

An Assessment of the Spatial Analysis for Refueling Stations based on Standard Specifications Utilizing Geographic Information System (GIS)

Soltan Ibrahim*, Mohammed Fator[†], Abubakr Hassan*

*Department of Surveying Engineering, College of Engineering, Karary University, Sudan.

[†]School of Surveying Engineering, College of Engineering, Sudan University for Science and Engineering, Sudan.
sultanibrahim110012@gmail.com

Abstract

Geographic Information Systems (GIS) are crucial technologies that facilitate the spatial and temporal connection of phenomena. They enable the extraction of hidden information through analytical conclusions drawn from current data, so aiding in the decision-making process. The primary objective of this research is to utilize the capabilities of GIS for the spatial analysis of refueling stations in the Jabal Al-Awliya locality in Sudan. The second objective is to select the most suitable sites for establishing a new refueling station in the study region, taking into account the standard specifications necessary for the creation of such service facilities in Khartoum State. In order to accomplish the goals above, a satellite image of the research area was obtained from the Google Earth system and subsequently transferred to a GIS platform. Analyzed data using spatial analysis, spatial statistics, and proximity analysis techniques. Several tests were carried out to verify that these stations comply with the standard specifications set by the Ministry of Energy & Petroleum in Khartoum State. These tests include evaluating the distance between the refueling stations and nearby service facilities such as buildings, markets, and hospitals, assessing the overall area of the station, measuring the distance between two adjacent stations, examining the width of the station's entrance and exit, and determining the maximum number of vehicles allowed inside the station simultaneously. The study found that 18 out of the refueling stations complied with the required distance from service facilities, achieving a 100% adherence rate. Additionally, 16 stations adhered to the standards for station area, with a compliance rate of 88.9%. Furthermore, 14 refueling stations met the required distance between adjacent stations, achieving a compliance rate of 77.8%. Moreover, 18 refueling stations adhered to the specified width for entrance and exit, achieving a 100% compliance rate. Lastly, 18 refueling stations complied with the maximum number of vehicles allowed inside the station at the same time, achieving a 100% compliance rate. These values and calculated percentages indicate a high level of commitment among most refueling stations in the study area to meet the required specifications. Finally, based on the minimum standard specifications for refueling stations, the study identified the best locations for establishing 4 new stations, representing a 22.2%

Key words-Refueling Stations, Standard Specifications, Spatial Analysis, Database.

I. INTRODUCTION

The equitable allocation of daily public services relies on appropriate geographic distribution[1][2]. This is crucial to ensure the satisfaction of citizens' needs and the effectiveness of these services[3][4]. Therefore, the distribution of services should be determined based on specific criteria[5][6], including population density, available land area, and the level of living standards, which vary between urban and rural areas[7][8]. The geographic information system (GIS) plays a crucial role in efficiently distributing services by linking spatial and temporal phenomena[9][10]. Additionally, GIS is capable of extracting hidden information from existing data through deductive analysis[11][12]. This is reflecting on the correctness of decision-making[13][14]. Refueling stations is one of the important services required for appropriate locations to provide service; refueling stations are defined as establishments licensed to sell fuel[15][16], for all types of private and public vehicles; these stations represent the continuity of the operation for these vehicles regularly on transportation routes in cities and villages[17][18]. One of the aims of this study is to take the capabilities and advantages of geographical information systems for the spatial analysis of the refueling stations located in the Jabal Al-Awliya locality - Khartoum

State, the capital of Sudan country. The second aim is to choose the most appropriate locations to build a new refueling station in the study area, based on the standard specifications required to allow to establishment of such service facilities in Khartoum State[7][19]. To achieve the previous objectives, a satellite image showing the study area was taken from the Google Earth system, and then it was exported to GIS. Spatial analysis, spatial statistics, and proximity analysis were performed. Several tests were conducted to ensure that these stations conform to standard specifications, such as the distance between the refueling stations and service facilities such as buildings, markets, and hospitals test, the station area test, the distance between two adjacent stations test, entrance and exit of the station width test, and finally the number of vehicles inside the station at the same time test[20].

A. Study Problem

Jabal Al-Awliya locality is one of the seven Khartoum State localities. It is characterized by high population density and a vast area approximately equal to 382.3 km^2 , along with many huge commercial markets. However, in recent years, the problem of large crowding of vehicles has emerged at some refueling stations in this locality; this may be due to the

small number of these stations, which are only 18 refueling stations in the whole of a locality, or maybe that is referred to the lack of a good distribution of refueling stations does not match to the vehicle's density. Therefore, this study attempts to find out the reason for the problem by using a geographic information systems technique and developing a proposal to solve the problem.

II. DATA AND METHODOLOGY

The study employed an analytical descriptive research methodology. Furthermore, the solution involved utilizing a geographic information system via the ArcGIS program. Additionally, a satellite image with a resolution of 10m was obtained from the Google Earth program in April 2024. For geo-referencing the satellite image, a total of 10 Ground Control Points (GCPs), as tabled in Table(I) were employed in the study. The research utilized both a field survey to gather data, which were then analyzed using statistical methods, and the standard specifications outlined by the Ministry of Energy & Petroleum of the Khartoum State for the construction of refueling stations[21].

A. Data

The study utilized geospatial data, categorized into two sections: field survey data and auxiliary data. The geospatial data were used to extract primary information, while thematic layers from different sources were used for mapping. Multiple maps were created using ArcGIS and QGIS software tools, including analyses measuring geographical, distribution, Density analyses, Proximity analyses, and Pattern analyses. All data is presented in the Universal Transverse Mercator (UTM) zone 36N projection in the metric units' system[22].

1) *The study area:* The study area is the locality of Jabal Al-Awliya, which positioned is in Khartoum city, the capital of Sudan. It extends between latitudes 15° 25' 44.4" and 15° 29' 2.4" E, and longitudes 32° 28' 59.23" and 32° 29' 51.74" N. The estimated area of the study area is approximately 382.3 km², as depicted in Figure(1).

2) *Ground Control Points (GCPs):* A number of 10 Ground Control Points (GCPs) were used for the satellite image georeferencing purpose. The observations were made using a GPS receiver model R8- GNN from Trimble Company in RTK mode. The expected accuracy was equal to 1cm ± 1ppm. Points are taken based on UTM projection, at zoon 36 North and WGS84 datum. The result is shown in Table(I).

TABLE I: Ground Control Points (GCPs)

Point	E (m)	N (m)	H (m)
1	444555.174	1717150.287	383.113
2	444285.249	1716714.844	383.415
3	444512.700	1714725.874	383.519
4	445577.283	1711438.651	381.851
5	447571.574	1710726.837	382.161
6	449494.837	1707422.603	383.810
7	447889.315	1703213.063	381.782
8	446379.883	1705454.973	384.543
9	445065.109	1708046.147	381.784
10	442489.663	1708595.984	383.997

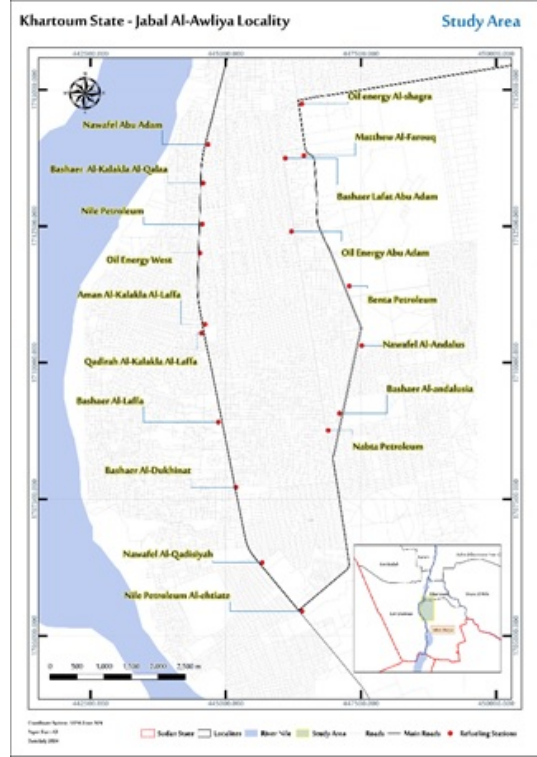


Fig. 1: The Study Area

3) *Locations of the refueling stations :* Jebel Al-Awliya locality contains 18 refueling stations, which distributed into the whole of study area. Table(II) shows the coordinates of these stations along with the station's names, noting that each station is given a concern code.

4) *Standards specifications:* This section talks about the main guides of the Ministry of Energy & Petroleum in Khartoum State to allow for the establishment of refueling stations such as:

- 1) The location of any station must be ≥ 20 meters from the residences, markets, cafeterias, transportation stops, hospitals, schools, and any sources of sparks (workshops, laboratories, etc.)
- 2) The location of each station must be ≥ 12 meters from electrical lines
- 3) The location of the station must be ≥ 20 meters from the streets or roads
- 4) The station area located in a city zoon must be $\geq 750m^2$.
- 5) The station area, located in a village zoon, must be $\geq 600m^2$.
- 6) The station area, which is located on a highway, must be in between $2000m^2$ and $4000m^2$
- 7) The distance between any two adjacent stations that are located in cities or villages must be $\geq 500m$.
- 8) The distance between any two adjacent stations which are located on a highway must be $\geq 8km$.

B. Methods

The research was conducted using the standard procedures of the analytical method[23]. The first step involves assessing

TABLE II: Coordinates of existing refueling stations

Station Name	Station Code	E(m)	N (m)	Area m^2
Oil Energy West	A	444526	1712009	2600
Oil Energy Abu Adam	A1	446216	1712403	2400
Oil energy Al-shagra	A2	446407	1714740	1000
Bashaer Al-Laffa	B	444862	1708912	2000
Bashaer Al-andalusia	B1	447105	1709073	1500
Bashaer Al-Kalakla Al-Qalaa	B2	444583	1713288	1000
Bashaer Al-Dukhinat	B3	445188	1707718	2000
Nawafel Al-Qadisiyah	N	445672	1706340	1000
Nawafel Abu Adam	N1	444673	1713996	1800
Nawafel Al-Andalus	N2	447515	1710314	2400
Nile Petroleum	K	444566	1712536	800
Nile Petroleum Al-ehiate	K1	446408	1705449	3000
Aman Al-Kalakla Al-Laffa	S	444616	1710703	1600
Nabta Petroleum	L	446893	1708760	800
Benta Petroleum	T	447283	1711403	1600
Matthew Al-Farouq	M	446446	1713794	1000
Qadirah Al-Kalakla Al-Laffa	G	444552	1710540	2000
Bashaer Lafat Abu Adam	B4	446102	1713743	1600

the geographic analysis of the current stations in the specific area of interest. Furthermore, the assessment of the suitability of the suggested new sites involves analyzing various maps generated by Geographic Information Systems (GIS)[24].

1) *Geographical distribution of refueling stations:* The geographical distribution of refueling stations had based on several categories, which are:

- 1) Distribution of stations according to the Residential Blocks: There are 90 blocks are covering the locality of Jabal Al-Awliya, the include only 18 refueling stations, which were distributed in 70 blocks and a rate 75% of these stations were concentrated in the northeastern part of the locality. See Figure(2).
- 2) Distribution of stations as stated by the Area: The refueling stations in Jabal Al-Awliya locality are differ in term of station areas. There are a large area stations is greater than or equal to $1000 m^2$ and that is conformed to the standard specifications. That is 16 out of the total stations in the locality were achieved these specifications with a rate of 88.9%. The remainder is a small area stations, that as shown in Table(III), and Figure(3) below.

TABLE III: Distribution of refueling stations according to the area

Category	Refueling stations		Area m^2	
	No	Rate%	value	Rate%
$3000m^2$ or more	1	5.6	3000	9.96
$2000m^2$ and less than $3000m^2$	6	33.3	13,400	44.52
$1000m^2$ and less than $2000m^2$	9	50	12.1	40.20
less than $1000m^2$	2	11.1	1600	5.32
Total	18	100	300001	100

- 3) Distribution of stations as stated by the storage Capacities: There is a noticeable variation in Jabal Al-Awliya, refueling stations according to the storage capacity as presented in Table(IV) and as shown in Figure(4): A large capacity storage stations, are exceeding 100,000 liters or more, with a total storage capacity of 406,000



Fig. 2: Refueling stations according to the Residential Blocks

liters. Only 3 stations had achieved this capacity, representing 16.7% of the total stations, by a storage capacity at a rate is 24.49% of the total storage percentage in a locality. A middle capacity storage stations, are exceeding 50,000 liters and less than 100,000 liters. There are 9 stations had achieved this capacity, are representing 50% of the total stations, by a storage capacity at a rate is 65.26% of the total storage percentage in a locality. Small capacity storage stations of 50,000 liters or less. There are 6 stations had achieved this capacity, are representing 33.33% of the total stations,

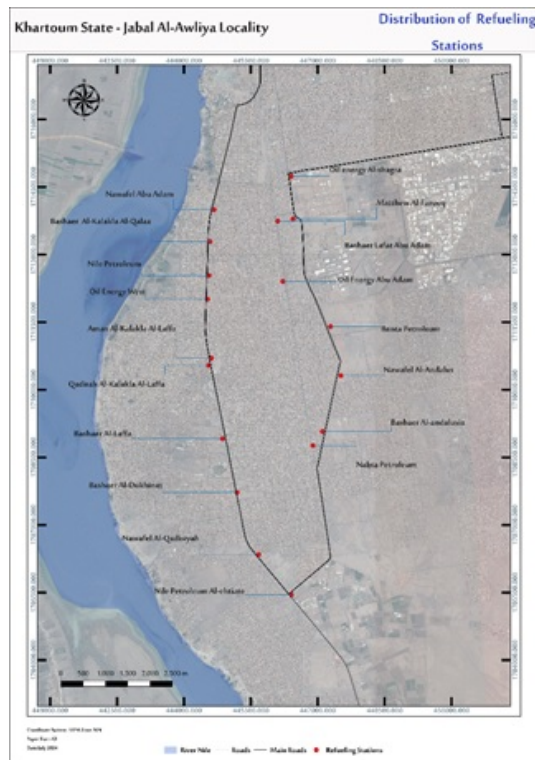


Fig. 3: Distribution station for refueling stations

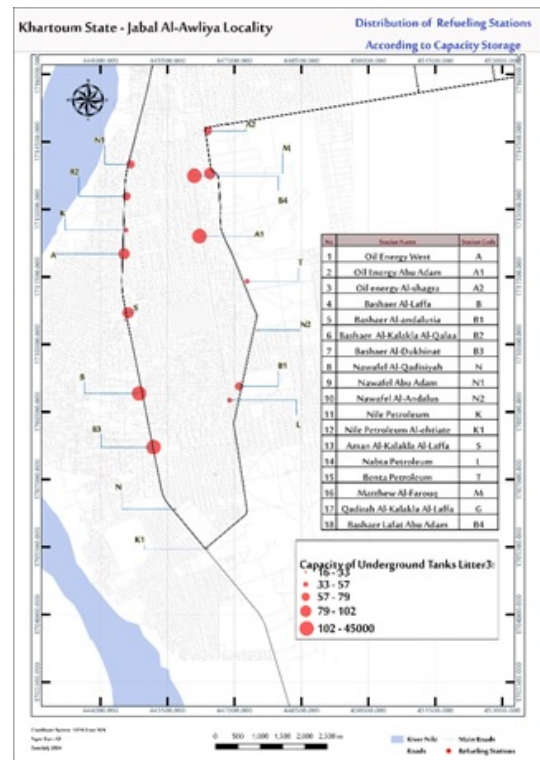


Fig. 4: Refueling stations according to the capacity storage

by a storage capacity at a rate is 10.25% of the total storage percentage in a locality. Table(IV) and Figure(4) are explained the mentioned variation in capacity storage s of refueling stations.

TABLE IV: Refueling stations according to the capacity storage

Category	No. of stations		Storage capacities	
	No	Rate%	Litter	Rate%
100000 liter or more	3	16.67	406000	24.49
50000 liter and less than 100000 liter	9	50.0	1081893	65.26
less than 50000 liters	6	33.33	1194926	10.25
Total	18	100	1657820	100

- 4) Distribution of refueling stations according to the Road Networks: All of the 18 refueling stations in a locality of Jabal Awliya were located near to the roads and 13 of these stations were located on the main roads, while the remainder of the stations were distributed on secondary roads as shown in Figure(5). In addition to that 6 of such stations are not in line with the standards specifications of the Ministry of Energy & Petroleum.
- 5) Distribution of refueling stations according to no. vehicles at the same time : The number of vehicles that can be accommodated by a refueling station at the same time is depends on two factors: first factor is the station area, and the second factor is the number of operating machines in the station[25][26]. The regulations is illustrated in Table(IV).
- 6) High concentration and no stations areas of refueling station: The study shows there is overcrowding of some stations in certain areas, which dictated by the codes



Fig. 5: Distribution of refueling stations according to the road networks

(G, S, B and L). Also, there is no service in areas were confined between the station with code (L) and the second with code (K1) as shown in Figure(6).

TABLE V: Number of vehicles in refueling station at the same time

Stations Categories	vehicles	No. refueling stations	Codes
Small	4 - 6	8	A1, B2, B3, G, L, M, N1, N2
Medium	7- 8	8	A, A2, B1, B4, K, N, S, T
Large	9 -13	2	B, K1

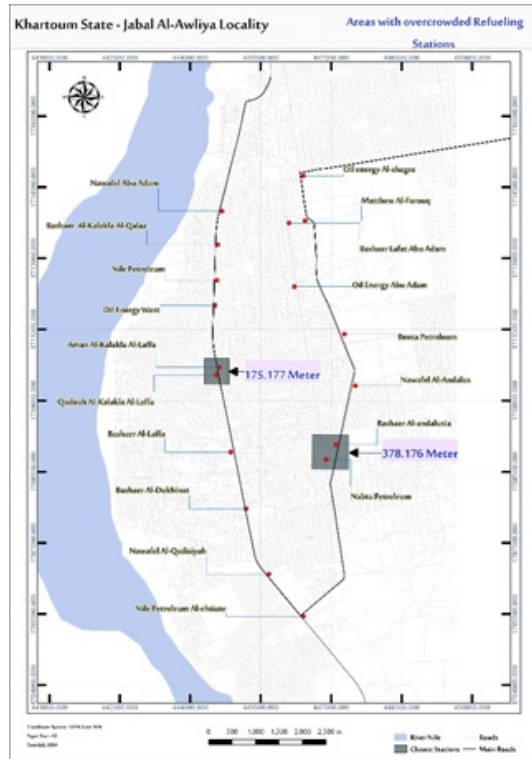


Fig. 6: Areas with overcrowded Refueling Stations

2) *Spatial analysis of refueling stations*: The spatial analysis was obtained according to standard specifications, which were based on the main evidence of the Ministry of Energy and Petroleum in Khartoum State as it is the responsible authority[19]. The Spatial analysis was based on the following elements:

- 1) **Buffering**: The purpose from a proximity analysis is to determine the spatial sector which are covered by the service and the areas where there is no service at all[27][28]. In addition to define the relation between the two areas, a proximity analysis of the distances of no less than 500 meters were determined in all directions, that as shown in Figure(7).
- 2) **Analysis of the distance between refueling stations**: This analysis is used to determine the distances between stations test, according to standard specifications of the Ministry of Energy & Petroleum, this analysis is shown in Figures(8 and 9).
- 3) **Analysis of the distance between refueling stations and neighboring sites**: This type of analysis is used to the distances between stations and neighboring sites test, such as schools, markets, hospitals, etc. According to

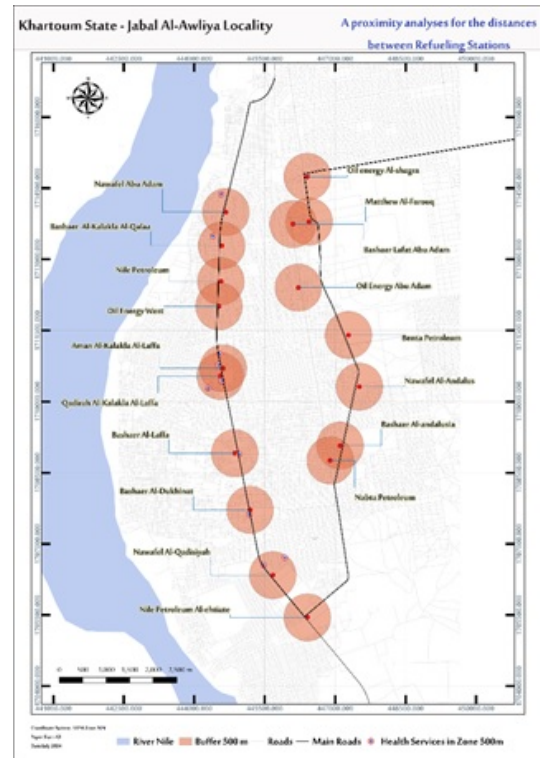


Fig. 7: A proximity analyses for the distances between refueling Stations

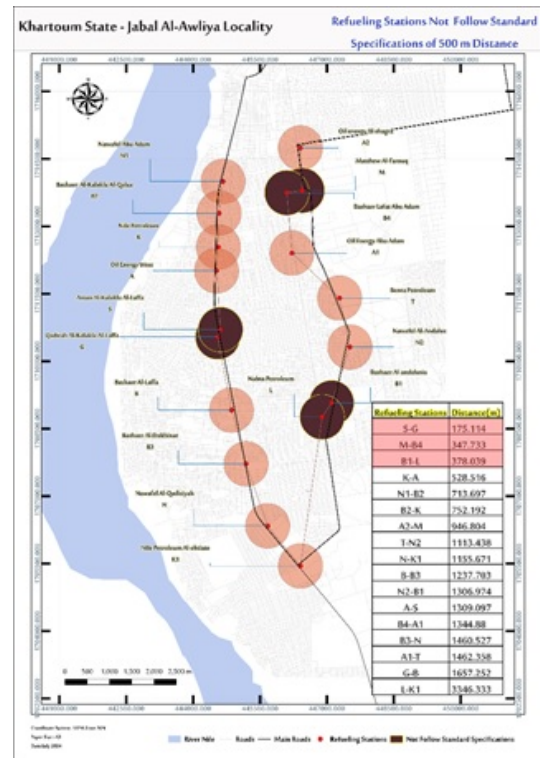


Fig. 8: Refueling Stations Not Follow Standard Specifications of 500 m Distance

standard specifications of the Ministry of Energy & Petroleum as represented in Figures(10 and 11).

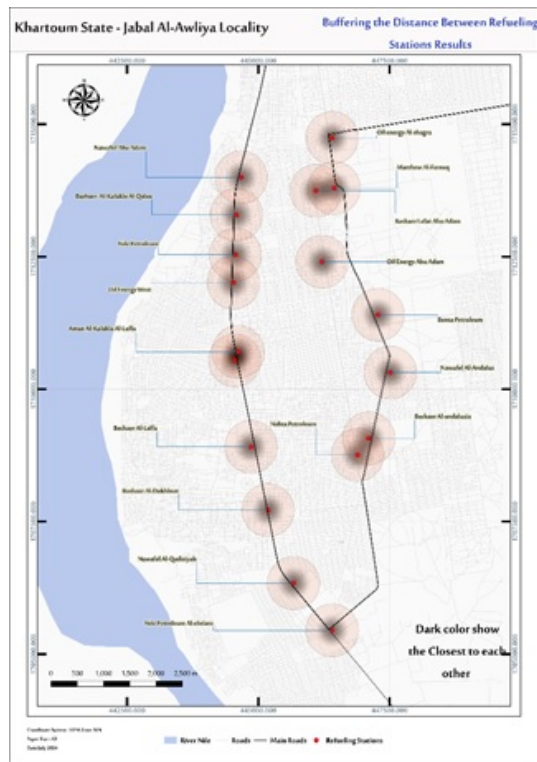


Fig. 9: Buffering the distance between refueling stations Results

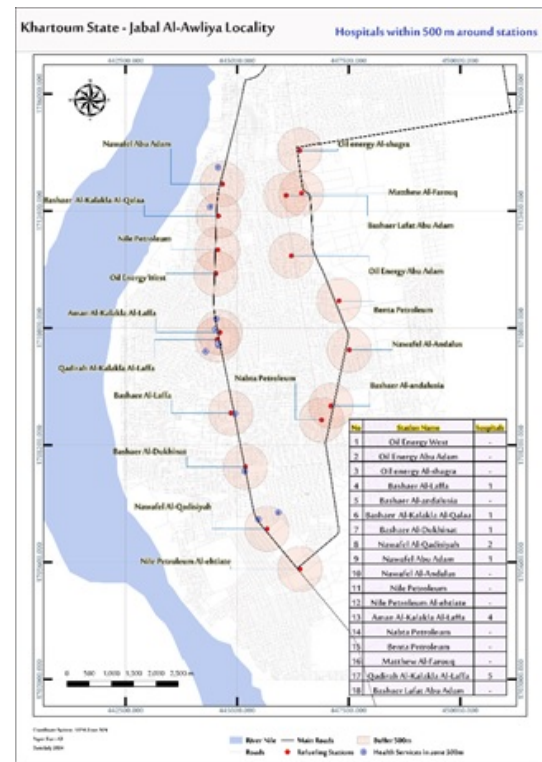


Fig. 11: Hospitals in Range 500 m around refueling Station

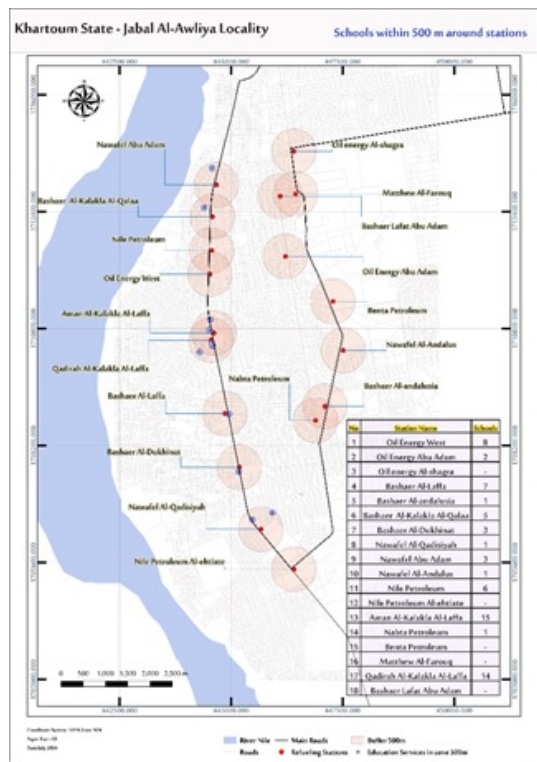


Fig. 10: Schools within 500 m around stations

stations[29]. Also to define the central feature plus the mean center of the study area[30][31], as presented in Figure(12 and 13). This helps the geographical information system to suggest the best locations for establishing new refueling stations.

- 5) Density analysis: The density analysis, or the Kernal method is used to compare the geographical distribution of refueling stations with the distribution of another objects in the targeted area[32], such as roads, schools, hospitals, markets, and etc. The evaluation is done through analysis density that is as shown in Figure(14).
- 6) Pattern analyses: Pattern analysis counted as one of analysis which is used for defining the Average Nearest Neighbor Summary between the adjacent refueling stations or others features[33]. The result of pattern analysis is shown in Figure(15).
- 7) Analysis of proposed sites for the construction of new stations: Based on the geographical analysis and the center of the study area[34], Figure(16) in addition to taken into account the standard specifications of the Ministry of Energy, a number of 4 new locations represent as the most suitable sites were suggested for establishing new refueling in Jebel Al-Awliya locality stations. The new locations of the suggested stations are presented in Figure(17). Also, the Coordinates of new sites were extracted and recorded in details in Table(VI).

III. RESULTS AND DISCUSSIONS

Referring to the previous refueling stations data inputs of different types; descriptive and spatial analysis models, there

- 4) Analysis of measuring geographical distribution: The objective from the geographical location analysis is to determine the distribution locations of existing refueling

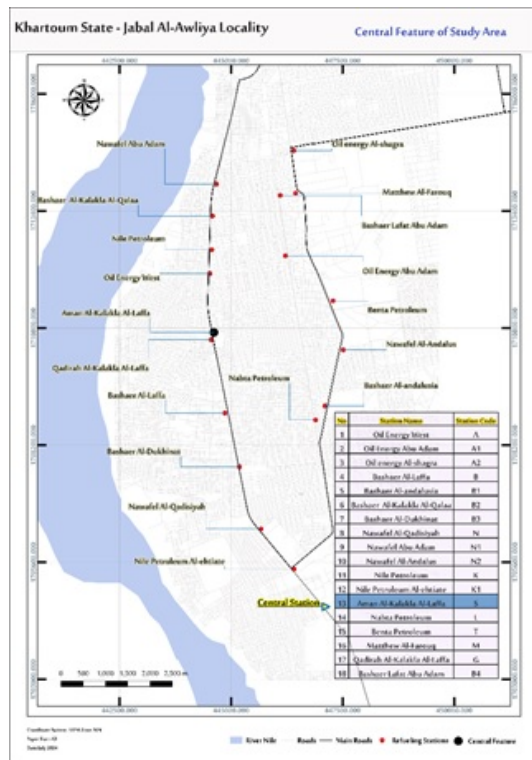


Fig. 12: Central Feature of Study Area

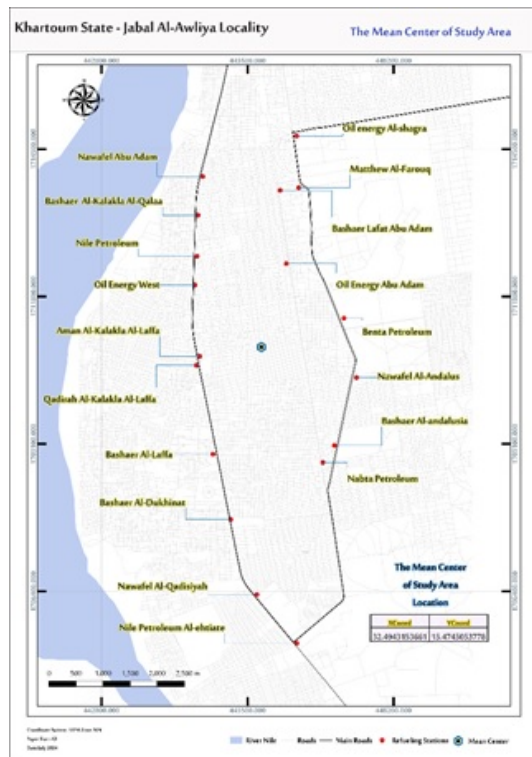


Fig. 13: The Mean Center of Study Area

are many results had obtained either in numerical form or in graphical form which were summarized, and discussed as follows:

- 1) The number of the refueling stations in Jebel Al-Awliya

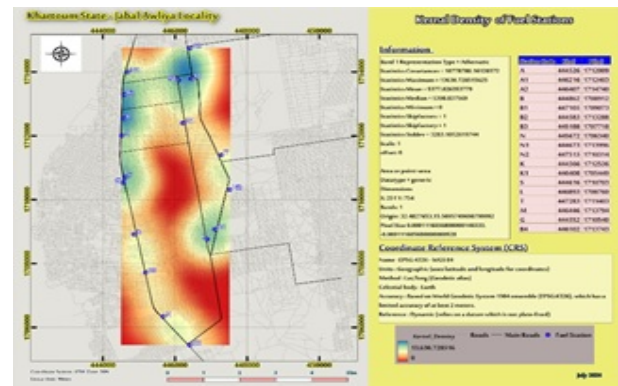


Fig. 14: Kernel Density of Study Area

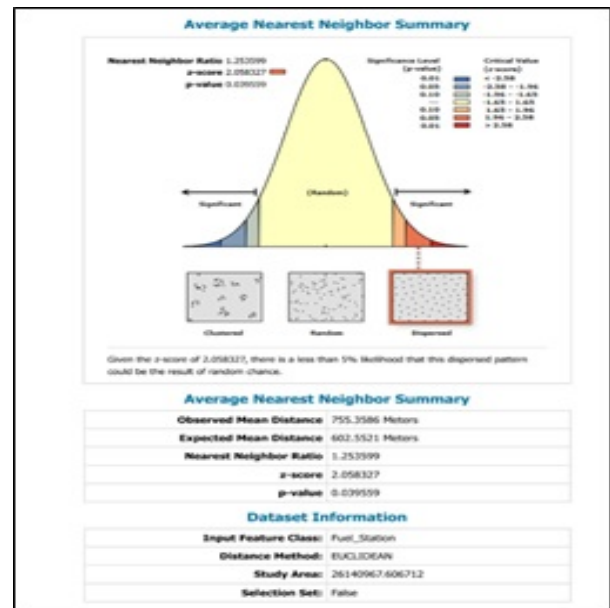


Fig. 15: Average Nearest Neighbor Summary

TABLE VI: Coordinates of a proposed locations for new refueling stations

Point	E (m)	N (m)
P1	445659	1711481
P2	446736	1709837
P3	447161	1707475
P4	447204	1706523

locality is reached to 18 stations. This number were distributed over the whole of a locality area, which is equal to 382.3 km^2 . Rates of 75 % of these stations were concentrated in the northeastern part of the study area. This is one of the reasons for the congestion of vehicles at stations in the other parts of the study area.

- 2) The locality contains 16 fuel stations, each one had an area exceeding to $1,000 \text{ m}^2$, and this is meets with the standard specifications of the Ministry of Energy & Petroleum in Khartoum State, at a rate of 88.9%.
- 3) The locality main roads have 13 refueling stations, with a percentage of 72.2%, while the rest stations are located on the secondary roads.

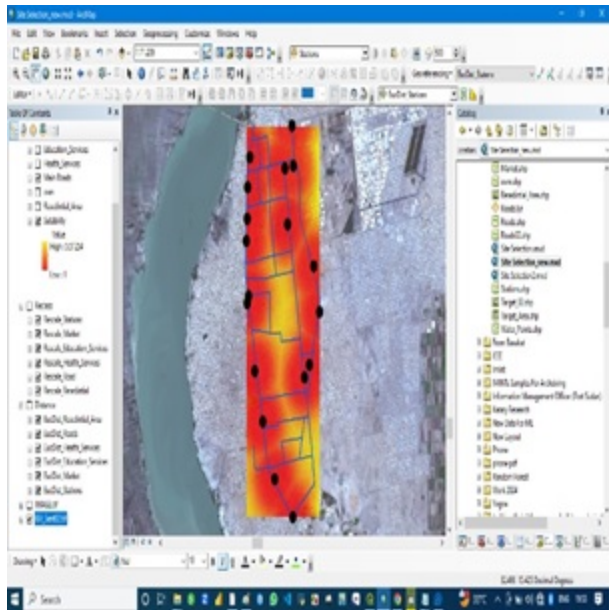


Fig. 16: Suitability Locations for New Fuel Stations

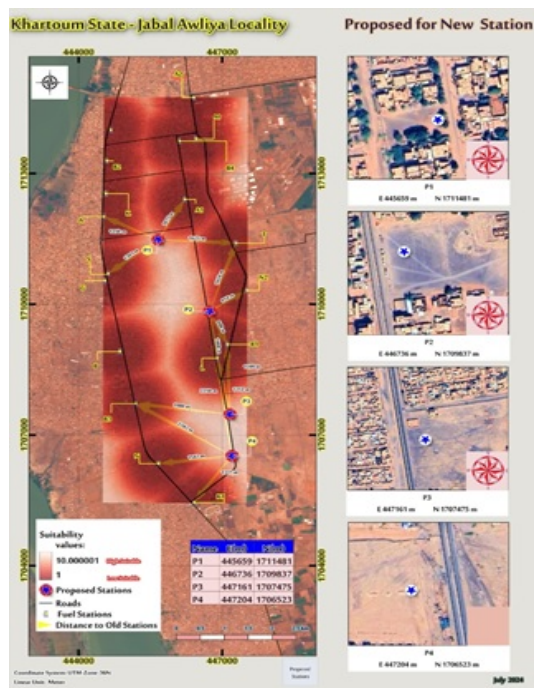


Fig. 17: A proposed location for a new refueling stations

- 4) There are three types of refueling stations were located in target area that is accordingly to the storage capacities, large, medium and small storage capacity stations that is had explained in a Table(V) before.
- 5) The approximate average number of stations that which are meet the specifications relating to the stations area and distance from the roads, and the service facilities such as schools, hospitals, and roads in study area is equal to 16 stations. That is represents 88.9% from the all stations. Accordingly, the average number of stations that are not meet the previous specifications is only two

stations, representing 11.1%. The above averages were calculated according to the statistics Table(VI) below.

TABLE VII: No. Identical and not identical stations for the distance and areas specifications

Criterion specification	Same as standards	Rate%	Not same as standards	Rate%
Station from the residences is ≥ 20 m	18	100	0	0
area $\geq 750m^2$	16	88.9	2	11.1
Near Station ≥ 500 m	14	77.8	4	22.2
From electrical lines ≥ 12 m	18	100	0	0
from the roads ≥ 20 m	13	72.2	5	27.8

- 6) When the both spatial and approximate analyses were performed by measuring the buffering coefficient, a circle with a radius of 500 meters was used in all directions that matching with the standard specifications, the following results had been obtained: Referring to Figure(10), the number of refueling stations which located in the vicinity of educational services equals to 13 stations, with 72.2 %. Also, in the same way from the Figure(11) shows that there are 7 refueling stations located in the vicinity of health services, which present a 38.9 %. The common numbers of stations were located in both health and educational services vicinity together was reached to 12 stations, at a rate of 66.7 %.
- 7) Finally, Figure(17) represents the final map which created from the collection of all layers that make up of the study area by using the geographical information system for the purpose of choosing the most suitability sites for establishing new refueling stations have been proposed. Taking into account the minimum required of the standard specifications, 4 sites, namely P1, P2, P3, and P4 were selected as the best sites for the new locations of refueling stations, with an increase of 22.1% compared to the number of stations in Jebel Al-Awliya locality

IV. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

The study was aimed to benefit from the advantages and capabilities of geographic information systems to evaluate and analyses the spatial distribution of refueling stations in Jebel Al-Awliya locality in Khartoum State. Also, to know the adherent of these stations to the required standard specifications, and finally for the future establishing of the refueling stations in Khartoum State in general. The study had concluded to the following:

- 1) One of the most reasons for the crowding of refueling stations in Jebel Al-Awliya locality is due to a few number of existing stations, which was amounted to only 18 stations in an area estimated at 382.3 Km^2 .
- 2) The Khartoum-Jebel Al-Awliya National Road, which connects Khartoum State to the states of central Sudan, passes through this locality, which had led to increased pressure on limited refueling stations in a locality.

- 3) 75% of the existing fuel stations are concentrated in the northeastern part of Jebel Al-Awliya locality, which means that the remaining rate 25% of those stations are shared by the rest of the locality, which had led to the emergence of vehicle congestion in stations which are located in those parts
- 4) The average number of refueling stations in Jebel Al-Awliya locality that had meet the standard specifications Ministry of Energy & Petroleum in Khartoum State for the purpose of establishing such as these stations are reached to 16 stations, with a rate of 88.9 %, which is a good indicator of the commitment of most refueling stations in the study area to the required specifications.
- 5) The study has suggested most suitable locations of establishment of a new 4 refueling stations in Jebel Al-Awliya locality using the GIS techniques represented by the ArcGIS program. These proposed stations are lead to an increase the rate of stations at a rate of 22.1%, that is compared to the number of existing refueling stations, which may be help to solve the problem of vehicle congestion at stations.

B. Recommendations

The study work was focused on using GIS techniques advantages to the spatial analysis for the fuel stations based on the main guides of the Ministry of Energy & Petroleum in Khartoum State. Therefore, studies may be extended to:

- 1) Using the same research methodology to study the some similar services problems, such as the distribution of bakeries and commercial markets to meet the needs of citizens.
- 2) Take the research idea to determine the locations of specialized refuelling stations that in providing self-service system.
- 3) Benefit from the study in selecting suitable sites for establishing integrated fuel stations including supper market , vehicle maintenance and lubrication, natural gas center , a cafeteria and worship places, that is along the national roads.

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Soltan Ibrahim M.Sc. candidate, B.Sc., Diploma. Soltan Ibrahim is a Master candidate in the College of Graduate Studies and Scientific Research at Karary University, Sudan. He obtained his Bachelor degree in Surveying Engineering from Karary University, Sudan. He obtained a Diploma degree in surveying Engineering from School of Surveying, College of Engineering at Sudan University of Science and Technology (SUST), Sudan. His current research is on Geographic Information Systems (GIS), Remote Sensing (RS), Engineering surveying,

and Practical surveying.



Mohammed Fator Zaid Mohammed PhD, M.Sc., B.Sc., Diploma Assistant Professor of Surveying Engineering and Digital Photogrammetry in the School of Surveying, College of Engineering at Sudan University of Science and Technology (SUST), Sudan. He obtained the aforementioned degrees in Surveying engineering and Photogrammetry from SUST. His present interests focus on Digital Photogrammetry, Geodesy, Geostatistics, Academic mentorship, and Technical support within the domain of Surveying engineering.



Abubakr Hassan Abdelwahab Kheiri PhD, M.Sc., B.Sc. Assistant professor in the Department of Surveying Engineering at Karary University, Sudan. He obtained his Bachelor and Master of Science degrees in Surveying Engineering and Geodesy from Sudan University of Science and Technology (SUST), Sudan. He obtained a PhD from Southwest Jiaotong University in Chengdu, China. His present work emphasizes Geomatics, Geodesy, GNSS, and providing emergency decision-making support.