Site Suitability Assessment for Petroleum hubs and Oil retail assets in the Jomoro District: A Hybrid Approach using Fuzzy AHP and VIKOR Method

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Abstract: The importance of petroleum infrastructure is undeniable in the face of both local and global energy needs. However, incidents such as explosions originating from these facilities often lead to tragic consequences, including the loss of life and property in nearby communities. This situation has raised significant concerns among government officials and citizens alike. This situation calls for a comprehensive study to identify tangible strategies for reducing the associated risks. Unlawful siting of oil refineries, petrochemical facilities, berthing terminals, pipelines, storage terminals, and oil and gas retail assets stems from a failure to evaluate the environmental impact on a growing human population, consumer competition, and a failure to enforce energy standards. The study aims to employ a multifaceted approach comprising of suitability, proximity and spatial statistical analysis in assessing viable areas for developing petroleum hubs in the district. Through validation using newly acquired land for petroleum hub and existing filling stations in the study area. This study investigated the efficiency of the method and level of adherence to established protocols by the Ministry of Energy, Environmental Protection Agency (EPA), and Town and Country Planning Department. The study relied on both primary and secondary data. The basic data set consists of the positions of filling stations as determined by the Garmin handheld GPS and the measured land border. The secondary data was gathered from Ghana's Land Commission's Survey and Mapping section. It consists of topographic data, geology, and pedology from which the area's soil types, lithology, road networks, terrain slope, water bodies and land use elements were extracted and utilised. Using Fuzzy AHP and VIKOR, the dataset was categorised and weighted. Spatial evaluations were performed using ArcGIS software to identify regions suitable or unsuitable for the placement of petroleum hubs in the research area. Results shows 67.44% of the area are highly suitable for establishment of petroleum hubs, 32.33% of the area falls within moderate suitability zones whereas the least suitability zones occupied 0.23% of the total area. The newly acquired government land for the petroleum hub project fell within the highly suitable zone confirming the validity of the studies in comparison with studies from field experts via environmental impact assessment. The proposed petroleum hub covered areas dominated by very high and high area suitability for its establishment constituting 75.9 km^2 (90.3%) of its entire area whereas the moderate suitability zones constituted 8.2 km^2 (9.7%) of the remaining areas. Towns situated in very high areas includes; Bakakole Nkwanta, Ahobre, Nawule, Allowule, Tikobo No.1, Edu, Damofu, Ave lenu and Ebonloa, Mpatabo. High areas comprises of Kengen Kpokezo, Alenda wharf, Tekyinta. Anwonakrom, Nkwamta, Elubo and Agege are among the moderate and low area zones for hub and oil retail assets establishment. 75% of the oil retail assets complied with the established protocols whiles 25% defaulted. The combination of GIS methodologies and multi-criteria decision analyses has proven to be an efficient method for highlighting acceptable areas for petroleum hubs, oil retail assets, and determining high-risk areas for adequate area planning. It is proposed that authorities and stakeholders implement efforts to educate, assess site suitability, and enforce specified standards in the construction of petroleum infrastructure.

Keywords: Multi-criteria decision analysis, petroleum infrastructure, Fuzzy AHP, VIKOR, petroleum hubs, oil retail assets

1. Introduction

Africa is endowed with large amounts of both fossil and renewable energy resources, with significant new oil and gas finds (Bank, 2009). Over the last 20 years, Africa's oil reserves have increased by more than 25%, with an expected growth rate of 6% per year. Africa's abundant oil reserves and the potential for future discoveries have positioned the continent as a significant contributor to global oil production and resource extraction (Bank, 2009). Recent years have witnessed more issues on licenses and unlawful siting of oil and gas infrastructure (Aslani and Alesheikh, 2011). The regular news of fuel explosions in the Republic of Ghana, as well as the resulting loss of life, property, and assets, necessitate quick involvement by the government, geospatial specialists, and numerous stakeholders in the energy industry (Peprah et al., 2018). The increasing number of petroleum hubs and oil retail assets operating along important roadways and habitat areas in several growing countries, like Ghana, necessitates the necessity to supervise and manage such activities in the country (Uzochukwu et al., 2018). As the human population grows, so does the number of vehicles on the road, resulting in increased demand for fuel (Njoku and Alagbe, 2015).

This creates the need for the establishment of petroleum hubs and fueling services within the communities. Furthermore, the use of natural gas for commercial and home reasons is increasing, making it critical to build a petroleum trading hub in order to assure national energy security (Xiaoguang et al., 2015). Petroleum trading hubs are increasingly being established due to their pivotal role in transmitting price signals, facilitating price reductions, reducing import price premiums, and securing pricing power for both petroleum and natural gas (Xiaoguang et al., 2015).

In semi-urban environments such as the one under consideration, the indiscriminate placement of petroleum hubs and oil retail assets causes traffic disruptions due to insufficient parking space for tankers during product offloading, hampered vehicle accessibility, rampant parking along the station. Also, commercial activities in and around the vicinity, explosions from highly flammable products and fuel tankers along the way, pollution of underground and surface water (Njoku and Alagbe, 2015). The sustainability of fuel supply is critical in ensuring a country's energy security, the location of environmentally sensitive commercial and service activities in rural or urban areas needs to be guided by standards enforced by government and non-governmental organizations (Tah, 2017; Xiaoguang et al., 2015).

In Ghana, the permit required to operate petroleum hubs and oil retail assets is usually obtained from the Ministry of Energy, Environmental Protection Agency (EPA), Town and Country Planning Department (Peprah et al., 2018). However, some operators fail to get permits from these agencies before launching commercial initiatives, possibly to avoid paying the needed costs. According to literature, there have been multiple reported occurrences of wildfires and explosions related with filling stations in Ghana, resulting in countless deaths and millions of dollars in annual losses (Addai et al., 2016; Norman et al., 2015). In most urban areas in Ghana, poor planning and disregard for planning norms have resulted in illegal land use and slum development, as well as the placement of oil and gas assets in hazardous regions (Kusimi and Appati, 2012).

Because everyone is concerned about their health, safety, and protection, there is a need to conduct a site appropriateness assessment before doing these activities in the spatial context of the research area. Site suitability assessments encompass both qualitative and quantitative evaluations. Qualitative assessments involve the consideration of factors such as climate, drainage, topography, vegetation, geology, and soil properties. In contrast, quantitative evaluations provide more detailed and statistically estimated results. (Mosleh et al., 2017). Geographic Information Systems (GIS) have proven to be highly valuable in addressing geospatially connected issues that encompass both qualitative and quantitative data (Guler and Yomralioglu, 2017; Njoku and Alagbe, 2015). (Boolean logic, Weighted Linear Combination (WLC), Weighted Overlay (WO), Storie and Square root, Multiple Linear Regression models, Multivariate statistics) and other parametric methods are among the traditional methods frequently employed in site appropriateness (Ghanbarie et al., 2016; Mugiyo et al., 2021).

Except for the WLC and qualitative approaches, category data is limited in most traditional methodologies (Mugiyo et al., 2021). The fluctuation in the geo-environmental parameters can affect the accuracy of the site suitability maps in the traditional approach, which ignores the continuous nature of site occurrence, resulting in site misclassification, discrete and sharply defined boundaries. Furthermore, the usual approach is time-consuming and expensive (Behrens and Scholten, 2006; Taghizadeh et al., 2020). Also, numerous studies have employed spatial layers and decision-making algorithms to determine site suitability.

These techniques include; the Analytical Hierarchy Process (AHP), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), and Weighted Overlay Analysis (Rahman et al.2021; Peprah et al., 2018; Jozaghi et al., 2018). Modern approaches such as machine learning (ML) based methods; (Random Forest(RF), Artificial Neural Networks (ANN), Logistic Regression (LR), Naïve Bayes classifier, Support Vector Machines(SVM)) and multi-criteria decision methods (MCDM) such as (Analytical Hierarchy Process (AHP), Elimination and Choice Expressing Reality (ELECTRE), Grey Relational Analysis (GRA) and Vlsekriterijumsko Kompromisno Rangiranje (VIKOR)) are gaining ground on traditional ways (Danvi et al., 2016; Mugiyo et al., 2021). In a study conducted by Taghizadeh et al. in 2020 on land suitability assessment for sustainable agricultural production, machine learning-based methods, specifically Random Forest (RF) and Support Vector Machine (SVM), outperformed traditional parametric land suitability maps. The ML-based maps demonstrated significantly higher Kappa index scores and overall accuracy, with values of 0.77 and 0.79 for RF and 0.69 and 0.73 for SVM, compared to the values of 0.45 and 0.50 for traditional parametric maps. This highlights the superior performance of ML-based approaches in land suitability assessment.

Based on the kappa index's specified class limitations; it was concluded that modern based methods for site suitability assessment have stronger levels of accuracy compared to traditional suitability assessment methods. Multi-criteria Decision Methods (MCDM) and Geographic Information Systems (GIS) are extremely important tools for solving spatial problems from the evaluation of decision variables (Peprah et al., 2018). When more than one MCDM approach (Fuzzy AHP and VIKOR) are used to construct a merged evaluation system in site suitability assessment, approximations of unclear, partial, and uncertain information observed in separate decision making methods are possible (Fazlollahtabar et al., 2009). Furthermore, rather than being discrete as in the classic Boolean approach, site suitability will be defined as continuous classes (Mugiyo et al., 2021).

The merging of fuzzy AHP with the VIKOR approach for site suitability analysis is an attempt to fill a gap in this regard. While both strategies have been employed alone, they must be combined to overcome the limits of each. A detailed assessment can be achieved from the merging of these methodologies, especially when data is partial or uncertain (Kumi-Boateng et al., 2020). GIS and MCDM procedures can give better appropriateness analysis than independent parametric approaches because they can accept attribute values and features near category boundaries based on their respective importance to get the optimal selection (Broekhuizen et al., 2015; Kihoro et al., 2013). Furthermore, MCDM may judge both qualitative and quantitative criteria (Boroushaki and Malczewski, 2008). Furthermore, it is straightforward to grasp, simple to apply and adapt, and appropriate for problems with a hierarchical framework (Aslani and Alesheikh, 2011). GIS and MCDM has been applied in solving majority of problems in geo-scientific disciplines. Oil and gas station placement (Aslani and Alesheikh, 2011; Njoku and Alagbe, 2015; Tah, 2017), and forest risk mapping (Akay and Erdogan, 2017) are two examples. Selection of optimal rice-growing sites (Kihoro et al., 2013), landfill site selection (Guler and Yomralioglu, 2017), and planning of forest product primer transportation (Akay and Yilmaz, 2017).

Because numerous choice variables can be evaluated and weighted, multi-criteria decision methods (MCDM) and geographic information systems (GIS) are extremely effective tools for solving problems in a spatial context. Hence, MCDM and GIS techniques were adopted in the present study. The study aims to employ a hybrid approach of an MCDM technique comprising of Fuzzy AHP and VIKOR to investigate whether the newly proposed land for the development of the Ghana petroleum hub falls within a suitable area as well as provide locations of viable zones for future establishment of petroleum hubs and oil retail assets in the district.

Also, the study is to determine whether the oil and gas operators in Jomoro district adhere to the requirements established by Ghana's Ministry of Energy and Town and Country Planning Department for validation purposes. In addition, assess the spatial distribution pattern of current oil retail assets. This study will assist authorities in taking the right actions on existing filling stations that have not met the requirements set by Ghana's Ministry of Energy and Environmental Protection Agency (EPA). It will make it easier for the Town and Country Planning Department to verify and execute siting regulations for those yet to be built. Furthermore, due to limited literature on the subject, It will thus serve as a reference for future study and decision making for individuals, and all petroleum stakeholders (Njoku and Alagbe, 2015).

2. Study area

The research area is situated in Ghana's Western Region, encompassing latitudes 04° 80' N to 05° 21' N and longitudes 02° 35' W to 03° 07' W, as outlined by Andoh and Offei-Addo in 2014. The district's capital city is Half Assini. It shares its borders with Wassa-Amenfi and Aowin-Suaman to the north, Nzema East District to the east, La Côte D'Ivoire to the west, and the Gulf of Guinea to the south.

The district spans a total land area of 1,495 square kilometers, accounting for approximately 5.6 percent of the entire area of Ghana's Western Region (Ghana districts, 2013). The District's south-central region has rolling granite topography with several steep-sided tiny round hills reaching from 200 to 600 meters (Andoh and Offei-Addo, 2014). The relief is lower along the shore, with flat highland parts and plunging lowlands. There are formations of highland ridges running northwest to southeast from Tano to Bonyere and finishing on its northern side in the Nawulley scarp (Andoh and Offei-Addo, 2014).

The district can be categorized into five distinct geological formations: Lower Birimian, Upper Birimian, Granite Tertiary Sands, and Coastal Sands. The Lower Birimian is primarily composed of phyllites with injected quartz veins, while the Upper Birimian is characterized by volcanic rocks with limited amounts of phyllites. Notably, there are substantial deposits of limestone in Nawulley and significant reserves of Kaolin in areas like Bawia, Nvellenu, and Tikobo No. 2. Of significant economic importance is the discovery and development of oil and gas in the Tano Basin off the coast of Jomoro (Ackah et al. in 2018).

The current vegetation includes a forest reserve in Ankasa, which is recognized for its dense forest cover. The district also features designated fallow lands, tree crop areas, and farms or plantations (Damnyag et al. 2013). Additionally, there are extensive sections of swampy woodlands that are less utilized for farming due to their consistently wet conditions throughout the year.

Regarding climate, the district experiences substantial rainfall, occurring in two distinct wet seasons, coupled with consistently high temperatures. The climate is described as Equatorial Monsoon, with rains caused by low pressure zones over the Sahara that attract winds from the south of the Equator (Jomoro District Assembly, 2010). The monthly mean recorded temperature is 26 degrees Celsius. Relative humidity is also very high across the district, reaching 90% at night and falling to 75% as the temperature increases in the afternoon. The map in Figure 1 depicts the Jomoro district.

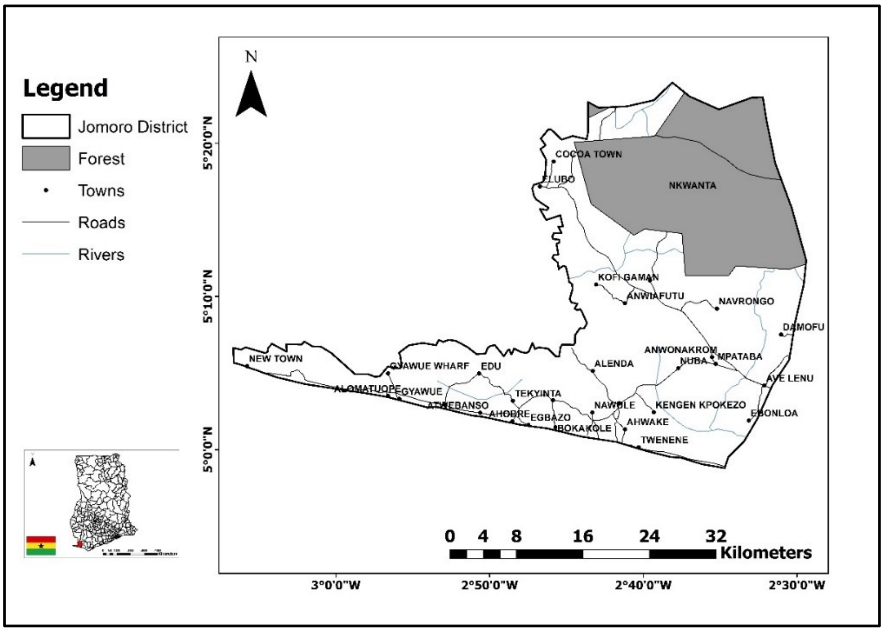

Figure 1. Map of the Study area

3. Resources and Approach

3.1 Resources

The study's input set includes both primary and secondary sources. The existing locations (Garmin Handheld GPS) of the filling stations formed the primary set, while the secondary set (topographic maps containing features such as contours, vegetation, roads, soil types, and water bodies) obtained from the Land Commission of Ghana's Survey and Mapping Division, Geological and Mineral Department of Ghana. The earth explorer website (https://earthexplorer.usgs.gov) was used to download the land use and land cover data (LULC). These characteristics were utilized as spatial criteria for determining site suitability. Table 1 shows a list of the data that was used and its repository. Table 2 depicts a selected set of the existing filling stations.

3.2 Methods

3.2.1 Field data collection

A preliminary inspection was conducted to investigate the area around the stations and to establish the best procedures to use for the survey. The government proposed land for the establishment of the petroleum hub in the study area was surveyed using static Trimble GPS. This was to determine its boundary location and area. Garmin Handheld GPS receivers were used to map the positions of the filling stations in the study region. Geographic features in each station's immediate vicinity were measured and documented. Green areas proximities, pump station to road proximity, filling stations perimeters, neighbouring stations proximities, and proximities of public facilities were all measured.

Table 1. Inputs and Repository

Inputs Used	Repository
1.Land Use and Land Cover (LULC)	https://earthexplorer.usgs.gov.
2.Geological and Soil data	Geological and Mineral Department of Ghana
3.Digital Elevation Model (DEM)	https://lpdaac.usgs.gov/product/astgtmv003/
4.Linear features (roads, rivers)	Survey and Mapping Division of Ghana

Table 2. A sample location of the fueling stations (meter units)

ID	Eastings (m)	Northings (m)	Fueling stations	Locations
1	550407	561170	JD station	Ave lenu
2	535141	559235	Petrol station	Tikobo No.1
3	528029	583824	Shell	Elubo
4	526481	584544	Blanko oil	Elubo
5	525863	584441	Pacific	Elubo
6	525246	584503	Total	Elubo
7	531073	556334	APCO	Nawule
8	513398	558178	Goil	Half Assini

3.2.2 Proximity analysis

In the ArcGIS environment, buffer assessments of fuel pump length to road, gap between neighboring stations, and distance between stations to any state facilities were performed. This was done to ensure that the stations met the standards stipulated by the Ministry of Energy and the Town and Country Planning Department. Filling stations that fell beyond the prescribed buffer limits met the standards and will offer less of a risk to the environment, but those that fell inside the defined buffer are projected to cause environmental risk, particularly in settlement areas (Njoku and Alagbe, 2015). The set guide for the pump stations and roadways gap is at least 100 m, so a buffer of 100 m was utilized in the ArcGIS environment. Generated buffers for the gap between filling stations, state facilities and water was at least (500 m to 1000 m) to assess the level of compliance (Peprah et al., 2018). Buffer analyses were also performed to check whether the proposed petroleum hub complied to the set standards necessary for its establishment. A distance-based analysis was performed to evaluate the spatial link between the filling stations and their neighboring characteristics. It also allowed spatial features that met the stated criteria to be categorized depending on distance (Aslani and Alesheikh, 2011; Peprah et al., 2018; Tah, 2017). Table 3 shows the criteria for selecting appropriateness.

3.2.3 Model generation

The approach employed in this study involves a weighted overlay of six thematic layers, which were derived from both the Survey and Mapping division and remotely sensed data. The resolution of these scores was achieved through the use of Fuzzy Analytic Hierarchy Process (AHP) and VIKOR methods. Initially, Fuzzy AHP was used to estimate the weights, and subsequently, the final weights were derived from the VIKOR method. Each parameter was ranked based on its relative importance, determined through the compromise solution offered by the VIKOR method. The Suitability and Proximity model was executed within the ArcGIS environment, following (Equation 1) as defined in Peprah et al. (2018). Figure 2 provides a visual representation of the methodology, illustrating the steps taken to generate suitability zones and validate the data.

$$S = \sum_{i=1}^{n} W_i C_i \prod_{j=1}^{n} p_j \qquad (1)$$

where; S = Suitability sites for oil and gas establishments; W_i = variable scores; C_i = Criteria cost; p_j = proximity.

Table 3. Proximity standards for suitability assessment (Peprah et al., 2018)

Restriction source	Min. buffer (m)/degree	Max. buffer (m)/degree	Analysis buffer(m)/ degree
Slope	0⁰	20⁰	≤ 20⁰
Built up areas	500m	1000m	500m
Roads	100m	500m	100m
Surface water	100m	500m	100m

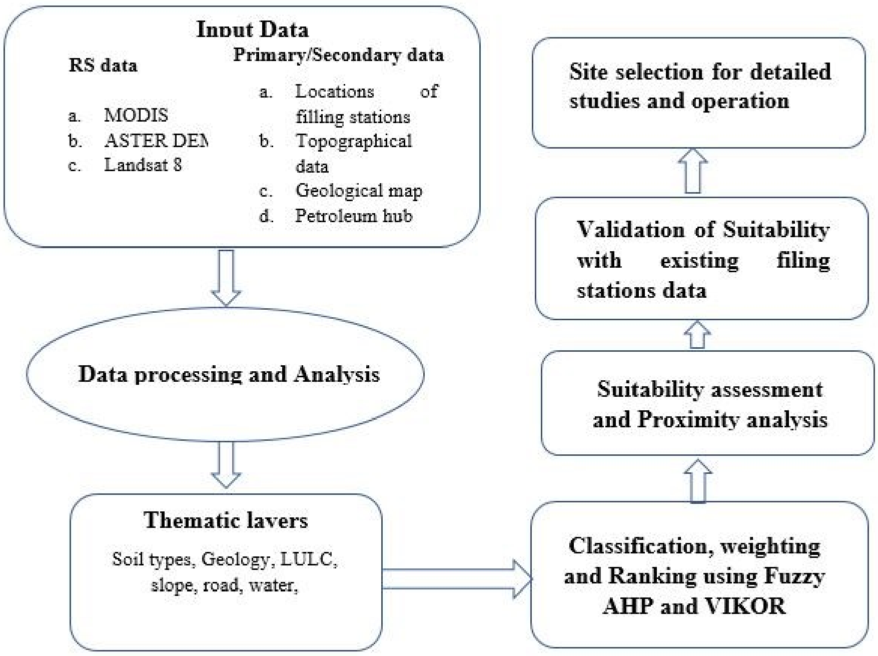

Figure 2. Flow Chart of Methods

3.2.4 Fuzzy AHP (FAHP)

The initial weights for variables were determined using Fuzzy AHP to address uncertainties and variations in judgment scales, which are common in traditional AHP. (Fazlollahtabar et al., 2009; Kumi-Boateng et al., 2020). Fuzzy AHP's computational complexity grows as the number of possibilities increases, influencing large-scale decision-making problems (Fazlollahtabar et al., 2009). The fuzzy members are represented as follows: $\tilde{q}_i = (e_{ij}, f_{ij}, g_{ij})$ and in geometric space as shown in Figure 3 (Firoozi et al., 2017). Equation (2) represents the fuzzy judgment matrix, which was created using feedback from respondents and experts (Kim et al., 2019):

$$\begin{bmatrix} (1,1,1) & (e_{12}, f_{12}, g_{12}) & \cdots & (e_{1n}, f_{1n}, g_{1n}) \\ (e_{21}, f_{21}, g_{21}) & (1,1,1) & \cdots & (e_{2n}, f_{2n}, g_{2n}) \\ (e_{n1}, f_{n1}, g_{n1}) & (e_{n2}, f_{n2}, g_{n2}) & \cdots & (1,1,1) \end{bmatrix} \quad (2)$$

Equation (3) is used to get the row geometric mean. (Kumi-Boateng et al., 2020):

$$\tilde{\sigma}_i = \left(\prod_{j-1}^{n} \tilde{q}_{ij}\right)^{\frac{1}{n}} \quad (3)$$

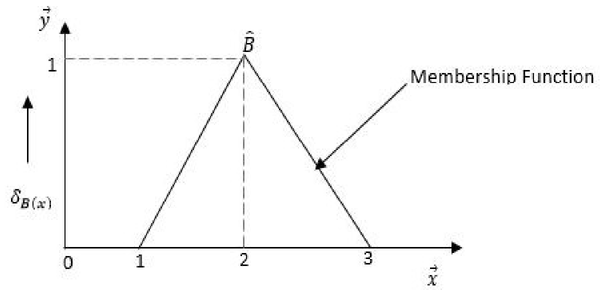

Figure 3. Triangular fuzzy membership

where; $\tilde{\sigma}_i$ = Geometric mean values, $\tilde{q}_{ij}$ = Triangular Fuzzy set, n = criteria number. The Fuzzy Geometric Mean is computed by adding the Geometric Means of each criterion as defined in Equation (4):

$$\sum_{i=1}^{n} \tilde{\sigma} i = \tilde{\sigma} 1 + \tilde{\sigma} 2 + \tilde{\sigma} 3 \cdots \tilde{\sigma} n \quad (4)$$

Normalization yields the Fuzzy weights as shown in Equation (5).:

$$\tilde{r}_{ij} = \tilde{w}_{ij} = \frac{\tilde{\sigma} i}{\sum_{i=1}^{n} \tilde{\sigma} i} \quad (5)$$

where; $\tilde{r}_{ij}$ = secondary variable normalized weights (option i weighted more than criterion j), $\tilde{w}_{ij}$ = main variable score. The final scores $\tilde{U}_i$ are thus determined using Eqn (6), which is represented as:

$$\tilde{U}_i = \sum_{i=1}^{n} \tilde{w}_{ij} \tilde{r}_{ij} \quad (6)$$

3.2.5 VIKOR

The final scores of the specified variable were generated using the VIKOR method, a well-known MCDM technique. The essence is to emphasize the ranking of alternatives sets of the conflicting criteria (Mardani et al., 2016). The VIKOR method may not be appropriate for complex problems with non-linear relationship (Rostami et al., 2010). First, the decision matrix between the criteria and alternatives is constructed using the AHP technique and the linguistic term in Table 4 given by Equation (7) (Abdullah, 2021; Akay and Erdogan, 2017).:

$$C^D = \begin{bmatrix} C_{11}^D & \cdots & C_{1y}^D \\ \vdots & \ddots & \vdots \\ C_{m1}^D & \cdots & C_{my}^D \end{bmatrix} \text{m=1,2,3…n;y=1,2,3…x} \quad (7)$$

Resolve the best and worst solution from the beneficial and non-beneficial variable as given by Equation (8) and Equation (9) respectively (Peleckis, 2022):

Best solution: $C_m^+ = (C_{my})\max$ for beneficial criteria, $C_m^+ = (C_{my})\min$ for non-beneficial criteria; (8)

Worst solution: $C_m^- = (C_{my})\min$ for beneficial criteria, $C_m^- = (C_{my})\max$ for non-beneficial criteria (9)

The utility S_i and regret measure R_i is calculated from Equation (10) and Equation (11) respectively (Mardani et al., 2016):

$$S_i = \sum_{y=1}^{x} \left[w_y \frac{(c_m^+ - c_{my})}{(c_m^+ - c_m^-)} \right] \quad (10)$$

$$R_i = \max_y \left[w_y \frac{(c_m^+ - c_{my})}{(c_m^+ - c_m^-)} \right] \quad (11)$$

The value of Q_i is calculated as shown in Equation(12) (Abdullah, 2021):

$$Q_i = \left[v \frac{(s_i - s^-)}{(s^+ - s^-)} \right] + \left[(1-v) \frac{(R_i - R^-)}{(R^+ - R^-)} \right] \quad (12)$$

where; $s^- = \max s_i; R^- = \max R_i (\max\ value)$; $s^+ = \min s_i; R^+ = \min R_i (\min\ value)$; $(1-v)$ is the weight of the separate remorse, $0 \le v \le 1$

The criteria's are ranked in ascending order of Q_i based on the conditions in Equation (13) (Mardani et al., 2016);

$$\begin{cases} (Q(A_2) - Q(A_1) \ge \left(\frac{1}{(n-1)}\right) \\ (Q(A_m) - Q(A_1) < \left(\frac{1}{(n-1)}\right) \end{cases} \quad (13)$$

3.2.4 Cost criteria and Buffer Analysis

The Cost friction surface is a grid-cell-based pixel dataset established using predefined criteria. Multiple thematic maps were formed in the ArcGIS environment, utilizing these cost criteria to facilitate the identification of suitable locations. Its feasibility is contingent on various factors such as; slope, road, geological structures, soil types and rivers (Kumi-Boateng et al., 2020). For a more reliable suitability assessment, the interdependent nature of these factors needs to be considered. Six (6) main cost variables (geology, soil type, water, road, slope, land use and land cover (LULC)) were employed for the assessment. Buffer distance analysis was performed on the research area's drainage features (rivers), built-up areas, and paved surfaces (roads). This was done to establish the appropriate distance to build oil and gas structures near rivers, roadways, and settlement areas in order to avoid fires and contamination from surface runoffs. This process was undertaken to measure the level of adherence to the regulations set forth by the Ministry of Town and Country Planning, the Ministry of Energy, the Environmental Protection Agency (EPA), and the Ministry of Lands and Administration. A 100-meter analytical buffer was applied to rivers and roadways, while a 500-meter buffer zone was utilized for built-up areas. Figure 3 depicts the criteria's suitability model, while Figure 4 depicts the linear and built-up regions' proximity models.

Road buffer

The road closeness distance was measured across a 100-meter radius. This is significant since roads are a crucial factor in site appropriateness selection when accessibility is necessary. The Ghana Lands Commission's Survey and Mapping Division provided the road network. The network of roads is relevant in the transportation of oil and gas products from their production centres to their destination areas. Figure 5 represents the road proximity analysis applied in the studies.

Geology and Soil types

Geology and soil types of the area were considered and evaluated to see whether their physical and chemical properties will be suitable for siting of the petroleum infrastructure. Certain geological structures and soil types contain metallic constituents that form impurities in fuels. Furthermore, some soil types and their technical features are unsuitable for construction, which is a limitation because most filling stations have their oil reservoir in deep excavations (Peprah et al., 2018). The geology and soil data came from Ghana's Geological and Mineral Department. Figures 6 and 7 depict data on geology and soil types, respectively.

Slope

Slope is a key element in suitable site selection for petroleum hubs in decision making process. Areas of mild slopes are very suitable as compared to areas of steep slopes. This factor was considered because places of higher relief are not suitable for siting petroleum hubs due to stability and high fire risk reasons (Akay and Erdogan, 2017). The slope was formed using Aster DEM data obtained from the USGS archives (http://lpdaac.usgs.gov/products/astgtmv003/). The data has a resolution of 30 x 30 meters. Figure 8 depicts the slope of the research area.

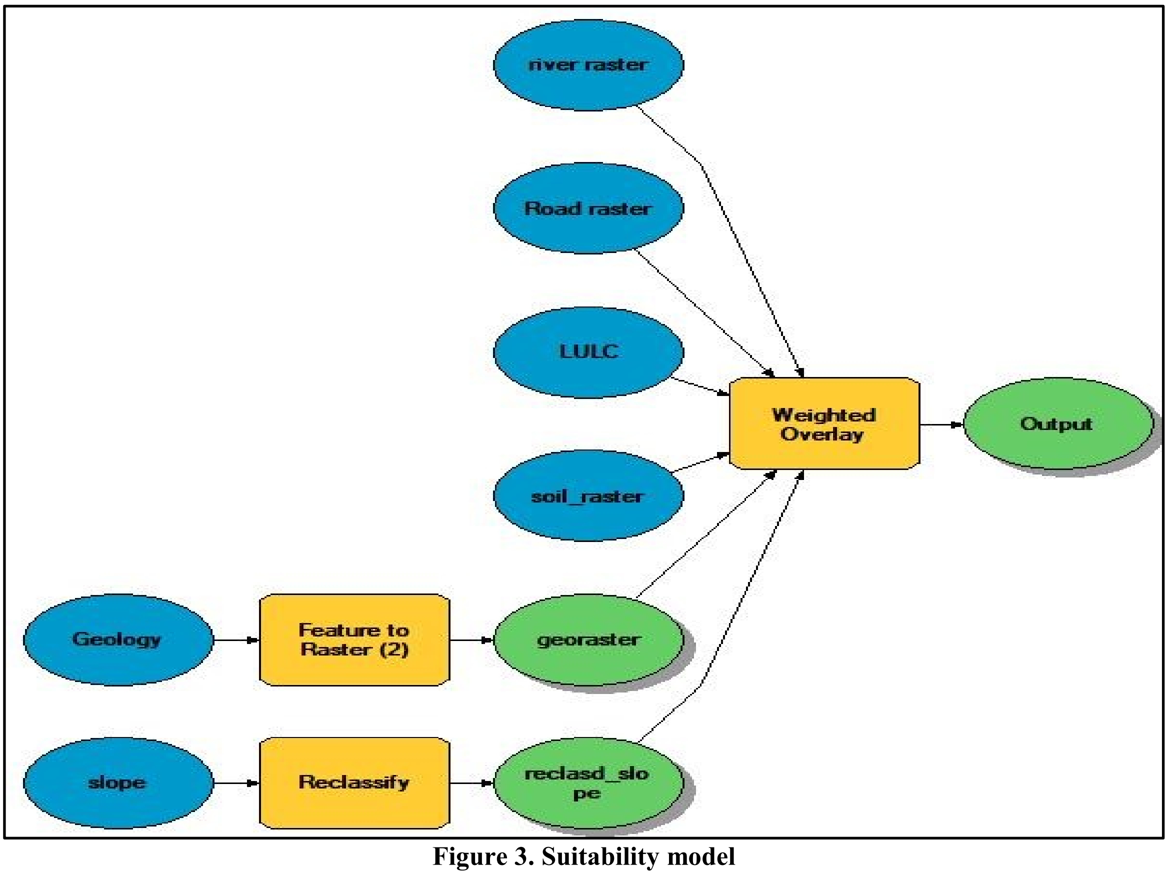

Figure 3. Suitability model

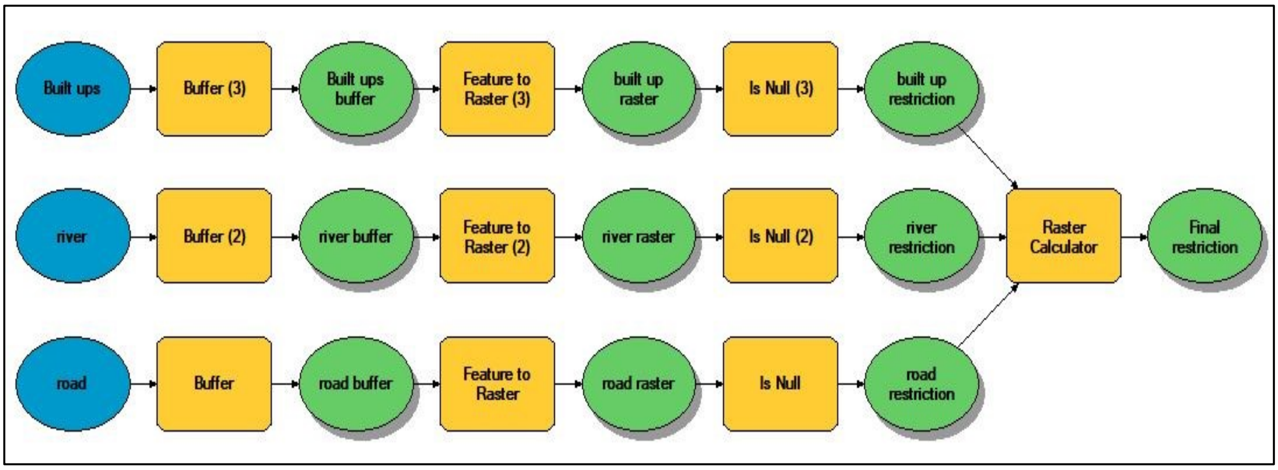

Figure 4: Restriction model

LULC

A very significant criterion to evaluate because it considers human safety, health, and settlement in the decision-making process. The land use and land cover was grouped into five (5) classes namely; dense forest, cropland, built/urban areas, barren/sparsely vegetated and water. The LULC data was gathered from MODIS satellite photography and identified using the IGBP classification scheme, which may be found at https://earthexplorer.usgs.gov. Figure 9 depicts land use and land cover data.

River buffer

Water bodies are indispensable factors to be considered in suitable site assessment. A buffer distance of 100m was established for the rivers in order to manage or avoid surface runoffs from petroleum hubs and filling stations into the water bodies in the event of rain. The river data were gathered from the Ghana Lands Commission's Survey and Mapping Division. The river proximity analysis used in the studies is depicted in Figure 10.

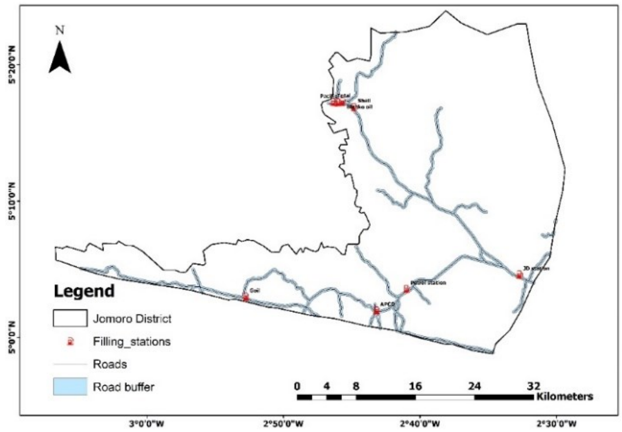

Figure 5. Road proximity analysis

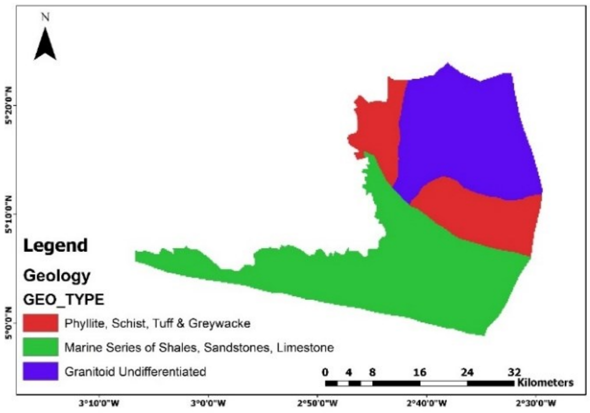

Figure 6. Geology map

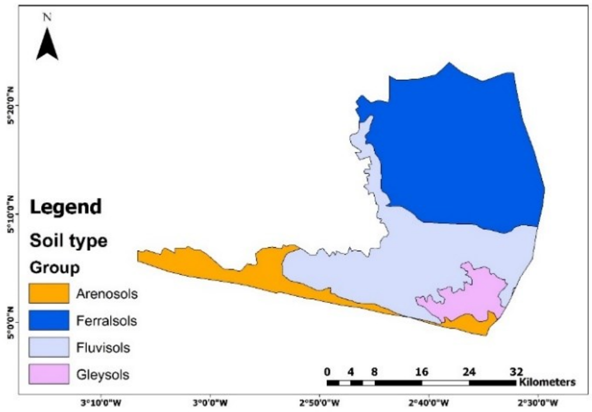

Figure 7. Soil type

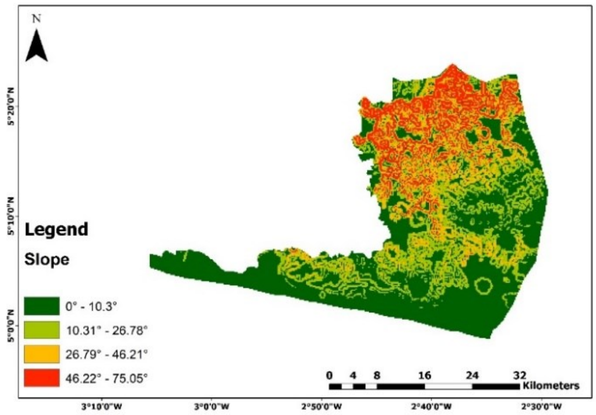

Figure 8. Slope map

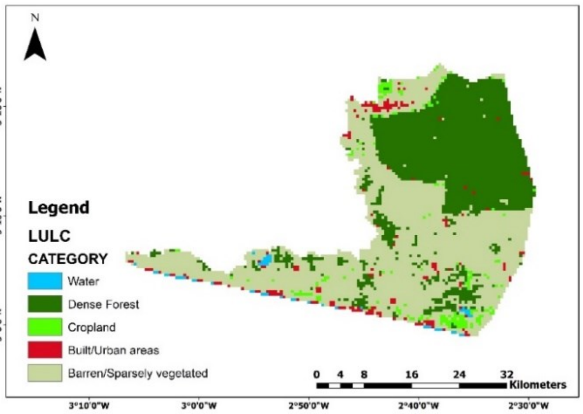

Figure 9. Land use Land cover (LULC)

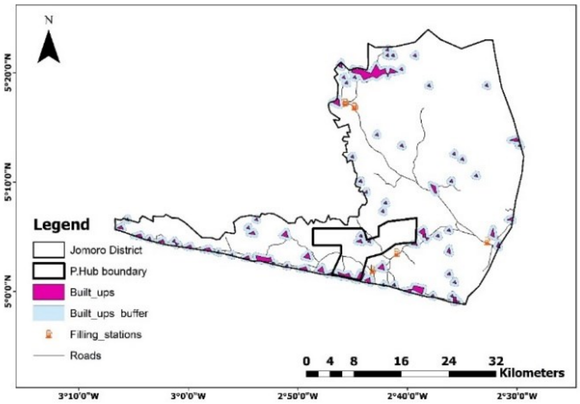

Figure 10. Built ups buffer

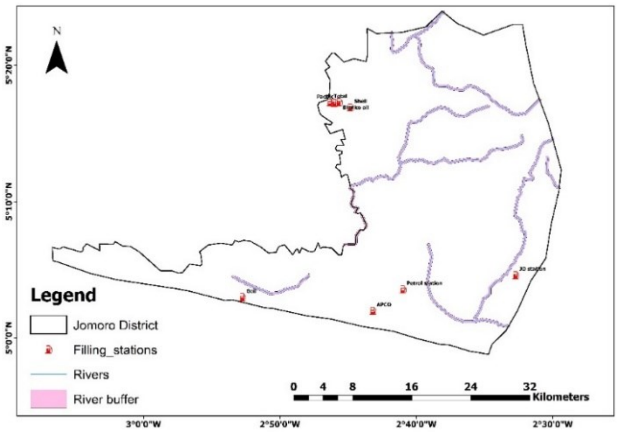

Figure 11. River proximity analysis

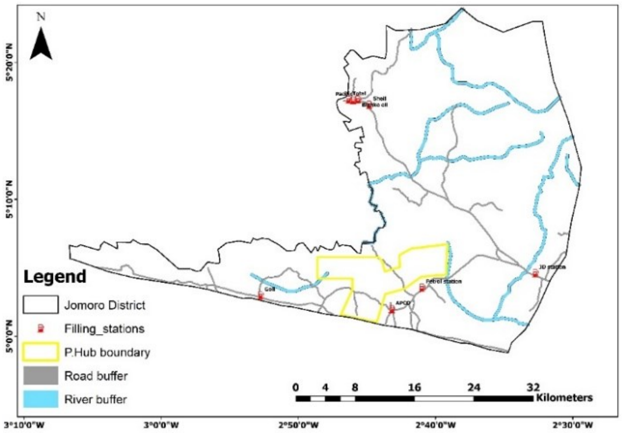

Figure 12. Proximity analysis for petroleum hub

Index Value Scoring

Index value scoring can be used to assess the relative importance of several options based on their weights. The susceptibility of observed values to ground water infiltration can also be scored and graded (Sharma et al., 2012). The Index score was computed using the scoring overlay tool within the ArcGIS environment. Table 4 displays the rating scores used for the different classes, and Table 5 presents the thematic layer categories.

4 Results and Discussions

The paper aims to perform a site suitability assessment prior to the establishment of a petroleum hub at the Jomoro district of Ghana as well as assess the suitability of the existing oil retail assets by integrating Fuzzy AHP, VIKOR, proximity analysis and remote sensing techniques in the GIS environment. The weights, selection criteria, and restriction model from Equation 1 comprise the Suitability model. Figure 2 depicts the methodological flow chart used in the research process. According to Equation 2, the initial weights were created using Fuzzy AHP from the fuzzy judgment matrix. This approach was adopted to mitigate the uncertainties and unequal judgment scales encountered in the traditional AHP, as defined in Equation 2. The decision matrix utilized in the research, as shown in Table 6, was derived from pairwise comparisons using the AHP method, ensuring a valid consistency ratio of 0. 09. This was done to eliminate any subjectivity in the cost criteria analysis. The VIKOR method was applied to determine the ultimate weights and rankings of the cost factors, taking into account the conditions set by the compromise solution as defined by Equation 12 and 13.

Table 4. Index Value Scoring (Source :(Sharma et al., 2012))

Index Score	Representation
1	Very Low
2	Low
3	Moderate
4	Moderate High
5	High
6	Very High

Table 5. Classification of Thematic layers

Variables	Classes	Rating	Representation
Roads (R_d)	1	3	Moderate
Land use and Land cover (L_u)	Cropland	3	Moderate
	Dense forest	1	Very Low
	Built/Urban areas	2	Low
	Barren/sparsely vegetated	5	High
	Water	1	Very Low
Rivers(R_i)	1	1	Very Low
Geology (G_e)	Granitoid undifferentiated	2	Low
	Marine series of shales, sandstone, limestone	1	Very Low
	Phyllite, schist, tuff, greywacke	1	Very Low
Slope (S_l)	0°- 10.3°	6	Very High
	10.31°- 26.78°	4	Moderate High
	26.79°- 46.21°	3	Moderate
	46.22°-75.05°	1	Very Low
Soil type (S_t)	Ferrasols	2	Low
	Fluvisols	4	Moderate High
	Arenosols	3	Moderate
	Gleysols	1	Very Low

The study' cost criteria include remotely sensed data, primary and secondary data received from Ghana's Survey and Mapping Division, and field data collecting. ArcGIS 10.4 software was employed to produce all the maps of the weighted alternatives. The cost criterion used in the studies include remotely sensed data as well as secondary data gathered from Ghana's Survey and Mapping Division. ArcGIS 10.4 software was used to create all maps of the weighted alternatives.

$$\begin{bmatrix} (n) & S_l & L_u & G_e & R_d & R_i & S_t \\ S_l & (1,1,1) & (1,1,1) & (1,1,1) & (1,1,1) & (1,1,1) & (1,2,3) \\ L_u & (1,1,1) & (1,1,1) & (1,1,1) & (1,2,3) & \left(\frac{1}{3},\frac{1}{2},1\right) & (1,1,1) \\ G_e & (1,1,1) & (1,2,3) & (1,1,1) & (1,2,3) & \left(\frac{1}{3},\frac{1}{2},1\right) & (1,1,1) \\ R_d & (1,1,1) & (1,1,1) & \left(\frac{1}{3},\frac{1}{2},1\right) & (1,1,1) & \left(\frac{1}{3},\frac{1}{2},1\right) & (1,1,1) \\ R_i & (1,1,1) & (1,2,3) & (1,2,3) & (1,2,3) & (1,1,1) & (1,2,3) \\ S_t & \left(\frac{1}{3},\frac{1}{2},1\right) & (1,1,1) & (1,1,1) & (1,1,1) & \left(\frac{1}{3},\frac{1}{2},1\right) & (1,2,3) \end{bmatrix} \begin{bmatrix} (n) & U & M & L & W_y \\ S_l & 1.000 & 1.122 & 1.201 & 0.181 \\ L_u & 0.833 & 1.000 & 1.201 & 0.167 \\ G_e & 0.833 & 0.891 & 1.000 & 0.149 \\ R_d & 0.833 & 0.891 & 1.000 & 0.149 \\ R_i & 1.000 & 1.587 & 2.080 & 0.262 \\ S_t & 0.693 & 0.794 & 1.000 & 0.137 \end{bmatrix}$$

where; n = criteria; U=Upper Values; M = Middle values; L= Lower values

Table 6. Decision matrix

criteria(n)	slope	LULC	geology	road	water	soil type
slope	1.0000	1.0000	1.0000	1.0000	1.0000	2.0000
LULC	1.0000	1.0000	1.0000	2.0000	0.5000	1.0000
geology	1.0000	2.0000	1.0000	2.0000	0.5000	1.0000
road	1.0000	1.0000	0.5000	1.0000	0.5000	1.0000
water	1.0000	2.0000	2.0000	2.0000	1.0000	2.0000
soil type	0.5000	1.0000	1.0000	1.0000	0.5000	1.0000
best	*0.5000*	*2.0000*	*2.0000*	*2.0000*	*0.5000*	*2.0000*
worst	*1.0000*	*1.0000*	*0.5000*	*1.0000*	*1.0000*	*1.0000*

Table 7. Calculation of unity measure, Si

criteria(n)	slope	LULC	geology	road	water	soil type	Si
slope	0.17	0.14	0.106667	0.15	0.25	0	0.8166667
LULC	0.17	0.14	0.106667	0	0	0.13	0.5466667
geology	0.17	0	0.106667	0	0	0.13	0.4066667
road	0.17	0.14	0.16	0.15	0	0.13	0.75
water	0.17	0	0	0	0.25	0	0.42
soil type	0	0.14	0.106667	0.15	0	0.13	0.5266667

Table 8. Compromise solution, ranking and weighting

Si	Ri	Qi	Rank	W_y (%)
0.81667	0.25	1	6	39
0.54667	0.17	0.27073	3 A(m)	11
0.40667	0.17	0.1	1 A(1)	4
0.75	0.17	0.51869	5	20
0.42	0.25	0.51626	4	20
0.52667	0.15	0.14634	2	6
$S_{min;}$ *(0.4067)*	$R_{min;}$ *(0.15)*	*2.552*		
$S_{max;}$ *(0.8167)*	$R_{max;}$ *(0.25)*			

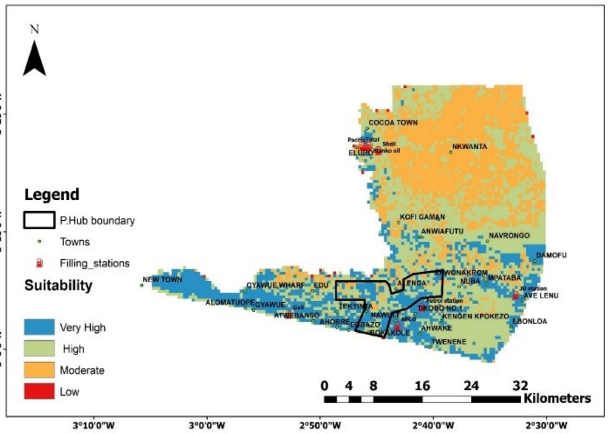

Figure 13. Suitability map

Table 9. Distance to neighbouring stations

From	To	Linear distance (km)
JD station	Petrol station	15.39
Petrol station	APCO	4.99
APCO	Goil	17.77
Total	Pacific	0.62
Pacific	Blanko oil	0.63
Blanko oil	shell	1.71

Table 10. Area and percentage coverage (Suitability)

Description	Area (Km^2)	Coverage (%)
Very High	300.521	22.90
High	584.513	44.54
Moderate	424.200	32.33
Low	3.010	0.23

The fuzzy judgment matrix is represented by Equation 2, and the Geometric mean is calculated using Equation 3. A triangular fuzzy membership function, illustrated in Figure 3, was used to define the fuzzy set, as outlined in Equation 4. The initial fuzzified weights are thus obtained from Equation 5. The VIKOR method was used for the final ranking of the alternative set. The essence is to emphasize the ranking of alternatives sets of the conflicting criteria (Mardani et al., 2016). The decision matrix utilized in the VIKOR method is specified by Equation 7 and Table 6. The best and worst solution (Equation 8 and Equation 9) is factored from the beneficial and non-beneficial criteria as shown in Table 6. The unity measure is computed using Equation 10, as shown in Table 7. The regret measure is determined through Equation 11. The values of Qi were derived from the results of the utility and regret measures, as presented in Table 7. The values of Qi are calculated as given in Equation 12. The criteria are then sorted in ascending order based on the Qi values shown in Table 8. In VIKOR, a compromised solution is proposed according to Equation 13. This is to satisfy two conditions an acceptable advantage and an acceptable stability in decision making. These conditions needs to be satisfied for the method to be valid. Six (6) main cost factors namely;

water, road, geology, slope, soil types, land use and land cover (LULC) were selected and used for mapping the suitability sites. Buffer distance analysis was performed on the research area's drainage features (rivers), built-up areas, and paved surfaces (roads). This was done to establish the appropriate distance to build oil and gas structures near rivers, roadways, and settlement areas in order to avoid fires and contamination from surface runoffs. This process was carried out to assess compliance with regulations set by the Town and Country Planning, Ministry of Energy, Environmental Protection Agency (EPA), and Ministry of Lands and Administration. The suitability and restriction models are depicted in Figure 3 and 4, respectively. Figure 6 depicts the geological nature of the research area. Figure 7 depicts the soil map of the study area, which is divided into four (4) classes: fluvisols, ferrasols, gleysols, and arenosols. The slope analysis is given by Figure 8. Areas of mild slopes are very suitable as compared to areas of steep slopes. Previous studies show areas with steep slopes have a high risk of fire spread compared to areas with gentle slopes. The land use and land cover was grouped into five (5) classes namely; dense forest, cropland, built/urban areas, barren/sparsely vegetated and water as shown in Figure 9. The classification of the various thematic layers and index scores are tabulated in Table 5. Figures 5, 10, 11 and 12 shows the proximity analysis carried out in the study area. Figure 5 represents road proximity analysis which is the distance of the pump station to the roads. All oil retail assets were found sited along the major highway. All stations fell outside the 100m buffer zone implying stations complied to the set standards by the Ministry of Energy with regard to roads. APCO filling station recorded 129m distance to the road which is the closest station to the road whiles JD station recorded the farthest distance of about 329m. The river buffer analysis is demonstrated in Figure 11. In the analysis, it was observed all available stations were sited away from the 100m set standard away from existing water bodies. Goil station had the closest proximity of 1 865m to the rivers whereas Total station had the farthest distance from the nearest water body available which was 11 195.154m. The set standard was to guard oil spillage and water pollution in the event of flooding. The analysis for the built up areas were carried out as seen in Figure 10. Two (2) of the oil and gas stations defaulted in the 500m buffer analysis, forming 25% of the available oil and gas stations. Total and Goil station recorded a distance of 314.29m and 60.33m respectively from the built up areas. Table 7 elaborates on the distance between the neighbouring stations. The minimum set distance between the neighbouring stations should be at least 400m. All stations complied with the standard. Total and Pacific recorded the least distance of 620m whereas Goil and APCO recorded the largest distance of 17 770m (Table 9). The proposed land for the development of the petroleum hub had an area of 20 513.83 acres (84.25km^2). Figure 12 shows the proximity analysis performed on the siting of the petroleum hub. The closest proximity of the existing stations to the hub was 1937.39m and 1475.86m occupied by Petrol station and APCO station respectively. The boundary of the hub went through as well as enclosed few built up areas as observed in Figure 12. The hub comprises of a network of roads running through the proposed land. An 11.5 km river stretch extended 1km of its length into the hub. The Suitability analysis of the map is represented in Figure 13. The suitability map was formed from the suitability and restriction model as depicted in Figure 3 and 4 respectively. The suitability was divided into four (4) categories: extremely high, high, moderate, and low. The area and percentage coverage of the suitability classes are shown in Table 8. Very high areas occupied 22.9%, high areas occupied 44.54%, moderate areas occupied 32.33% and low areas scored 0.23% of the suitability of the total area (Table 10). From Figure 13, the proposed petroleum hub felled on areas dominated by very high and high area suitability for its establishment constituting 75.9 km^2 (90.3%) of its entire area whereas the moderate suitability zones constituted 8.2 km^2 (9.7%) of the remaining areas. Towns situated in very high areas includes; Bakakole Nkwanta, Ahobre, Nawule, Allowule, Tikobo No.1, Edu, Damofu, Ave lenu and Ebonloa, Mpatabo. High areas comprises of Kengen Kpokezo, Alenda wharf, Tekyinta. Anwonakrom, Nkwamta, Elubo and Agege are among the moderate and low area zones for hub and oil retail assets establishment. The need for the establishment of a petroleum hub continues to remain a major concern due to increasing importation of petroleum products from year to year. Figure 14 represents the trend of import of petroleum products from 2007 to 2016.

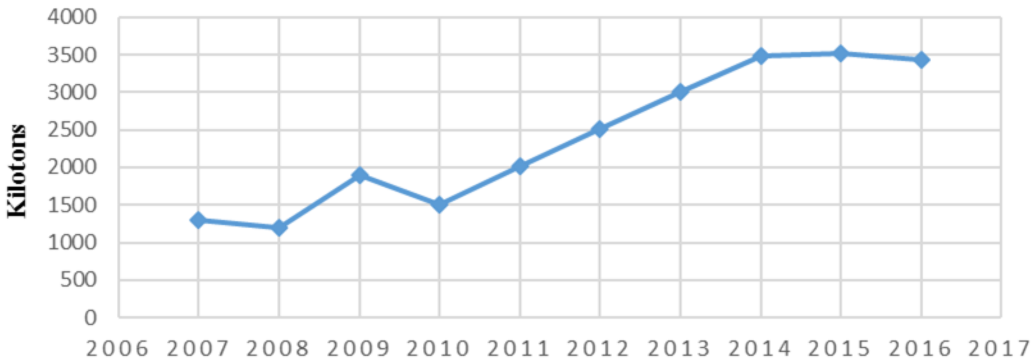

Figure 14. Petroleum products imports from 2007 to 2016 (Source: Abudu and Sai, 2020)

5 Conclusions and Recommendations

The Ministry of Energy has regulatory responsibility on behalf of the State under Act 84. All petroleum operations must be carried out in a manner without adverse effects on Ghana's environment, resources, or people (Ten, 2014). The paper aims to perform a site suitability assessment prior to the establishment of a petroleum hub at the Jomoro district of Ghana as well as assess the suitability of the existing oil retail assets by integrating Fuzzy AHP, VIKOR, proximity analysis and remote sensing techniques in the GIS environment in compliance with the policies by the Ministry of Energy and Environmental Protection Agency (EPA). The weights, selection criteria, and restriction model comprise the Suitability model. Fuzzy AHP was used to construct the initial weights from the fuzzy judgment matrix. This was done to address the uncertainties and imbalanced scale of judgment that existed in classical AHP. The decision matrix used in the studies was employed from the pairwise comparison of the AHP method with a valid consistency ratio of 0.09. This was done to eliminate any subjectivity in the cost criteria analysis. VIKOR method was used to generate the final weights and ranking of the cost factors based on the conditions set by the compromise solution. The essence is to emphasize the ranking of alternatives sets of the conflicting criteria (Mardani et al., 2016). The study' cost criteria include remotely sensed data, primary and secondary data received from Ghana's Survey and Mapping Division, and field data collecting ArcGIS 10.4 software was used to create all maps of the weighted alternatives. The suitability was divided into four (4) categories: extremely high, high, moderate, and low. Very high areas occupied 22.9%, high areas occupied 44.54%, moderate areas occupied 32.33% and low areas scored 0.23% of the suitability of the total area. From the study, the proposed petroleum hub felled on areas dominated by high area suitability for its establishment constituting 75.9 km^2 (90.3%) of its entire area whereas the moderate suitability zones constituted 8.2 km^2 (9.7%) of the remaining areas.

75% of the filling stations complied with the established protocols by Ghana's Ministry of Energy and Town and Country Planning Department, but 25% fell short in terms of proximity to public services. For future planning objectives, the study unveiled the geographical spread of filling stations along the major road. The proximity evaluation point demonstrates that some of the existing stations found expressions in an unsuitable setting, posing a risk to the people and properties in their neighborhood. The non-existence of firefighting stations was also observed in the vicinity. The study has once again proved the utility of multi-criteria decision analysis (MCDA) and geographic information system (GIS) techniques in handling spatially associated topical problems (Peprah et al., 2018). Furthermore, this report indicated that Ghana is reliant on petroleum imports (Abudu and Sai, 2020). It is recommended that the suitability map produced for the study area should be used and further environment impact assessment should be carried out by the authorities to assess the significant impacts the sited stations have on the environment. It is also recommended that site suitability analyses be incorporated in the Town and Country Department's planning scheme for future development and policy formulation. Measures should be put in place to enforce the set standards and prosecute offenders to bring sanity in the oil and gas projects. This study should be duplicated in other parts of the country or used for future redevelopment of the study area. Furthermore, for stations located in inappropriate zones, the authorities must conduct a proper environmental impact assessment to identify the substantial implications they may have on the ecosystem and the steps that may be implemented to mitigate those impacts (Njoku and Alagbe, 2015).

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