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Optimal Location Determination of Some Public Facilities within Minna Metropolis: A Geospatial Technique Approach

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Abstract

Theoretical frameworks used to explain the location of services include central place theory, aspects of industrial location theory and spatial diffusion theory. They are all described as normative theories which optimize with respect to defined criteria operating in prescribed environmental conditions (Rushton, 1979). However, recent advancement in geospatial technologies has led to several applications in geographically orientated challenges, hence, the adoption of an effective decision tool like Geographic Information System (GIS), high resolution products of satellite remote sensing as well as the Global Positioning System (GPS) in solving the rather challenging task of optimal location for facilities with respect to necessary criteria. Minna metropolis is being affected adversely by the problem of appropriate location of public facilities. These facilities are either too far from their market zone or they are too congested in a particular location and in some cases, political consideration to the siting of these facilities dominate without given considerations to the necessary criteria for demands and public interest. The study is an investigation into the "optimal determination of the locations of some public facilities in Minna metropolis of Niger State, using geospatial techniques". The fusion of remote sensing, geographic information system (GIS) and GPS techniques was explored. Geodata base of existing facilities was created and Euclidean-distance geometry used to spatially analyze the appropriate locations with regards to the set of standard criteria. The results showed the haphazard and uncontrolled pattern of development of schools location. However, petrol stations met the evaluated criteria and optimal location indexes.

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Keywords

Optimal Locations, Conformity Assessment, Geo-Spatial Technologies, Spatial Analysis and Planning

1. Introduction

The concept of optimal location is one that concerns everyone around the world, because facilities location is indeed an important aspect of man's activity either as an individual, group, community, private sector or the entire public [1]. The optimal location of public facilities in any geographical area determines the level of orderliness, effective planning and ease to accessing such facilities [2] [3] thus strengthening the regards for the welfare and commitment to distribution of goods and services to the citizens of such area, which is thus the responsibility of any government to ensure.

The determination of optimum location of facilities can be a very complicated task due to lack of effective planning coupled with the organic development of major towns and cities. Facilities provisions are always an afterthought event to ameliorate the obvious lack of such facilities. In addition, the establishment of standard criteria upon which objective optimal location of facilities is said to be achieved.

The complexity of this study owing to various considerations and criteria may include; technical requirements, economic and social considerations, environmental and geographical dimensions etc. All these tends to make the decision making (optimality choice) a rather tough one. Hence, a decision support tool such as GIS which is characterized with the advantage of integrating different datasets is aptly required [4], as it is very pivotal in the approach of geospatial technologies to optimal locations selection. GIS is by no means a system that will give a final solution to a user, but it will provide the possibilities for a better and more organized analysis of information, which is a prerequisite for making quality decisions [5].

Over four decades, there has been an increasing interest in the problem of effective facility location in many societies [6]. Hence, the question arises as to how many school, hospitals, warehouses, emergency centres are needed and their respective locations to achieve a prescribed level of service.

The location pattern of any activity influences the quality and quantity of services received and methodologies which exists to evaluate the location effectiveness of any location pattern to determine improvements that can be made to compute such location patterns that are optimum with respect to defined criteria. Theoretical frameworks for explaining the location of services activities which includes central place theory, aspect of industrial location theory and spatial diffusion theory which are all described as normative theories which optimizes with respect to defined criteria operating in prescribed environmental conditions [7].

However, recent advancement in geospatial technologies has led to several applications in geographically orientated challenges [8] hence the adoption of effective decision tools like geographic information system, high resolution products of satellite remote sensing as well as the Global Positioning System (GPS), in solving the rather challenging task of optimal location for facilities with respect to necessary criteria. The research is aimed at determining the optimality of the existing public facilities within Minna metropolis with geospatial technique. The analysis and evaluation of the existing facilities with imposed evaluation criteria assessed the level of conformity with the criteria and finally an optimal location for facilities is produced.

2. Study Area

Minna is located within geographical latitudes 9˚31'20"N to 9˚41'27"N and longitudes 6˚24'59" to 6˚37'42". A graphical representation is shown in **Figure 1**. The city enjoys a climate typical of the savannah rainforest, the relief consists of undulating terrain. It is a city with population of 304,113 [9]. It is the capital of Niger State and comprises of two local governments (Bosso and Chanchaga Local Government Area). Archaeological evidence suggests settlement in the area dated back to about 47,000 - 37,000 years ago.

The vegetation is a savannah vegetation but rain gives it a mixed leguminous wooded savannah. It rains during the period of April to October, with August being the peak of its raining season. Dry season is from the late October to early April [10]. The ethnic groups in the area are mostly Hausa, Nupe, Gbagyiand Yoruba with the Gbagyi making the larger population and their occupation is mainly farming.

The study area is divided into 26 sub-districts which were captioned as regions in the course of the research.

These include; Kpakungu, Fadipe, Bosso Estate, Jikpan Hayan Gwari, Bosso Town, Tudun Fulani, Dutsen Kura Hausa, Dutsen Kura Gwari, G.R.A, Limawa, Minna Central, Barkin Sale, Sauka Kahuta, Sango, Nigeria Army Barracks, Chanchaga, Tunga, Tudun Wada South, Tudun Wada North, Sabo Gari, Makera, Maitumbi, Nasarawa, F-layout, Angwan Daji and Tayi Village.

3. Data

The research used both primary and secondary dataset to achieve the result presented. Spatial and aspatial dataset were combined for the analysis and result. Primary data collection and conversion involved the acquisition of the relative positions (X, Y coordinates) of the facilities, that is, petrol stations and schools (primary and secondary) within the metropolis using the Garmin GPS64. Extraction of the population data at sub-district level from the National Population (NPC) 1991 census catalogue. This makes up the attribute data for the sub-districts.

Table 1 shows summary breakdown of the dataset and their attributes used in the course of the research.

4. Methodology

The methodology adopted in this research ranges from data conversion from analogue to digital, information extraction, manipulation and analyses, overlay of the Georeferenced Street guide map of Minna metropolis on the very high resolution Quickbirdimage. On the ArcMap environment, features of interest (road networks, river, rail line, and sub-district boundaries) were all digitized and the subsequent overlay of the positional data (*x*, *y*

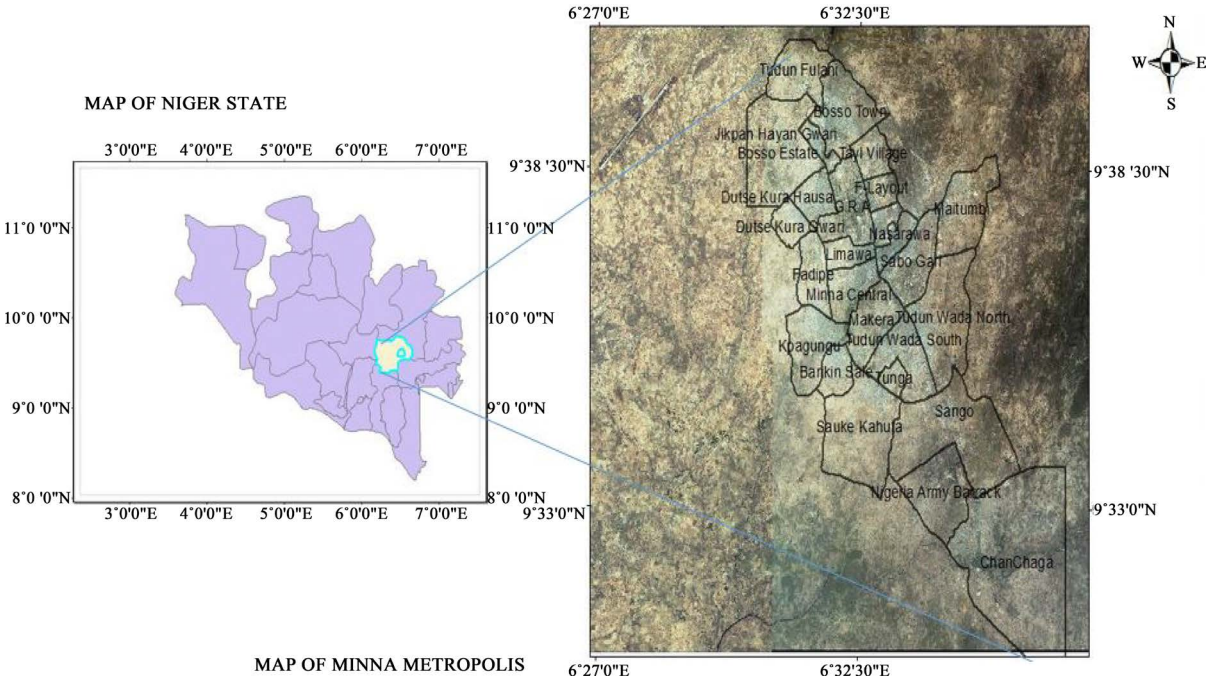


Figure 1. Map showing the study area—Minna metropolis (authors' work).

Table 1. A breakdown of dataset.

S/N	Data name	Data type	Source	Year	Format	Resolution
1	Quick bird image of Minna	Secondary	Infoterra Gmb	2009	Digital	0.65 m
2	Street guide map of Minna	Secondary	Ministry of works, transport and housing, Minna	1986	Digital	NA
3	Relative positional X,Y coordinated of facilities	Primary	Field survey (Garmin *GPSmap* 60Cx)	2013	Excel	NA
4	Population breakdown statistics	Secondary	Population record units, federal secretariat, Minna	1991	Printed paper	NA

coordinates of facilities) on the image leading to spatial and statistical analysis of the distribution of the facilities under study. Utilizing the spatial analyst tool (Euclidean distance function, reclass tool, conditional tool and weighted overlay tool) and the proximity analysis function of the ArcMap, [11]-[13] Analysis was carried out to ascertain the level of conformity with the evaluated criteria and subsequently, suitability maps were generated.

Criteria Used for Selecting the Best Location for the Facilities

Facilities are located within the growth centre or an urban area except in circumstances where it can be shown through appropriate studies that the need exists otherwise.

Conditions for siting a school:

1) Schools should be located majorly in a densely populated and infrastructure developed area (good roads)**,** *i.e.* all students served by the school would be in a convenient and safe walking distance to the site (maximum distance of not more than 5 km).

2) Schools should be located at a minimum distance of 400 metres from each other to minimize competition and encroaching in to each other's catchment areas.

3) Schools should be located far from hazardous facilities such as Petrol Station, pollution areas, industrial zones etc

4) At least 5 schools should be cited for a region greater than 10,000 in population [14] [15].

Condition for siting a Petrol Station:

1) Petrol pumps should be located along the major road at a minimum distance of 10 m and maximum distance of 50 meter.

2) Stations should be located at a minimum of 152.4 m (500 ft) from any public utility such as schools, churches, public libraries, auditoriums, hospitals, public playgrounds, etc. This implies that it should be far from school.

3) Stations should be located within a growth center or an urban area except in circumstances where it can be shown through appropriate studies that the need exists otherwise [16].

Below is **Figure 2**, depicting simple flowchart representation of research procedures, analysis and the results.

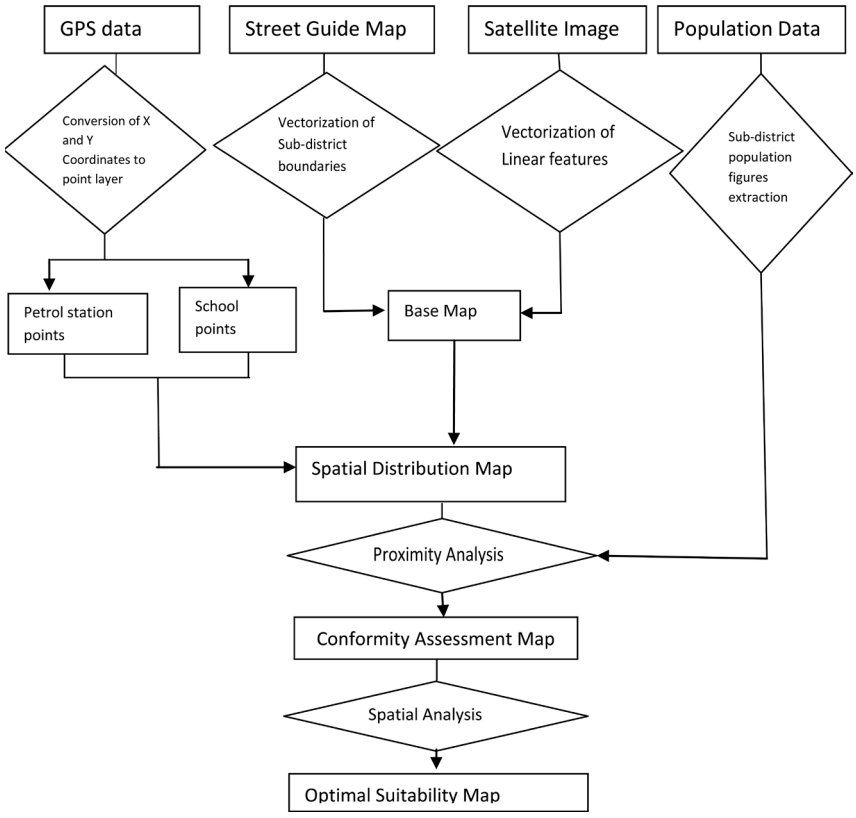


Figure 2. Datasets and analysis flowchart.

5. Analysis and Results

The result is presented through three major spatial analysis carried out to explored the locational pattern of the selected facilities. These are spatial distribution, conformity assessment and suitability analysis.

5.1. Spatial Distribution Analysis

The spatial distribution map is one of the first products of the research result which depicts the distribution of the facilities (schools and petrol stations) under study throughout the study area. This revealed the relative positional location of these facilities prior to further analysis. The haphazard and uncontrolled manner for which the schools were sited was immediately revealed. This was achieved through the fusion of the base map with the facilities positional data extracted from GPS device. **Figure 3(a)** and **Figure (3b)** show the spatial distribution of the locational pattern of facilities under study.

5.2. Facilities Conformity Assessment

The assessment was carried out with regards to the evaluated criteria to ascertain the level of conformity of the location of these facilities using the proximity tool, a buffer radius of 400 m was set around each existing school to evaluate the nearness to another. This revealed that so many schools have overlapping boundaries within the catchment zone criteria. Just about 11 schools satisfied the 400 m radius condition and about 69 failed the test. A 10 m and 50 m buffer condition along major roads set to ascertain the safety and convenient conditions for Petrol stations also revealed that all petrol stations within the study area met these criteria. Also the least number of schools to be sited with regards to estimated population for a given sub-district was also assessed as a query was set to determine the distribution of schools across the sub-districts with emphasis on sub-districts with a populace of over 10,000. **Figure 4** and **Figure 5** show the proximity analysis maps of the facilities understudy, while **Figure 6** depicts sub-districts with population of above 10,000 with existing school facilities distribution.

5.3. Optimal Facilities Suitability Analysis

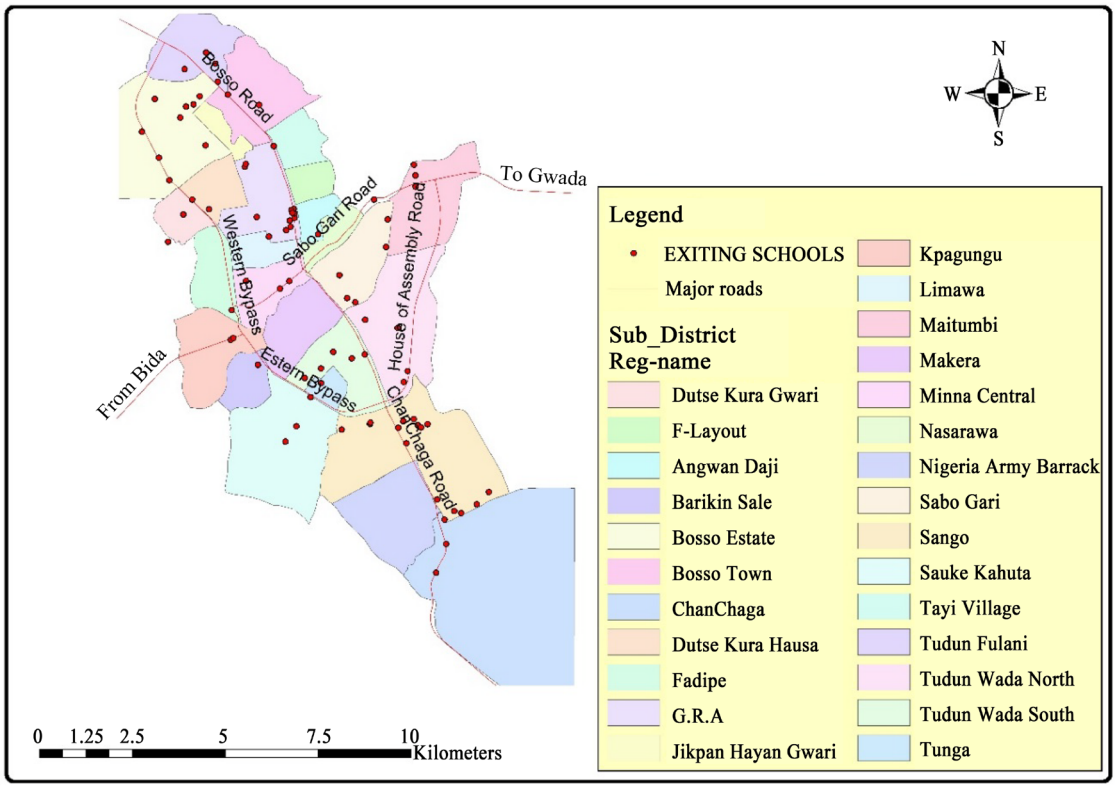
The optimal facilities suitability map generated presents suitable areas having evaluated the criteria considered for the possible relocation of those schools that have not met the criteria and the location of new ones employing the spatial analysis tools such as the euclidean distance, condition, reclass and weighted overlay. **Figure 7** reveals the optimal place within the study area as it eliminates the threat from petrol stations as considered within this research. The green outline on the map represents an approximate radius of 900 m from petrol stations with regards to the existing school's locations, that is, at such distance away from petrol stations, schools locations are safe.

6. Discussions, Conclusions and Recommendation

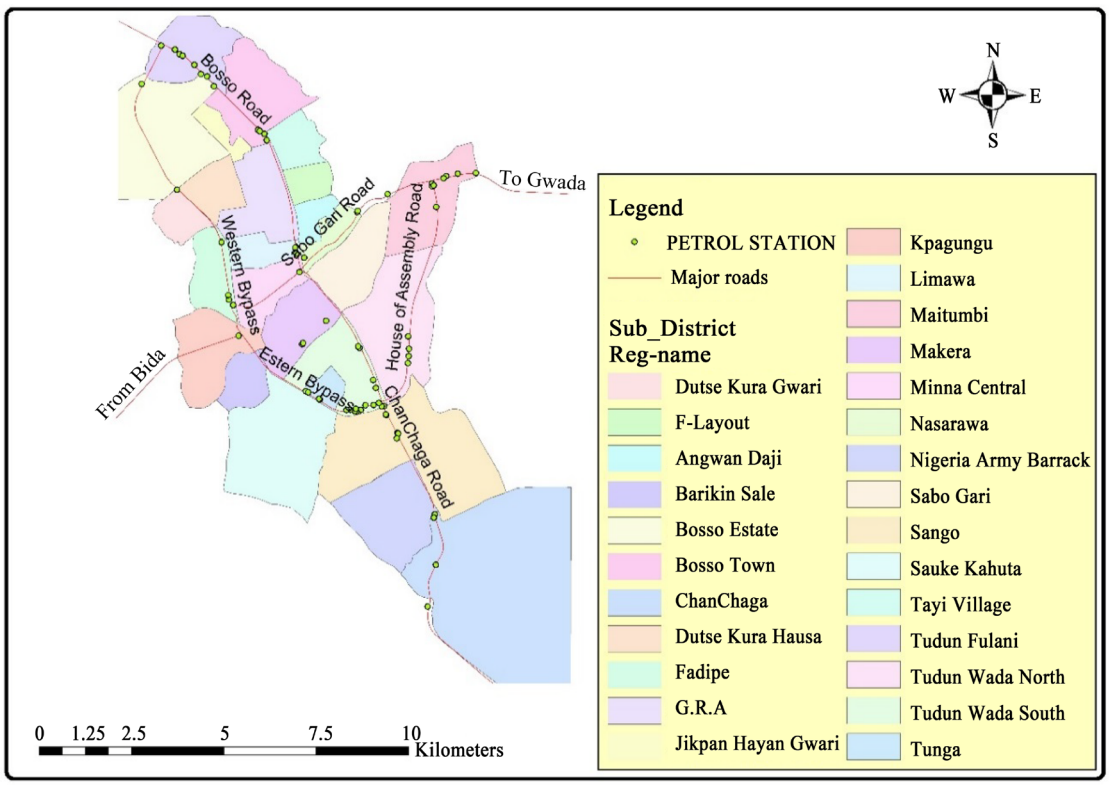
6.1. Discussions

Suitable location of facilities is an integral part of physical planning which is responsible for the overall development of any place. Based on the result of this research, the problem of clustering and haphazard pattern of location of facilities was assessed with geospatial techniques. The seeming overlap of buffer radius in **Figure 4** shows the non-conformity to the catchment zone criteria which should enhance healthy competition between school facilities. It also revealed the uneven distribution of school facilities across the sub-districts with the population criteria that were evaluated. Sango for instance, was found to have 17 school facilities, whereas, others with similar population index such as Tunga, Chanchaga, etc have just 2, Sabo Gari and Tudun Wada South were the two sub-district found to have an average number of 5 schools.

However, **Figure 5** showed that all the petrol stations located within the study area are in conformity to the criteria evaluated. The research proposes optimal areas for facilities location in the study area. This is represented by the green outliers in **Figure 6**. The area is the safest and best suitable zones for the relocation and situation of school facilities having been able to isolate the threat of petrol stations to schools within these zones using the weighted condition overlay [12].



(a)



(b)

Figure 3. (a) Spatial distribution of schools; (b) Spatial distribution of petrol stations.

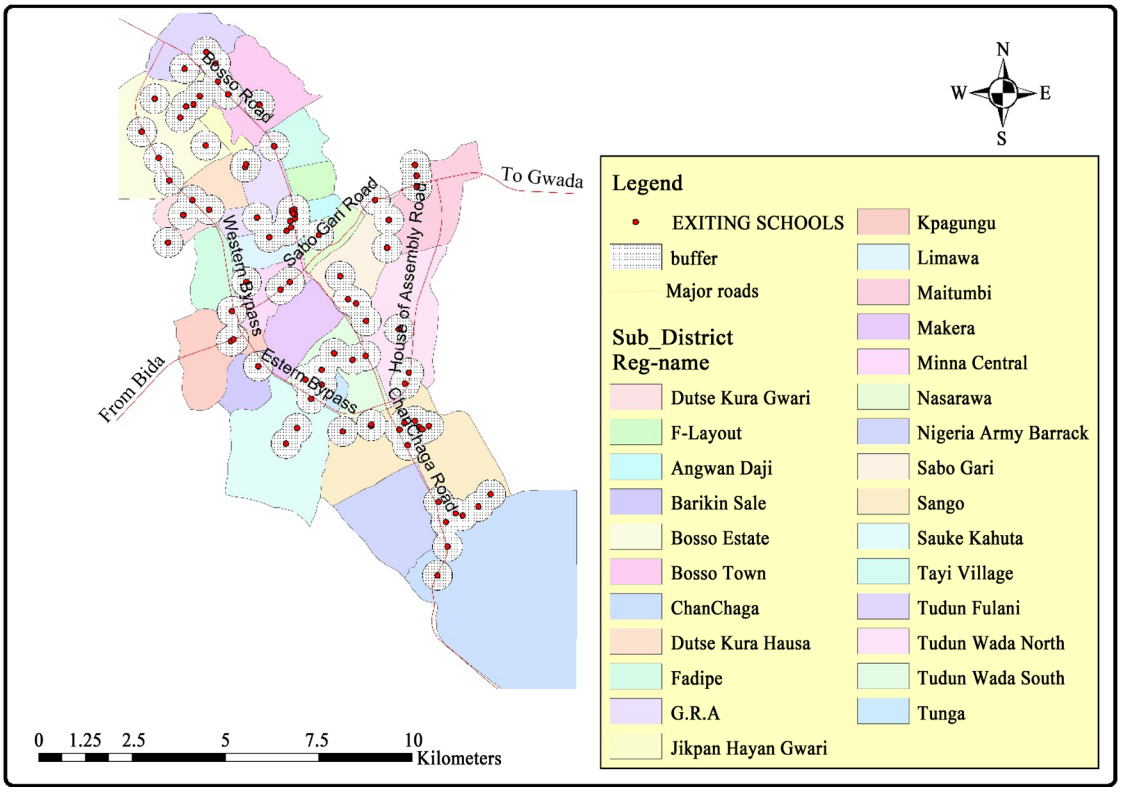


Figure 4. Proximity analysis map for schools.

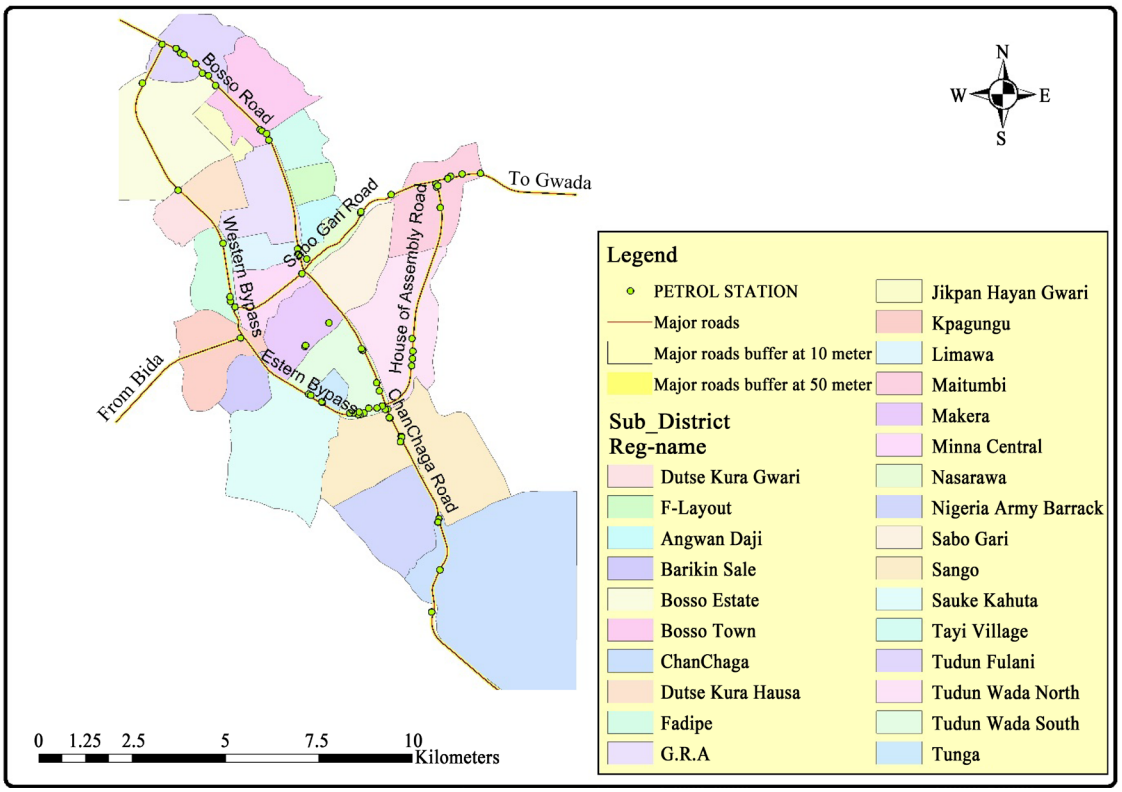


Figure 5. Proximity analysis map for petrol stations.

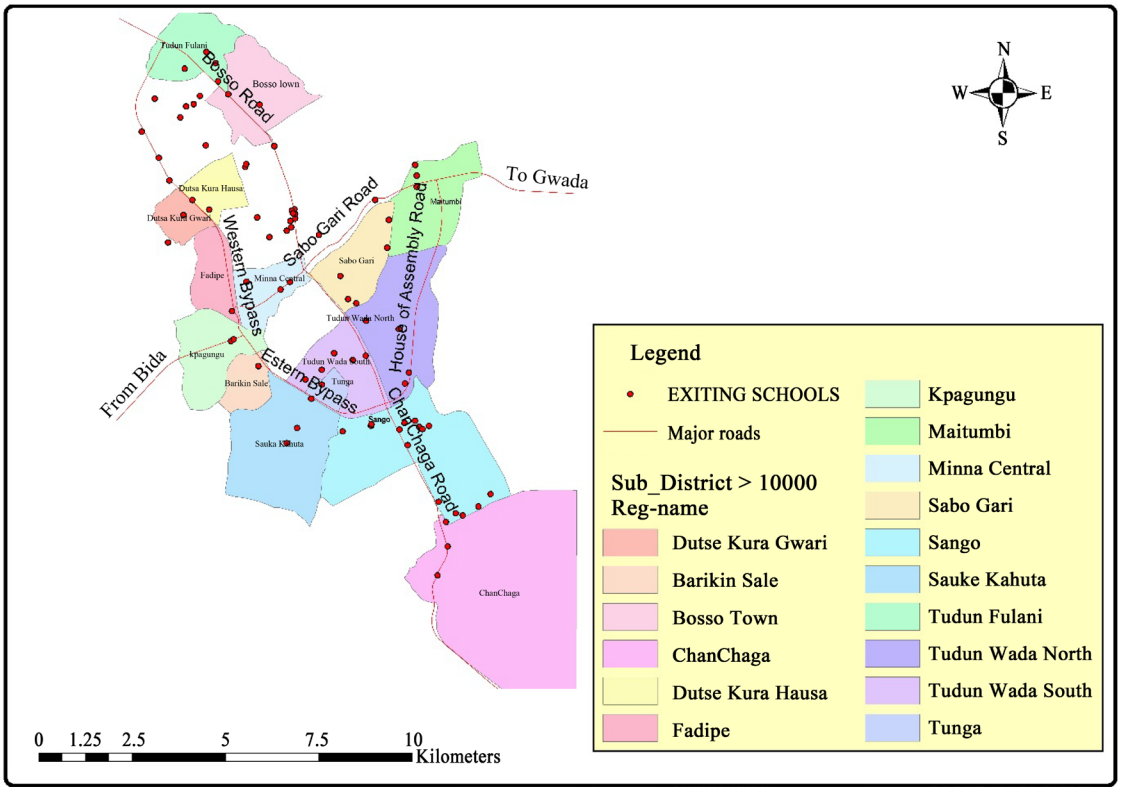


Figure 6. Sub-districts with population over 10,000.

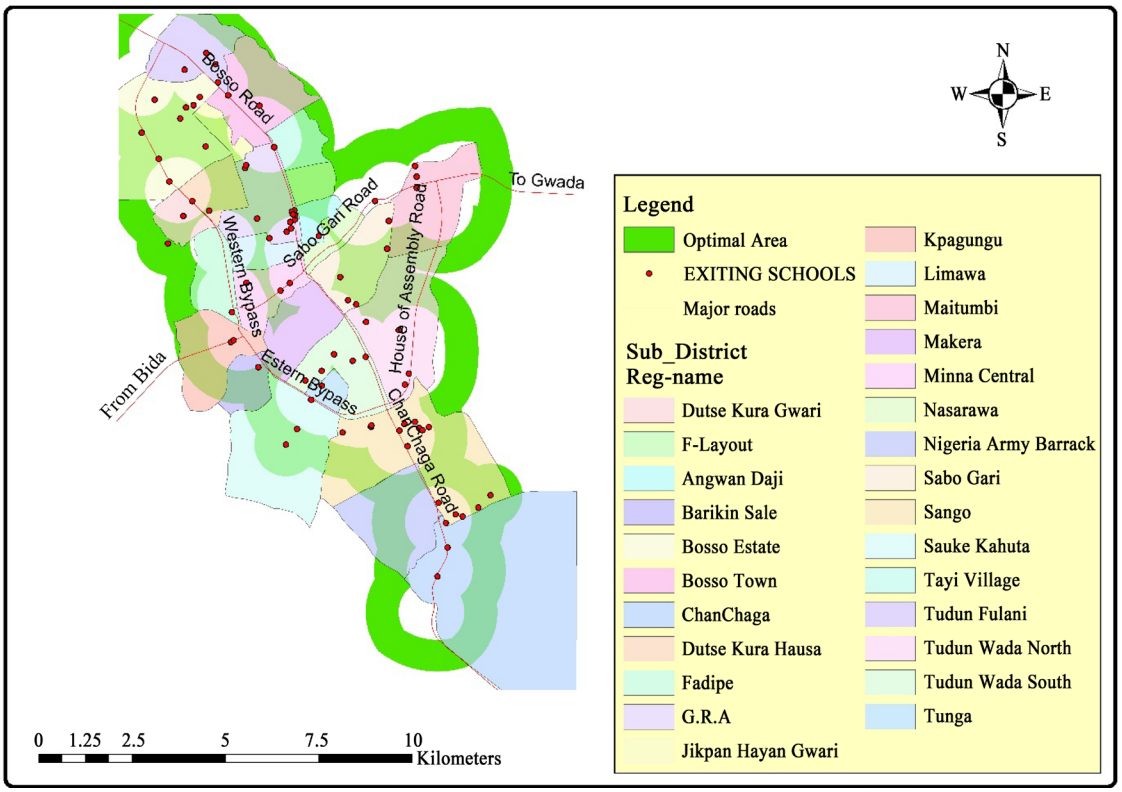


Figure 7. Optimal suitability map for schools.

6.2. Conclusions and Recommendations

The clustering of school facilities and seeming haphazard manner of location is one of planning deficiency affecting Minna metropolis which need urgent action to meet developmental goal of the city. In conclusion, this research applied geospatial techniques in the determination of optimal location of facilities which has been proved to be efficient and veritable tool for sound and effective decision making to solve difficult planning, management and environmental challenges.

It is hereby recommended that sub-districts with population of over 10,000 that has less than five schools, more schools should be sited within the suitable regions proposed to meet the demands of the growth centre. While, for "Sango" area that had 17 schools efforts should be made to ensure an even distribution of these facilities with regards to the criteria evaluated and the suitability areas proposed. The schools that didn't meet the 400 m buffer radius should either be relocated or merged, as the case may be in order to ensure a healthy competition and off course, defining their catchment zones. It is highly recommended that further research should explore the socio-economic and physical factors underlining the haphazard and exponential growth in numbers of schools located within Sango area while other zones have inadequate schools.

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