

GIS-Based Spatial Distribution and Road Proximity Analysis of fuel Stations in Gharyan Municipality, Libya

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ABSTRACT

Fuel stations are the lifeline of fuel transport, trade, and urban expansion, and as such the development of communities and the integration of infrastructure services are closely and directly linked to fuel stations. There has been a growing need for this essential service, on which various aspects of daily life depend. The study investigated measures of centrality, in particular, the spatial distribution pattern of fuel stations and their closeness to roads in the municipality of Gharyan. A database of 23 petrol stations was analyzed using Geographic Information Systems (GIS). The average nearest neighbor analysis (ANN) produced a nearest neighbor ratio of (1.16), a Z-score of (1.51), and a P-value of (0.130). The ratio shows a tendency toward a dispersed pattern, but this result is not statistically significant. The standard distance was (13.49) km; the directional distribution (elliptical standard deviation) was (10.4) km; the Kernel Density Estimate (KDE), and Z-score criterion, which ranges from (-1.65 to 1.65), showed that the spatial distribution of petrol stations is random.

Distance to the nearest road was also examined in the study. These analyzes were selected to provide additional information on the general spatial pattern, geographical dispersion, prevailing orientation,

local concentration, and the relationship between petrol stations and the road network. The analysis of proximity to the roads showed a minimum distance of 5.06 m, a maximum distance of 64.6 m, a mean of 31.85 m, and a standard deviation of 16.26 m. These results indicate that petrol stations are generally located at a relatively short distance from the road network shown on the map, although the degree of proximity varies between sites.

The study creates a spatial and descriptive database of the current fuel station network and forms the basis for future analyses of accessibility and the usage of land and municipal planning.

ملخص

يرتبط تطور المجتمعات وتكامل خدمات البنية التحتية بعلاقة طردية وثيقة مع محطات الوقود حيث تمثل هذه المحطات الشريان الحيوي الذي يغذي حركة النقل والتجارة والتوسع العمراني، تناولت هذه الدراسة مقاييس النزعة المركزية الخاصة بتحليل نمط التوزيع المكاني لمحطات الوقود وقربها من الطرق في بلدية غريان، تم تحليل قاعدة بيانات تضم 23 محطة وقود باستخدام نظم المعلومات الجغرافية (GIS)، تحليل الجار الأقرب المتوسط (ANN)، مما أسفر عن نسبة أقرب جار البالغة 1.16 مع درجة Z تبلغ 1.51 وقيمة P تبلغ 0.130 وعلى الرغم من أن النسبة تشير إلى ميل نحو نمط متناثر، فإن النتيجة ليست ذات دلالة إحصائية، والمسافة المعيارية (13.49 كم)، والتوزيع الاتجاهي الذي بلغ (10.4 كم)، وتقدير الكثافة النواة (KDE)، ومن خلال معيار تصنيف الدرجة الحرجة، (Z-Score) التي تتراوح بين (-1.65 – 1.65) وذلك يدل على التوزيع المكاني لمحطات الوقود، أنه توزيع عشوائي.

وأهتمت الدراسة بتحليل القرب (Near)، من أقرب طريق. وقد تم اختيار هذه التحليلات لتوفير معلومات تكميلية عن النمط المكاني العام، والتشتت الجغرافي، والاتجاه السائد، والتركيز المحلي، والعلاقة بين محطات الوقود وشبكة الطرق. وأسفر تحليل القرب من الطرق عن مسافة دنيا تبلغ 5.06 م، ومسافة قصوى تبلغ 64.6 م، ومتوسط يبلغ 31.85 م، وانحراف معياري يبلغ 16.4 م. وتشير هذه النتائج إلى أن محطات الوقود تقع عمومًا على مسافة قريبة نسبيًا من شبكة الطرق على الرغم من تباين درجة القرب بين المواقع، وتضع

الدراسة امام صناع القرار قاعدة بيانات مكانية ووصفية لشبكة محطات الوقود الحالية، وتضع أساساً لتحليلات مستقبلية تتعلق بإمكانية الوصول واستخدام الأراضي والتخطيط في البلدية. كلمات مفتاحية: نظم المعلومات الجغرافية، محطات الوقود، التوزيع المكاني، معامل الجار الأقرب، ظاهرة الكثافة، المسافة المعيارية، التوزيع الاتجاهي، القرب من الطريق.

1. INTRODUCTION

Fuel stations are an important part of the transportation infrastructure of cities and regional centers. Population density, settlement patterns, road networks, and movement patterns closely relate to the spatial distribution of fuel stations. Therefore, knowledge of the location of filling stations and their spatial structure is useful to describe the existing fuel-service network and to support future infrastructure planning. Geographic Information Systems (GIS) offer a useful framework for analyzing the spatial organization of filling stations since their locations can be examined in relation to other geographical features. The services provided by transport-linked petrol stations are vital in ensuring the flexibility and continuity of transport links between different parts of the city (Mohammed 2025).

A map can show where fuel stations are located, but a map alone cannot show whether the stations are clustered, randomly distributed, dispersed, aligned in a particular direction, or closely associated with the road network. These characteristics imply a spatial analysis of the stations as a set of geographic objects. Several GIS-based statistical measures can provide complementary information on this spatial organization. Average Nearest Neighbor (ANN) describes the global point pattern, and Standard Distance describes the general spatial dispersion of the stations. The standard deviational ellipse provides information about the directional characteristics and orientation of the distribution, and the kernel density identifies areas of relatively high and low station concentration. Nearest-road analysis also provides a quantitative measure of the distance of each station to the mapped road network. GIS-based

studies have increasingly examined the distribution, accessibility, density, and site suitability of filling stations across various geographical contexts. The standard deviational ellipse provides information about the directional characteristics and orientation of the distribution, whereas kernel density identifies areas of relatively high and low station concentration. In addition, nearest-road analysis provides a quantitative measure of the distance between each station and the mapped road network.

GIS-based studies have increasingly been used to examine fuel-station distribution, accessibility, density, environmental considerations, and site suitability in different geographical contexts. Previous research in Libya has examined filling-station distribution in locations including Tripoli

Bani Walid (Alghareb January 2024), Ajeelat, Sabratha, and Al-Marj (Balhamd* August 25, 2026). These studies demonstrate the usefulness of spatial analysis for identifying differences in station concentration and distribution between urban and peripheral areas. Other studies in Iraq, Nigeria, Turkiye, and other regions have similarly applied GIS and spatial statistics to investigate petrol-station distribution, accessibility, location characteristics, and planning factors. The available literature therefore demonstrates the value of GIS for examining fuel-station locations, while also indicating that the spatial characteristics of individual study areas need to be examined within their own geographical contexts.

In Gharyan Municipality, fuel-station locations can be identified geographically; however, there remains a need for an integrated quantitative description of their spatial organization. In particular, information is needed on the overall spatial extent and dispersion of the stations, their directional characteristics, areas of higher and lower concentration, and their distance from the nearest mapped roads. A systematic analysis combining these different spatial dimensions can provide a more complete description than visual interpretation of station locations alone. Accordingly, this study addresses the need for a GIS-based assessment of the spatial organization of fuel stations in Gharyan Municipality and their geometric relationship with the road network.

These stations provide fuel to private, public, commercial, and other road users. Their placement is tied to the road network, since access to it is a key factor both in where stations are established and in their capacity to serve nearby communities. As cities and transportation

demands evolve, the spatial structure of fuel stations becomes an informative feature for understanding the present condition of the fuel service network.

A map shows where fuel stations are located, but it reveals nothing about whether they tend to cluster in particular places, are scattered at random, follow a preferred direction or orientation, or bear any relationship to the road network. These characteristics emerge through detailed spatial analysis that treats fuel stations as a complete set within a geographic context.

Geographic Information Systems offer a range of tools for this purpose, chiefly for identifying patterns in the distribution of objects of interest. These patterns can then be characterized through statistical measures like Standard Distance, which estimates the spatial spread of a feature class or point set. A related tool, the Standard Deviational Ellipse, is capable of detecting a preferred direction within the observed pattern. Kernel Density analysis is another valuable method, estimating the intensity with which a given set of points clusters. Lastly, proximity analysis can evaluate how close points are to an established set, in this case the road network.

Even though fuel stations are an integral component of transportation infrastructure, research on the study area does not describe their spatial structure and accessibility. The locations of fuel stations can be determined, yet without knowledge of their spatial distribution pattern, their role in transportation infrastructure cannot be properly evaluated.

In particular, current research has little understanding of their overall extent, direction of spread, degree of clustering, and distance to the nearest roadways. This research therefore seeks to fill that gap by describing the spatial structure of fuel stations as a network of objects spanning the study area. This paper thus examines fuel stations in terms of their spatial distribution pattern and their interaction with the road network as a set of objects, rather than as individual points of interest. Using Geographic Information Systems tools, this study will characterize the current state of fuel stations by visualizing their extent, pattern, and proximity to the established road network. The findings will offer a quantitative description of the spatial structure of the fuel service network in the study area, supplementing the visual information provided by standard mapping. This study seeks to characterize the spatial distribution pattern of fuel stations and their relationship with the road network in the study area by means of Geographic Information Systems tools. This effort will therefore pursue the following goals: (1) map and document how fuel stations are currently distributed; (2) characterize the overall

extent and geographic center of that distribution; (3) estimate the directional spread of gas stations; (4) identify areas of higher and lower concentration; (5) estimate the distance from gas stations to the nearest roadways; and (6) analyze how gas station locations relate to the road network and its various types. Fuel stations form a core part of transportation infrastructure, providing fuel to private, public, commercial, and other road users. Their placement is tied to the road network, since access to it is vital for both their establishment and their ability to serve nearby communities. As urban areas and transportation needs grow, the spatial structure of Fuel stations becomes a compelling way to understand the current state of the fuel service network.

Their spatial distribution is closely associated with population concentration, settlement structure, road networks, and patterns of movement. Understanding where fuel stations are located and how they are spatially organized is important for describing the existing fuel-service network and supporting future infrastructure planning. Geographic Information Systems (GIS) provide an effective framework for investigating the spatial organization of fuel stations because their locations can be analyzed in relation to other geographical features. A map can show where fuel stations are located, but visual representation alone cannot determine whether they are clustered, randomly distributed, dispersed, oriented in a particular direction, or closely related to the road network. These characteristics can be examined by treating fuel stations as a set of geographic objects and applying appropriate spatial-statistical measures. Average Nearest Neighbor (ANN) evaluates the overall point pattern in terms of clustering, randomness, or dispersion. Standard Distance describes the overall spatial dispersion of the stations. The nearest neighbour class of estimators represents an attempt to adapt the amount of smoothing to the 'local' density of data. The degree of smoothing is controlled by an integer k , chosen to be considerably smaller than the sample size; typically $kn^{1/2}$. Define the distance $d(x, y)$ between two points on the line to be $|x - y|$ in the usual way, (Silverman 1986). while the Standard Deviation Ellipse provides information about their directional characteristics and spatial orientation. Kernel Density Estimation identifies areas of relatively high and low station concentration, while nearest-road analysis provides a quantitative measure of the distance between fuel stations and the mapped road network. GIS-based studies have increasingly been applied to examine road fuel-station distribution, accessibility, density, environmental considerations, and site suitability in different

geographical contexts. Within Libya, previous studies have examined fuel-station distribution in Bani Walid, Al-Ajeelat, Sabratha, and Al-Marj. These studies demonstrate the usefulness of spatial analysis for identifying differences in station concentration and distribution between urban and peripheral areas. The Al-Marj study, in particular, applied several GIS-based spatial measures to investigate fuel-station distribution, illustrating the value of combining different spatial-statistical techniques (Balhamd* August 25, 2026). rather than relying on visual interpretation alone. Similar GIS-based approaches have been reported in Iraq, Nigeria, Turkiye, and other regions, where studies have examined petrol-station distribution, spatial relationships, accessibility, and location suitability. The findings of these studies indicate that fuel-station locations can be associated with several spatial factors, although the importance of individual factors varies according to the geographical context and purpose of the study.

Fiseha Study, Ethiopia, East Africa. The problem of haphazard location of petrol stations is one of the major difficulties in Wolayita Sodo towns. Due to less scientifically accepted sites and lack of attention to planning standards that has experienced the planning methods are expressed in poor sitting(Fiseha, Manugula et al. 2023).

A major advantage of spatial-statistical analysis is that it allows different dimensions of spatial organization to be examined separately and then considered together. ANN provides information about the overall point pattern, Standard Distance summarizes geographic dispersion, and the Standard Deviation Ellipse describes directional characteristics. Kernel Density complements these measures by identifying areas of relatively high and low concentration. The road network represents another important component of fuel-station location because fuel stations primarily serve road users. Consequently, examining the spatial relationship between stations and roads provides an additional quantitative dimension to the description of the existing fuel-service network.

Although the geographic locations of fuel stations in Gharyan Municipality can be identified, there remains a need for a more integrated quantitative description of their spatial organization and relationship with the road network. In particular, information is needed on the overall spatial pattern, geographic dispersion, directional characteristics, areas of concentration, and distance from each station to the nearest mapped road. Accordingly, this study addresses the need for a systematic GIS-based assessment of the spatial organization of

fuel stations in Gharyan Municipality. Geographic Information Systems (GIS) have become an effective tool for decision support (Rayed 2012).

A map shows where fuel stations are, but only whether they exist at a given site. It reveals nothing about whether they cluster in certain areas, scatter randomly, follow a preferred direction or orientation, or relate in some way to the road network. Such traits emerge only from in-depth spatial analysis that treats fuel stations as a whole set within a geographic context.

Geographic Information Systems provide many tools for this, chiefly for detecting patterns in the distribution of objects of interest. These patterns can then be described with statistical measures such as Standard Distance, which estimates the spatial spread of a feature class or point set. A related tool, the Standard Deviational Ellipse, can identify a preferred direction in the observed pattern. Kernel Density analysis is another useful method, estimating how strongly a given set of points clusters. Finally, proximity analysis can assess how close points lie to an established set, here the road network.

Although Fuel stations are a critical part of transportation infrastructure, research on the study area does not describe their spatial structure and accessibility. Fuel station locations can be identified, yet without information on their spatial distribution pattern, their role in transportation infrastructure cannot be properly assessed. In particular, current research knows little about their overall extent, direction of spread, degree of clustering, and distance to the nearest roadways. This research aims to fill that gap by describing the spatial structure of fuel stations as a network of objects spanning the study area.

This paper therefore examines fuel stations in terms of their spatial distribution pattern and interaction with the road network as a set of objects, not as individual points of interest. Using Geographic Information Systems tools, this study will characterize the current state of fuel stations by visualizing their extent, pattern, and proximity to the established road network. The results will provide a quantitative description of the spatial structure of the fuel service network in the study area, complementing the visual information from standard mapping.

Their spatial distribution is closely associated with population concentration, settlement structure, road networks, and patterns of movement. Consequently, understanding where gas stations are located and how they are spatially organized is important for evaluating the existing level of service and supporting future infrastructure planning. Geographic Information

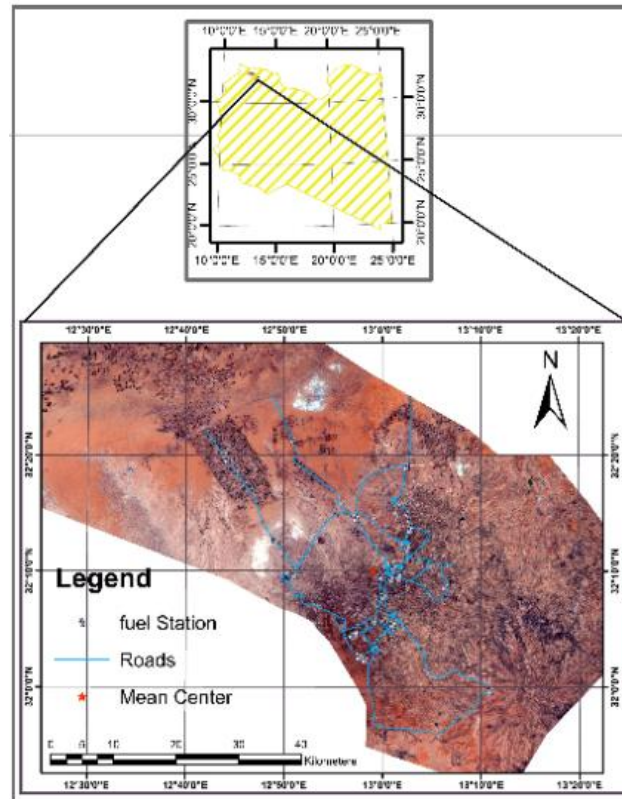
Systems provide an effective framework for investigating the spatial organization of fuel stations because locations can be analyzed simultaneously in relation to other geographical features (Zhou, Wu et al. 2021, Ayyildiz and Taskin 2022). GIS-based studies have increasingly been used to examine fuel-station distribution, accessibility, density, environmental considerations, and site suitability. Recent research has applied GIS and spatial statistics to fuel stations in several geographical contexts, including Libya, Iraq, Nigeria, Turkiye, and other regions. Within Libya, fuel-station distribution has received increasing attention (Ayyildiz, Taskin Gumus et al. 2020, Hussein Bedewy, Abdulameer et al. 2023). Recent studies have examined the spatial distribution of stations in Bani Walid, (Alghareb January 2024) Al-Ajeelat, Sabratha, and Al-Marj. These studies demonstrate the usefulness of spatial analysis for identifying differences in station concentration and distribution between urban and peripheral areas. In particular, the recent study of Al-Marj used several GIS-based spatial measures to investigate the distribution of fuel stations, illustrating the value of combining different spatial-statistical techniques rather than relying on visual interpretation alone. Similar approaches have been reported internationally. Studies in Iraq and Nigeria have used GIS to examine petrol-station distribution and spatial relationships, while other research has focused on location suitability and planning using GIS integrated with multi-criteria decision-making techniques. Such research demonstrates that fuel-station location is influenced by several spatial factors, although the relative importance of these factors differs according to the purpose and geographical context of each study (Njoku 2015, Terzi, Atasoy et al. 2025).

A major advantage of spatial-statistical analysis is that it distinguishes between different dimensions of spatial organization. Average Nearest Neighbor analysis evaluates the overall point pattern and determines whether locations tend toward clustering, randomness, or dispersion (Floch, Marcon et al. 2018, Purba, Balisi et al. 2024). The method is based on comparing observed and expected nearest-neighbor distances. Standard Distance summarizes the overall geographic dispersion of a point dataset, while the Standard Deviation Ellipse provides additional information about directional characteristics and spatial orientation. Kernel Density Estimation complements these global measures by identifying areas of relatively high and low spatial concentration (Ogunkan, Joseph et al. 2023). The road network represents another important component of Fuel-station location. Because Fuel stations primarily serve road users, their spatial relationship with roads is an important characteristic of

the existing network. Previous research has examined Fuel-station locations in relation to road-network characteristics and has demonstrated the importance of accessibility and network structure in fuel-service analysis (Antwi, Okai et al. 2024, Liu, Kan et al. 2024). The Study of Gharyan examined the geographic distribution and characteristics of fuel stations in the municipality. However, there remains scope for a more integrated quantitative analysis combining global point-pattern statistics, overall dispersion, directional distribution, local density, and road proximity. Accordingly, this study addresses the lack of a systematic GIS-based assessment of the spatial organization of Fuel stations in Gharyan Municipality and their geometric relationship with the road network. The objectives are to determine the overall spatial pattern of the gas stations; measure their overall geographic dispersion; identify the directional characteristics of their distribution; identify areas of relatively high and low station concentration using Kernel Density; and quantify the distance between each gas station and the nearest mapped road. The study is intended to characterize the existing spatial pattern rather than evaluate regulatory compliance or determine the suitability of future station locations (Hussein Bedewy, Abdulameer et al. 2023).

2. STUDY AREA

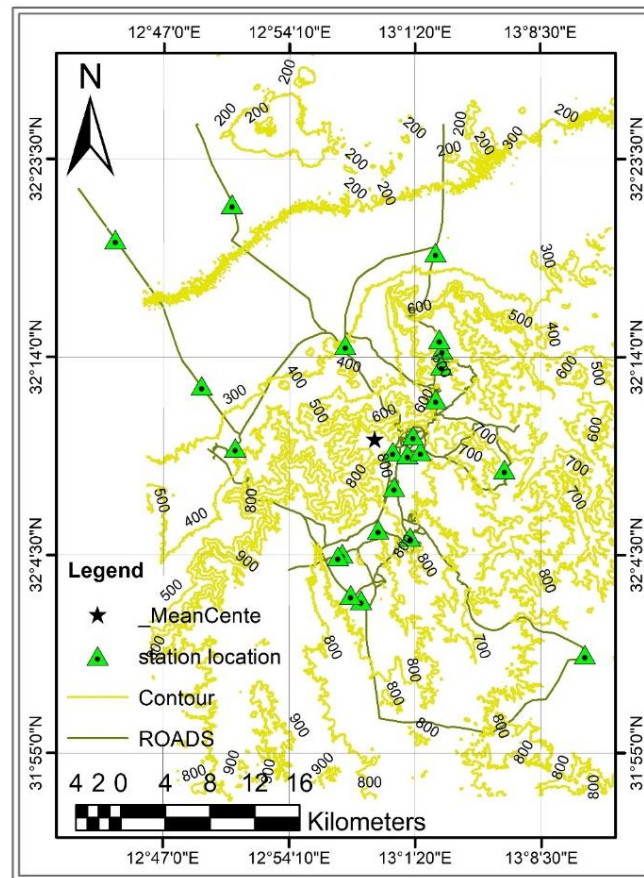
Gharyan Municipality is located in northwestern Libya, positioned between latitudes $31^{\circ} 52'$ and $32^{\circ} 27' N$, and longitudes $12^{\circ} 24'$ and $13^{\circ} 23' E$ (see Figure 1). It is recognized as an important urban and service center. Within the municipality, there are areas of concentrated settlement as well as less developed peripheral regions characterized by complex terrain, including elevated surfaces, valleys, and topographic features associated with mountains



Map (1). Study Area

The geographical variation within the municipality provides important context for understanding the distribution of transportation infrastructure. Built-up areas and major roads have different spatial conditions than mountainous and valley environments, where development may be limited. However, the current study does not statistically test the causal effect of topography on fuel-station locations. As a result, topographic characteristics are regarded as geographical context rather than established causal determinants.

Contour lines were used to depict the study area's topographic characteristics (Map 2). They depict the elevation range from relatively low-lying areas to higher terrain, including mountains and valleys. The contour pattern depicts the physical environment in which the road network and fuel stations are distributed. Although differences in elevation and terrain may influence the development of roads and settlements, the current study did not quantify their specific impact on fuel-station locations.



Map (2). Contour lines -Stations Location

1. MATERIALS AND METHODS

The spatial analysis was conducted using ArcGIS 10.8. Imagery from Sentinel-2A (ESA) with a resolution of 10 meters was acquired in 2020, while SPOT-6 imagery, with a resolution of 1.5 meters, was obtained in 2013. All images were georeferenced and rectified using the map-to-image georeferencing method, then projected to WGS 1984 UTM Universal Transverse Mercator Zone 33 North. Shapefiles were created in ArcCatalog, projected as the original images, and imported into ArcMap. The study area was clipped to align with the target region, and the Global Positioning System (GPS) was utilized. A Garmin device was used to accurately locate the fuel station pump as point features, which were subsequently displayed as point shapefile features. As Clarified in Methodology flow chart figure (1) Contour line information was sourced from Shuttle Radar Topographic Mission (SRTM) data. Google Earth served as ancillary data to enhance visual interpretation. Roads were digitized and represented as shapefiles and vector layer polyline feature.

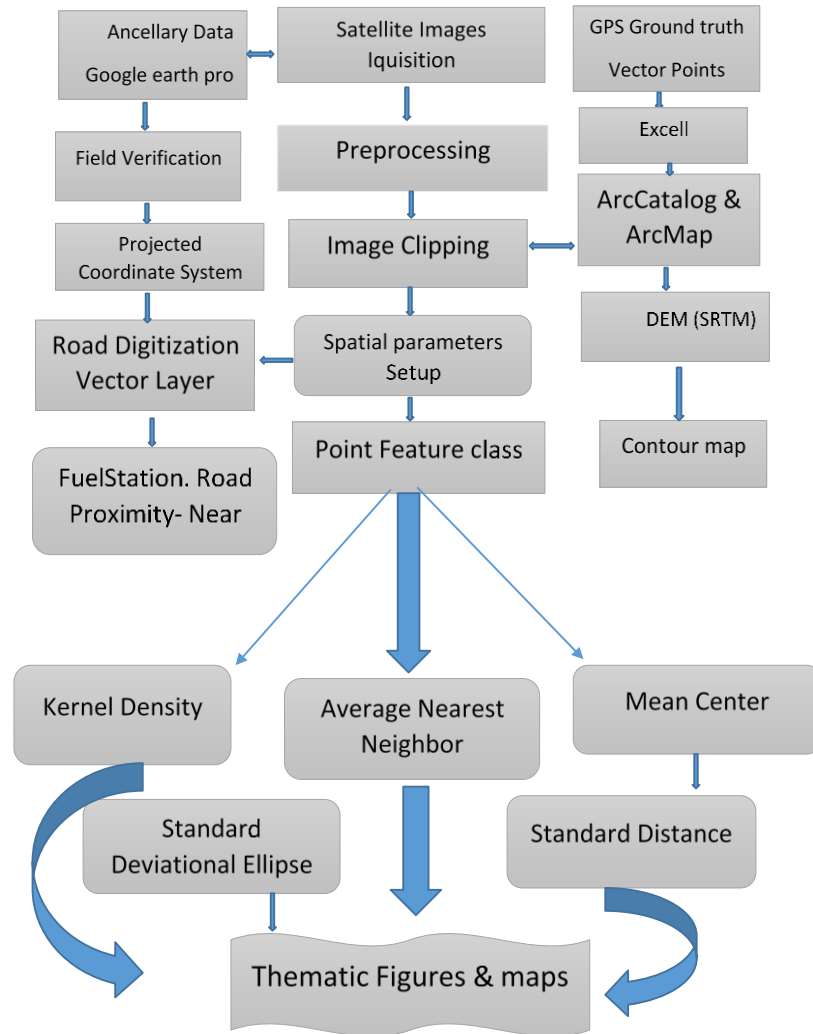


Figure (1) Flow chart methodology

5. Results

5.1 Distribution of Gas Stations

The final database contains 23 Fuel stations. Their spatial distribution is not uniform across the study area. The station locations show differences in concentration between the more developed parts of the study area and peripheral areas. The spatial distribution map provides an initial visual representation, while the subsequent statistical analyses quantify the pattern and its spatial characteristics.

5.2 Average Nearest Neighbor

Average Nearest Neighbor analysis was applied to determine the overall spatial pattern of the 23 Fuel stations. A ratio below 1 indicates a tendency toward clustering, a value close to 1 indicates a pattern approaching randomness, and a value greater than 1 indicates a tendency toward dispersion. The Z-Score and P-value are used to determine whether the observed deviation from randomness is statistically significant (Clark 1954). The final ANN results for the 23-station dataset are presented in Table 1

Table (1). Average Nearest Neighbor results

Number of Stations	23
Nearest Neighbor Ratio	1.16
Observed mean Distance	4345
NNZ Score	1.5
P Value	0.130
Expected mean Distance	3730

A ratio above table (1). indicates a tendency toward dispersion, yet it is the P-value that establishes whether this tendency differs significantly from one that would arise from random distribution, (Figure2) Explains the calculation of average Nearest Neighbor Diagram

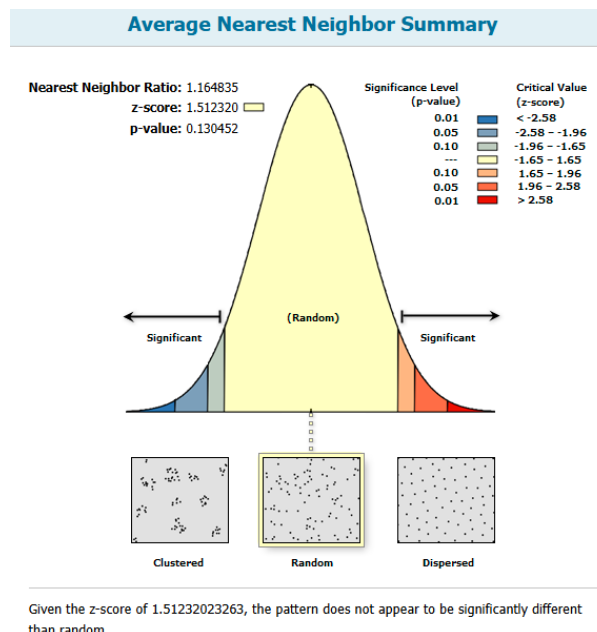


Figure (2). Average Nearest Neighbor output

5.3 Standard Distance

The Standard Distance analysis quantifies the overall geographic dispersion of the 23 stations (Table 2). The resulting circle summarizes the geographic extent of the station distribution around the mean center (Map 3). This analysis measures how the fuel stations are dispersed around their mean center, which is located at (X Coordinate = 310828.02709; Y Coordinate = 3560588.004476) outside Al-Boraj village a non-populated area. It is 1.092 kilometers northwest of the Al-Ruwaisa station. The circle illustrates the geographic spread of the station locations. A larger standard distance value indicates greater overall spatial dispersion, while a smaller value signifies a more compact distribution. The Standard Distance is a descriptive spatial statistic and should not be interpreted as a regulatory boundary or service radius.

Table (2). Standard Distance results

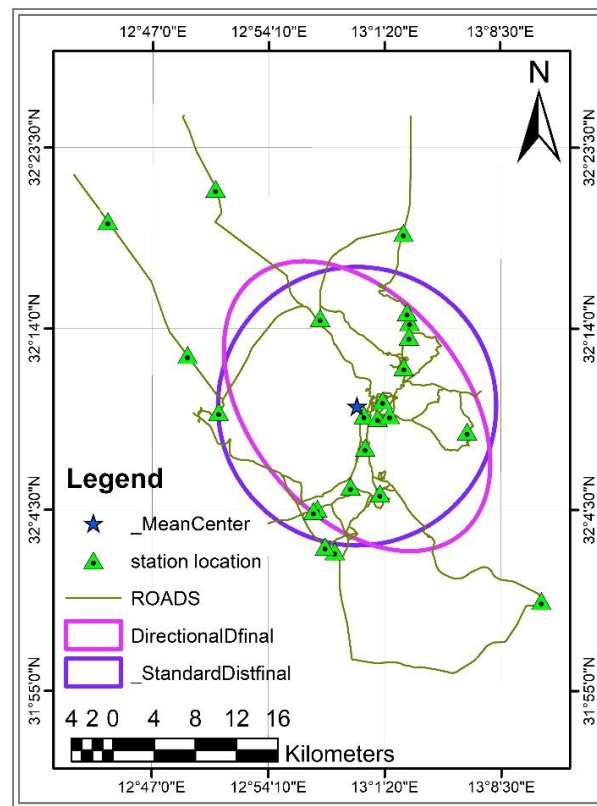
Mean Center X (m)	310828.02709
Mean Center Y (m)	3560588.004476
Standard Distance(m)	13495.293679
Standard Distance(km)	13.5
Area km²	586.198

5.4 Directional Distribution

The Standard Deviation Ellipse provides information about the directional structure of the station distribution (Table3). The difference between the two standard-distance axes indicates whether the station distribution is more dispersed in one principal direction than the other. The ellipse therefore adds directional information that cannot be obtained from the Standard Distance circle alone (Map3).

Table (3). Standard Deviation Ellipse result

Mean Center X	309903.303316
Mean Center Y	3560820.386576
X Standard Distance	10424.148951
Y Standard Distance	16265.650278
Rotation	146.104195
Ellipse Area	532.638 km ²

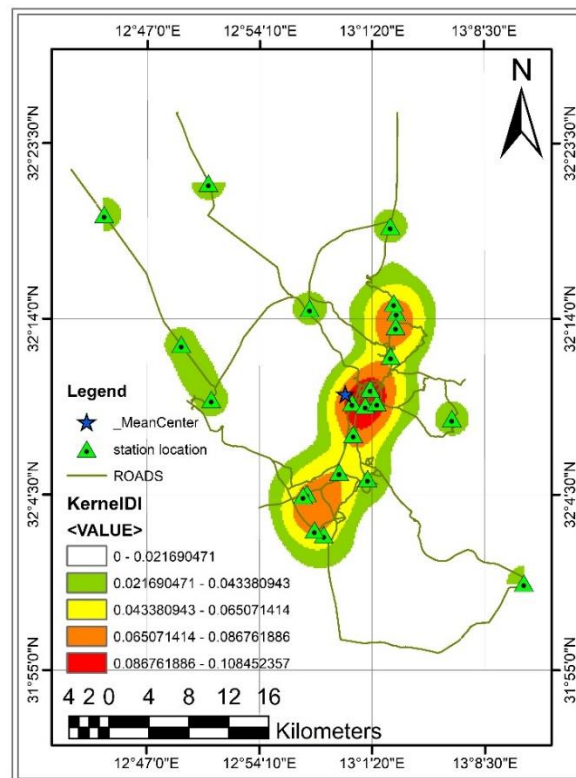


Map (3). Standard Distance & Standard Deviatonal Ellipse

5.5 Kernel Density

The Kernel Density analysis identified spatial variation in Fuel-station concentration, the resulting density surface shows that stations are not evenly distributed throughout the study area. Areas containing several stations within relatively short distances produce higher density values, whereas areas with fewer stations produce lower density values (Map4).

The variable kernel method is somewhat related to the nearest neighbour approach and is another method which adapts the amount of smoothing to the local density of data. The estimate is constructed similarly to the classical kernel estimate, but the scale parameter of the 'bumps' placed on the data points is allowed to vary from one data point to another (Silverman 1986).



Map (4). Kernel Density

The Kernel Density result is particularly useful for identifying concentration zones that may not be adequately represented by a single global statistic. However, high density should not automatically be interpreted as high demand, traffic congestion, environmental risk, or planning deficiency. Kernel Density measures the spatial concentration of the observed station locations.

Density analysis provides a cartographic representation of the extent of variation in the distribution density of the phenomenon across the study area; in other words, the result of this analysis will not be a single figure expressing the density of the phenomenon across its entire geographical extent, but rather represents the variation in the densities of the phenomenon from one location to another within the study area (Dawod 2018/2019).

5.6 Road Proximity

The connection between Fuel stations and the road network was assessed with the ArcGIS Near tool. For every station, the shortest straight-line distance was computed from the mapped Fuel pump location to the closest digitized road. This measurement reflects

geometric proximity rather than actual driving distance, travel time, or legal road setback. Network accessibility would demand a routable road network along with a suitable network-analysis procedure).

The road-proximity analysis was completed for all 23 stations. The results are shown in Table

4

Table (4). Distance from fuel-station pump locations to the nearest digitized roads

ID	Station Name	No.	status	NearDist.	Near X	Near Y
1	Al_jabal Alasham		Active	57.3	315648.674228	3577303.63868
2	Abugilan	270	Active	39.8	315859.891061	3569615.49291
3	Al-miamean		Inactive	34.2	316073.920561	3568654.80839
4	Al-Qawasim Algadida	377	Inactive	28.7	315995.063582	3567247.16622
5	Mahalet Alwaset	162	Inactive	5.2	315430.692337	3564292.27141
6	Al- kumishat	449	Active	5.6	321458.204826	3557911.57674
7	Al- sagayif	980	Active	34	313966.430215	3559639.24712
8	Markez AL-Madina	399	Active	5	313329.276118	3561075.62603
9	Al-Ruwaisa	990	Active	22	311480.848024	3559698.26658
10	Ben sisi	—	Inactive	26.7	312813.164515	3559451.28213
11	Tagrana	371	Active	17.7	311546.304464	3559639.24712
12	Abouzayan	369	Active	31.7	310065.090905	3552794.81768
13	Qaba	453	Active	8.7	312888.47268	3552096.8833
14	Al_Magharba	—	Inactive	19.3	306798.078758	3550715.24904
15	Al-kefah magharba		Active	33	306280.106082	3550491.81913
16	Al-khaliba 2	1005	Active	45.8	307473.311182	3547091.54134
17	Al-khaliba 1	882	Inactive	45	308365.276909	3546523.96944
18	Qhout AL_Reeh		Active	22.6	328365.276909	3541377.68802
19	Abourshada	—	Inactive	45.5	307427.6598	3569212.20619
20	Aboushiba		Inactive	64.6	297503.125	3581950.73678
21	Rabta 1		Active	44	297399.244457	3560328.40142
22	Rabta 2		Active	55	294490.54245	3565831.15832
23	Wadi AL_Hay	159	Active	32.9	287049.110309	3565831.15832

The distance from the fuel station pump locations to the nearest mapped road ranged from 5.06 m to 64.64 m. The mean distance was 31.85 m, with a standard deviation of 16.44 m. This mean indicates that the stations are generally located relatively close to the road network. However, the range shows significant variation among the individual stations. The standard deviation further implies that the proximity of the stations to the roads is not consistent across the study area. The maximum distance of 64.6 m does not necessarily indicate poor accessibility; rather, it represents the shortest geometric distance from the

mapped pump point to the nearest digitized road. This distance may be influenced by factors such as the internal layout of a station property, the placement of the pump facilities, or the design of the mapped road network.

6. Discussion

The results demonstrate how different GIS-based methods can provide complementary information about the spatial structure of fuel stations. Each method describes a particular aspect of the distribution: ANN evaluates the overall point pattern, Standard Distance describes the degree of spatial dispersion, the Standard Deviation Ellipse identifies the dominant direction of the distribution, Kernel Density reveals areas of relatively high concentration, and nearest-road analysis measures the proximity of stations to the road network. Using these methods together therefore provides a broader description of the existing fuel-station pattern than relying on a single spatial measure. Previous GIS-based studies have similarly demonstrated the usefulness of spatial analysis for examining fuel-station distribution in relation to roads, urban development, and planning factors.

The findings are also consistent with research conducted in other Libyan locations, including Bani Walid, Al-Ajeelat, Sabratha, and Al-Marj, where GIS has been applied to examine characteristics of fuel-station distribution. The present study combines several spatial indicators and supplements the spatial distribution analysis with a quantitative assessment of station proximity to the road network. This provides additional information that can be used in subsequent studies of accessibility and network development.

In current study the nearest neighbor analysis indicated a tendency of dispersion in the spatial distribution of petrol stations in Gharyan Municipality with a nearest neighbor ratio of 1.16. This trend was not statistically significant ($Z\text{-score} = 1.51$, $p\text{-value} = 0.130$). The $p\text{-value}$ was greater than the significance level of 0.05, therefore the null hypothesis of a random spatial pattern could not be rejected. The standard distance of about 13.49 km measures the spread of the petrol stations around the mean center.

Kernel Density Estimation (KDE) was used to investigate variations in the spatial concentration of petrol stations in Gharyan Municipality. This method generated a continuous density surface based on the locations of the 23 stations, allowing the identification of areas with relatively high and low concentrations. The resulting surface complements the Average Nearest Neighbor (ANN) analysis by revealing local variations in

station concentration, whereas ANN evaluates the overall spatial pattern statistically. As a result, KDE was used as a descriptive spatial analysis technique rather than an independent statistical test of randomness.

The nearest-road analysis highlights the importance of fuel stations to the road network. This relationship is expected because road accessibility is an important factor in fuel station locations. The relatively short average distance between stations and roads suggests that the studied stations are generally close to mapped roads, providing a basic indicator for future accessibility analyzes.

Petrol stations are found along the dual carriageway (main road) that connects the Al-Aziziyah-Gharyan area to the mountain towns and southern Libya. In particular, 11 stations are concentrated in densely populated areas such as Al-Qawasim and Abu Gilan, where five stations are found—four on the main road and one on a local road in Al-Kumishat Village. Two of these are open, while the other three are closed. In addition, Gharyan has four stations, two on the main road and two on local roads; one of these stations is out of service and is located on the main road. The remaining 12 petrol stations are spread out throughout the municipality, with one each in Tagrana and Abu Zayan. Al-Magharba and Al-Khaliba each have two stations, but only one is operational. The two stations in Al-Khaliba are located on the road that connects Gharyan with the southern regions. The Ghout al-Reeh station is located on the road connecting Gharyan and the Al-Urban regions, along with one station in the village of Qaba, which serves five nearby villages. There are also two stations in the villages of Al-Rabita al-Sharqiya and Al-Rabita al-Gharbiya, one on the road connecting the two villages and the other on the road connecting Al-Rabita and Wadi al Hay. Furthermore, there is one station in the Wadi al-Hay area, as well as one on the Aburshada road and one at the Abushiba project, both of which are currently out of service.

Future research can expand this approach by differentiating road classes and incorporating them in future research by differentiating road classes and adding traffic volume, travel distance, travel time, and shortest-path analysis.

Kernel density analysis provides another look at identifying areas where fuel stations are more concentrated. But the fact that there is a high-density area does not account for the reasons for that concentration. Prior to providing explanations for the observed

concentration, consideration should be given to such factors as the population distribution, traffic intensity, commercial activity, availability of alternative transportation, and the past development of settlements. Topography may also be relevant in Gharyan, as mountains and valleys can influence the location of settlements and roads and, indirectly, the locations of fuel stations. Because the present statistical analysis did not explicitly include topographical variables, the study cannot directly associate terrain features with fuel-station locations. Such relationships could be explored in a future study employing topographic and other explanatory variables.

The analysis identifies the locations and spatial distribution of the fuel stations and describes their proximity to the road network but does not determine whether individual stations comply with road-safety regulations, land-use requirements, or other planning standards. Such an assessment would require relevant regulatory documents, detailed road classification, cadastral information, and field-survey data. A separate analysis should address regulatory compliance.

The Standard Deviation Ellipse also shows the general orientation of the fuel station network. Its orientation can be compared with the configuration of the major linear features within the study area, i.e., the road network. The contour information also indicates the presence of mountainous and valley terrain that is part of the physical setting in which roads and settlements have developed. Thus, the observed directional pattern of fuel stations can be considered in relation to the wider spatial configuration of the study area, with the caveat that the current analysis does not establish a direct causal effect of topography on station locations.

7. Conclusion

The goal of this study was to use GIS-based spatial analysis to find out how the 23 gas stations in Gharyan Municipality are spread out in space. The chosen statistical measures are used to describe the current local spatial patterns in order to get a full picture of how the fuel station network is spread out. Even though looking at the point data pattern visually gives a good idea of the overall spatial, it is still necessary to give a detailed statistical description using the ANN statistic, the Standard Distance measure, the Standard Deviation Ellipse, and Kernel Density analysis. There are 16 gas stations inside a standard circle with a radius of 13.5 kilometers. This is 69.57% of all the gas stations in the municipality. Using the Average

Nearest Neighbor, Standard Distance, Standard Deviation Ellipse, Kernel Density, and nearest-road analyses showed important parts of how the fuel station network is set up right now. In the case of the gas stations, the road proximity analysis showed that the distance between the pumps and the closest mapped road ranged from 5.06 meters to 64.6 meters, with 31.85 meters being the average and 16.4 meters being the standard deviation. Overall, the distance wasn't always the same, but it was still pretty close to the road network. ANN measures how clumped or spread out points are, while Standard Distance measures how far data points are from the mean and how they spread out. In the same way, the standard deviation ellipse shows the direction of spread, and Kernel Density tells you how strong a point concentration is. So, this study helps figure out how the gas station is spread out in space, which is important for future studies on things like network accessibility, traffic demand, residential proximity, cadastral analysis, land-use potential, and mor

8. Recommendation

This study set out to delineate the geographic configuration of 23 fuel stations within Gharyan Municipality utilizing GIS-driven spatial analytics. By implementing a methodological framework that incorporated Average Nearest Neighbor, Standard Distance, Standard Deviation Ellipse, Kernel Density, and nearest-road assessment

The study recommends the following:

- 1-The GIS database of fuel stations should be maintained and updated whenever new facilities are established, abandoned, or relocated. Keeping the database current will provide a reliable basis for monitoring changes in the spatial pattern of the network and supporting future research on its development.
- 2-Future planning of fuel-station facilities should take the present spatial distribution into consideration, particularly when assessing network accessibility. Further accessibility studies could combine the measured distance between each station and the nearest road with travel time and route distance obtained through network analysis.
- 3-Additional research could investigate the relationship between areas of high Kernel Density and factors such as population distribution, traffic intensity, settlement development, and

topographical constraints. A separate cadastral and residential proximity analysis would also be useful for examining the relationship between fuel stations and nearby residences, buildings, and other sensitive land uses.

4-The Fuel Stations GIS database ought to be maintained and updated whenever new facilities are established, abandoned, or relocated, so that the data set can support future studies of the network's pattern and development trends.

5- In addition, future projects related to fuel stations are advised to incorporate the present findings into their planning, given that the spatial distribution pattern of the existing network will strongly influence future accessibility research.

6-Any future study of the network's accessibility should consider using the measured distance from the gas stations to the nearest road as well as the travel time between facilities through network analysis.

7- further research is advised to examine in greater detail the relationship between the Kernel Density analysis and population distribution, traffic intensity, settlement potential, and topographical constraints.

8- Also, a distinct cadastral and residential proximity analysis should be carried out to uncover the possible relationship between the distance from the Fuel stations to the nearest residences, buildings, and other sensitive land uses.

9 field verification should be performed for those Fuel stations with comparatively large station-road distances in order to confirm the accuracy of the distance measurements and the correctness of the mapped road network.

10- work towards resolving the issues with the stations that are currently out of service and finding solutions, whilst meeting demand 24 hours a day to ensure the fair distribution of fuel throughout the entire municipality, decision-makers should take this study into account when establishing new stations and applying the relevant local standards.

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