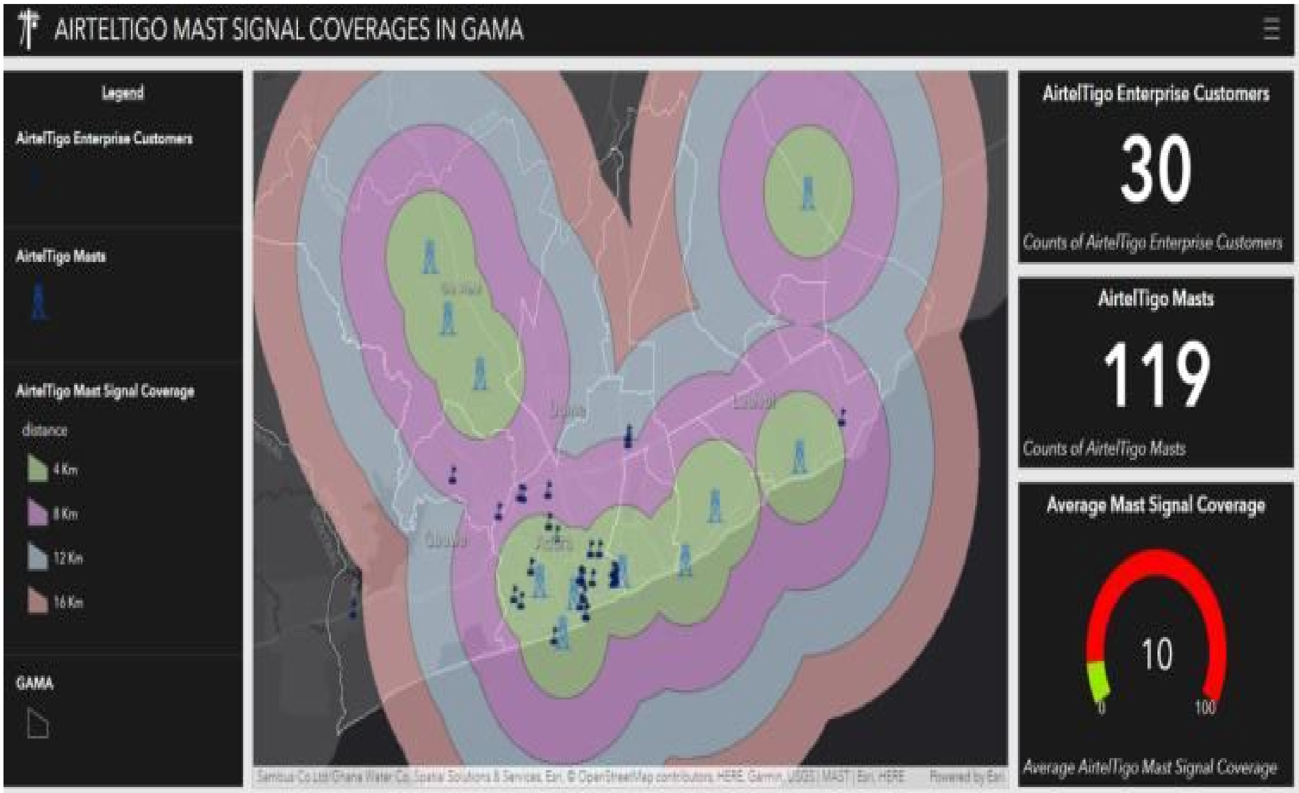

Fig 9. Web application depicting Airtel-Tigo Mast Signal Coverages in GAMA