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Site suitability analysis for locating petroleum stations using analytical hierarchy process (AHP) and MCDA approach: a case of Wolayita Sodo town, Ethiopia, Africa

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Abstract

This study allows the local people as well as planners for the appropriate plans of land use planning in sustainable petroleum station of Wolayita Sodo town, Ethiopia, East Africa. The problem of haphazard location of petrol stations is one of the major difficulties at 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. The main objective of this study is to identify appropriate for locating petroleum stations and assessing existing stations by using Analytical Hierarchy Process (AHP) & Multi-Criteria Decision Analysis (MCDA) techniques. This study demonstrates the use of an integrated Idris 17.1 and Arc GIS 10.3.1 are used for to designate petroleum station site in the study area. MCDA consists of a series of techniques that permit a range of criteria relating to a particular issue to be scored, weighted and then ranked by their degree of suitability or importance for locating a particular facility or service to locate the suitable petroleum station site. The thematic maps of these criteria were prepared and standardized using pair wise comparison matrix. A weight for each criterion was given by comparing them with each other according to their importance, the consistence of comparing matrix were checked by calculating the consistence ratio (CR). The consistency ratio of this study indicated that 0.04 which is less than 0.1. Thus, consistent matrix was formed which was acceptable in order to combine all the mapping layers.

Keywords: Analytical Hierarchy Process (AHP); MCDA; Petroleum stations; Site selection; Suitability analysis

1. Introduction

Petrol is the lifeblood of almost all countries in the world. Since the mid-1950s, it has been the world's most major energy source. Its products help to strengthen modern society by delivering energy to the power industry, providing gasoline for automobiles and motorcycles that transport goods and people around the world, and powering domestic machines (Mshelia et al.2015). Latin America saw an increase from 673 to 5319, and Africa saw an increase from 1 to 182 fuel stations.

Making the best location based on standard criteria for a business venture such as a fuel station is critical for entrepreneurs who want to invest money to make a lot of money. The proximity to populous regions (business center), distance from neighboring stations, the convenience of using available facilities, and the magnitudes of environmental pollution criteria are all important variables to consider when choosing a location for a fuel station (M. S. Peprah et al ,2018).

All of these factors make locational analysis vital in order to make the optimal locational decision when it comes to establishing a petrol station and to understand the effects that such stations may have or currently have on the neighborhood(s) where they are located

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Objectives of the Study area

- General Objective

The main aim of this research is to identify appropriate for locating petroleum stations and assess the existing by using Analytical Hierarchy Process (AHP) & Multi-Criteria Decision Analysis (MCDA) approach.

- Specific Objective

To generate map of final suitability of locations appropriate for sitting the petroleum stations.

1.1. Description and Location of the Study Area

The study area included the entire administrative boundary of Wolayita Sodo town delineated on master plan which has the area extents 165km^2.

1.1.1. Location of the Study Area Sodo is located in Ethiopia's Southern Nations and Nationalities Regional State (SNNRS).

It is the administrative capital of the Wolayita zone. The geographical location of the study area ranges from 6°45’0" N to 6°55’0" N latitudes and 37°38’0" E to 37°50’0"E longitudes, with an altitude of 1738 to 2760m a mean sea level.

The city is strategically placed in the center of southern Ethiopia, with six outlets connecting the north, south, east, and west regions. Sodo Arbaminch Jinka via Hossana Addis Abeba, Sodo Jimavia Waka Sodo Gofer/Sabula, Sodo Hawassavia Bedessa Moroch Boditi shashamene connects Sodo with Addis Abeba.

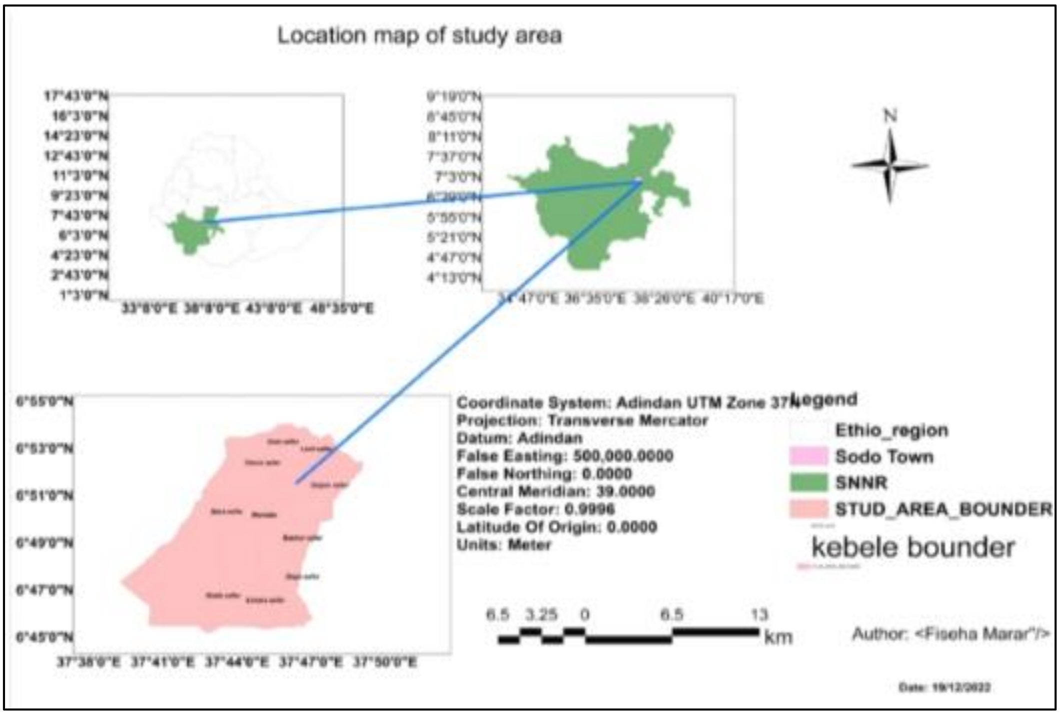

Figure 1 Location of Study area

2. Material and methods

The following flow chart diagram below summarizes the overall methods, techniques, approaches and materials used to carried out this study uses the Analytic Hierarchy Process was conceived by Thomas Saaty in 1980. AHP can simplify preference ratings among decision criteria using pair-wise comparisons [1]. It is used for addressing complex decision-making processes and supports the decisionmaker to give the best conclusion about the subject matter. Also, it reduces complex decisions to a series of pairwise comparisons to give the results {[2],[3]} so as to figure out this methodology is best suited for selection of suitable petroleum site accurately in time and cost-effective manner and hence it is used by many researchers.

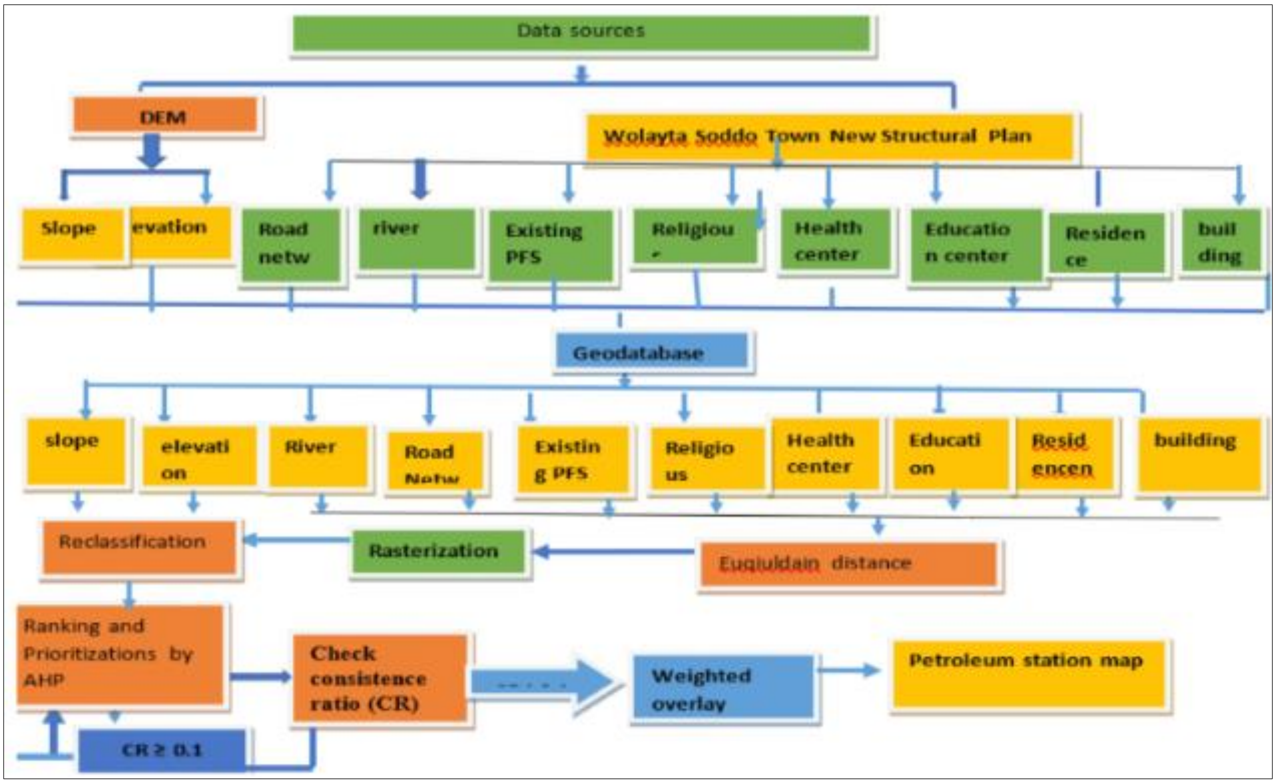

Figure 2 Schematic presentation of Methodology

2.1. Analytical Hierarchical Process (AHP)

Saaty's Nine point scale

Intensity of importance on an absolute scale	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over the other	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance	Evidence that favor one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed
Reciprocals	If activity i is assigned to one of the above numbers compared to activity j, then j has the reciprocal value compared to i	
Rational	Ratios that arise from the scale	if consistency were to be forced by obtaining n numerical values to span the matrix

Figure 3 Saaty's Nine-point scale

Spatial AHP is termed by Siddique et al., 1996 for the purpose of multi criteria decision analysis that integrates GIS and AHP. In this project Spatial AHP is used to spot suitable sites for industries and to quantify the levels through categorization and usage of knowledge, facts-based user preference and data contained in GIS maps. The most difficult assignment in carrying out land suitability analysis approach for an exacting land use type is to assign the relative weights of the entity criteria that are to be considered. Thus, the study limited the criteria to the nine most important aspects.

AHP is divided into three stages:

- Decomposition - Identify and structure the criteria
- Comparative judgment - through pair wise comparison
- Aggregating the priorities - Calculate suitability index. Structuring is comparatively subjective activity and depends on decision maker's skill and experience. Criteria are to be considered based on the importance of user's requirement [4].

The AHP weight derivation interface to derive the weights for each parameter, with its consistency ratio, for PFS site selection was shown by figure below.

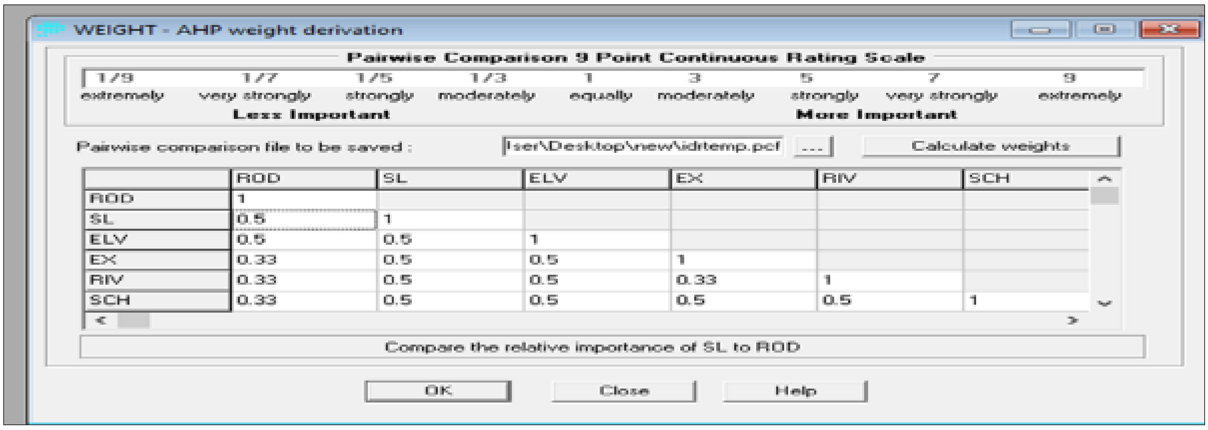

Figure 4 AHP weight derivation method of Pairwise comparison (PWC) Point Continuous Scale

2.2. Factors that were considered during the study

Table 1 Factors that were considered during the study

SNo	Name of factors	Way of influence
1	Roads Factors	Factors
2	Slope Factors	Factors
3	Elevation	Factors
4	Existing petroleum station	Factors
5	River	Factors
6	School	Factors
7	Health institutions	Factors
8	Building	Factors
9	Residence	Factors

For selection of suitable site for petroleum filling station this study uses standard criteria from (Thomas Kweku Taylor et al, 2016), Mohammed et al (2014), Esra Aleisa, et al, (Int. *J. Operational Research*, Vol. X, No. Y, pp.000–000.), Akbari et al., (2008)), Minna, Nigeria, kaduna, Oyo Town Ghana, and based on the geographical characteristics of the town.

3. Results

This part discusses the determination of criteria and classification of factors for the selection of suitable petroleum station site and the final results were also presented in the form of maps.

The suitability of a site for petroleum station is influenced by the various characteristics of the site. however, each characteristic only reflects an aspect of the overall suitability for the specific land use.

A GIS-based spatial analyzing information system for suitable site selection criteria should be identified and integrated into a GIS database in the form of map layers with associated attributes. The set of spatial analyzing information system criteria for petroleum station site selection have been identified based on different literature reviews and relevant expert's opinion. The criteria identified are obtained from neighbor country standard.

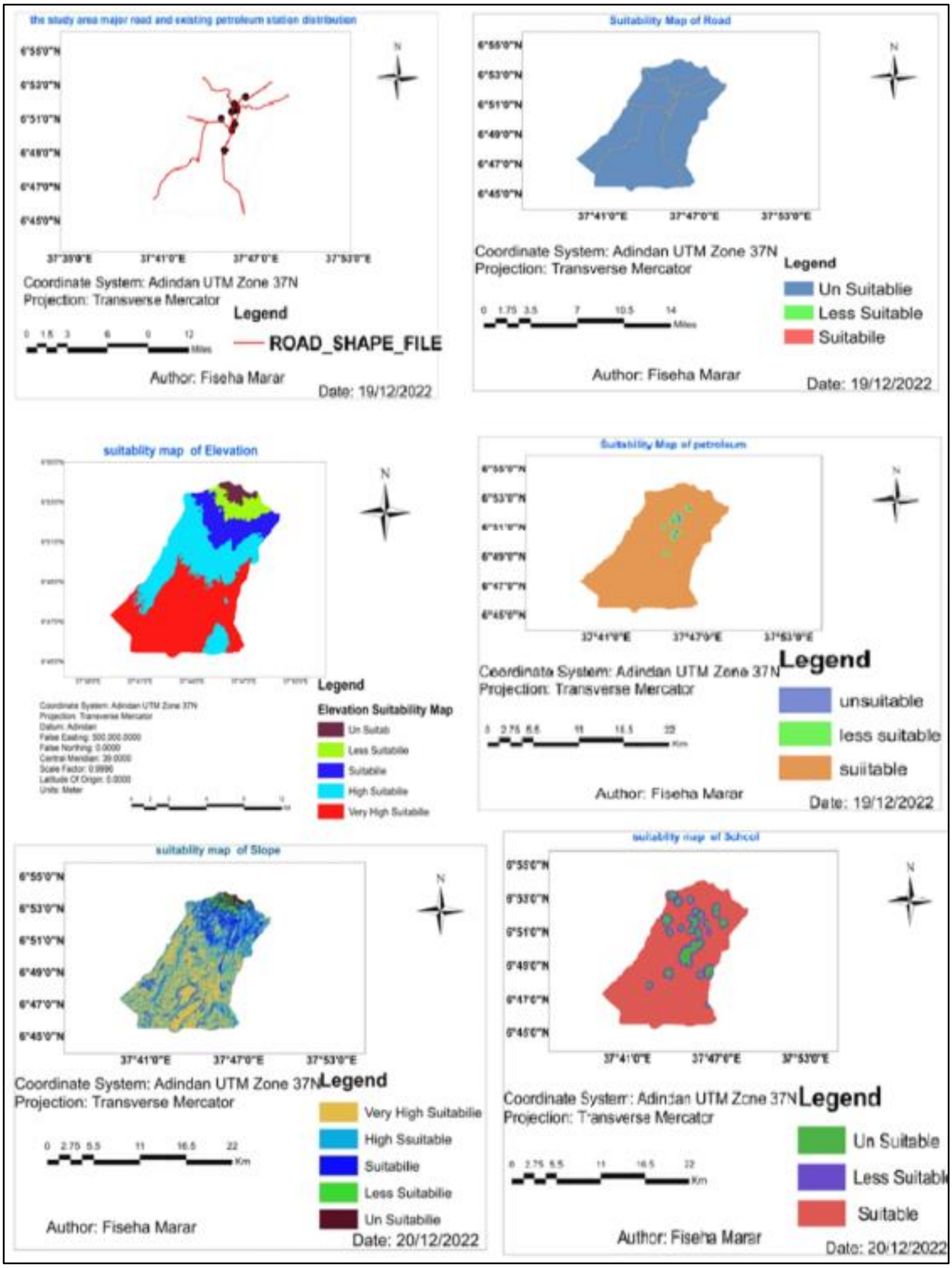

Figure 5 (a) Thematic map produced each criterion selected for suitability analysis

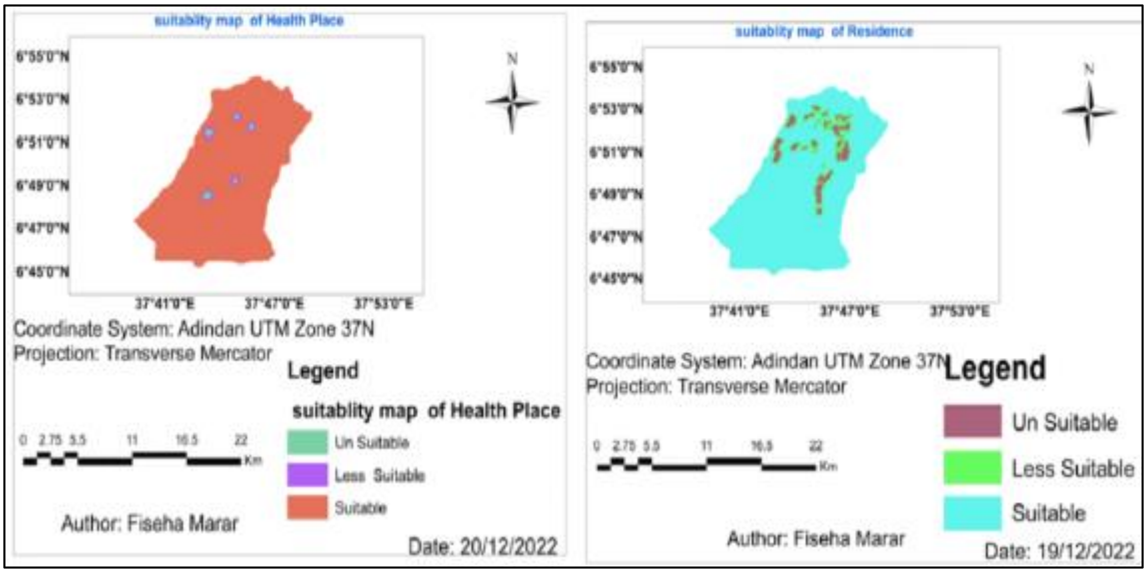

Figure 5 (b) Thematic map produced each criterion selected for suitability analysis

3.1.1. Ranking parameters by AHP

The main use of AHP is ranking and prioritization of parameters. Priority framework quality affects the effectiveness of available sources which are the essential judgment from the decision maker (Andi et al., 2017). All thematic layers were compared in a pairwise comparison matrix (Table 1) [5].

According to, this AHP weight derivation module, the following eigenvectors of weights for all factors considered for petroleum filling site selection is generated.

Table 2 Factors and their eigenvectors weights for suitable petroleum filling station

	Road	**Slope**	**Elevation**	**PFS**	**River**	**School**	**Health**	**Build**	**Residence**	**Weight**	**Percentage of Weight**
Road	1									0.23	23
Slope	½	1								0.14	14
elevation	1/3	½	1							0.12	12
PFS	½	½	½	1						0.11	11
River	1/3	½	½	1/3	1					0.11	11
school	1/3	½	½	½	1/2	1				0.10	10
Health	1/3	½	½	½	1/2	½	1			0.10	10
Building	¼	½	½	1/2	1/2	½	1/2	1		0.48	5
Residence	1/5	½	½	1/2	1/2	½	1/2	½	1	0.37	4
Total										1.00	100

Consistency Ratio = 0.040 <0.1 = acceptable

The value obtained here were an estimate of the relative weights of the criteria being compared. As shown in table 2 above the last column indicates the weight of each parameter and Percentage of Weight the consistency ratio of this study indicated that 0.040 which is less than 0.1. thus, consistent matrix was formed which was acceptable in order to combine all the layers to process overlay analysis.

Table 3 Weight of Factors from the pair-wise comparison eigenvectors

Factors No	Factors	Weight of each factor's	Percent (%) of Weight for each factor
1	Road	0.23	23
2	Slope	0.14	14
3	Elevation	0.12	12
4	PFS	0.11	11
5	River	0.11	11
6	School	0.10	10
7	Health	0.10	10
8	Building	0.48	5
9	Residence	0.37	4
Total		1.00	100

3.2. Developing PFS Suitability site

After all parameters were prepared in raster format the overlay analysis was performed using weighted overlay tool in GIS spatial analysis extension by considering weight of parameters and buffer zones as shown in table 3, according to FAO (1976) suitability classification standard. The standard establishes five suitability ratings whether the area is suitable or not suitable.

Table 4 Weight of parameters and rank of buffer zones determined using AHP method

Planning parameters	Buffer zone /class	Suitability class	Rank	Weight of parameter	Area	Percent
Proximity to road	0-15	unsuitable	1	23	134	81.36
	15-30	Suitable	3		7	3.99
	>30	Less Suitable	2		24	14.65
Slope in degree	<1-5	Very High suitable	5	14	78	45.16
	5-10	High suitable	4		54	33.42
	10-15	Suitable	3		20	12.72
	15-20	Less suitable	2		9	5.99
	>20	Un Suitable	1		4	2.71
Elevation	1738-1847	Very High suitable	5	12	71	40
	1847-1961	High suitable	4		61	25
	1961-2115	Suitable	3		17	15
	2115-2319	Less suitable	2		11	15
	>2319	Un Suitable	1		5	5
Existing petroleum	0-500	Unsuitable	1	11	2	0.81
	500-600	Less Suitable	2		3	1.85
	>600	Suitable	3		160	79.34
Health center	0-100	Unsuitable	1	8	1	0.81

	100-200	Less Suitable	2		2	1.49
	>200	Suitable	3		162	97.7
School center	1-100	Unsuitable	1	7	12	7.27
	100-200	Less Suitable	2		14	8.31
	>200	Suitable	1		139	84.41
Religion	0-100	Unsuitable	1	5	153	93.19
	100-200	Less Suitable	2		8	4.76
	>200	Suitable	3		4	2.05
River	0-100	Unsuitable	1	5	5	2.05
	100-200	Less Suitable	2		7	4.76
	>200	Suitable	3		1153	93.19
Built up	0-100	Unsuitable	1	5	15	9.8
	100-200	Less Suitable	2		11	6.1
	>200	Suitable	3		139	84.82
Residence	0-100	Unsuitable	1	4	9	4.86
	100-200	Less Suitable	2		11	6.28
	>200	Suitable	3		145	88.87

By considering important factors elevation, slope, river, proximity to road networks, EPFS, residential areas, public institutions (school, HC,) and important buildings were considered to determining PFS sites. Weighted overlay Combination a in the ArcGIS software conducted and it gives three sites for the petroleum filling station of Wolayita Sodo town these are suitable, less suitable and unsuitable sites

The coverage area was calculated for each suitability class of the sites was calculated and the result showed that 45km^2 (27%) were unsuitable for petroleum filling station sites as the areas are topographically unacceptable and socially unacceptable to be proposed as a PFS sites. The unacceptable areas, therefore, include mountains, rivers and stepper slope.

However, the remaining areas of about 30km^2 area (23%) of the town were less suitable, and 90 km^2 area 50% of the total area were suitable, and satisfies criteria set for the PFS site selection.

According to final map suitable PFS sites were identified in the central part of the town major and minor road and on the 6 outlet (north-east, north-west, south-east, south-west, west and east outlet).

Table 5 Final suitable Site for petroleum station

No	**Suitability class**	**Suitability Rank**	**Area in (km2)**	**Area in (%)**
1	Un suitable	1	44	27%
2	Less Suitable	2	36	23%
3	Suitable	3	85	50%
Total			165	100%

Based on the above table final suitable Site for petroleum station, from the total study area 50% and 23 %, were found suitable and less suitable respectively. While the remaining 27 % of the study area is unsuitable for filling petrol station potential sites.

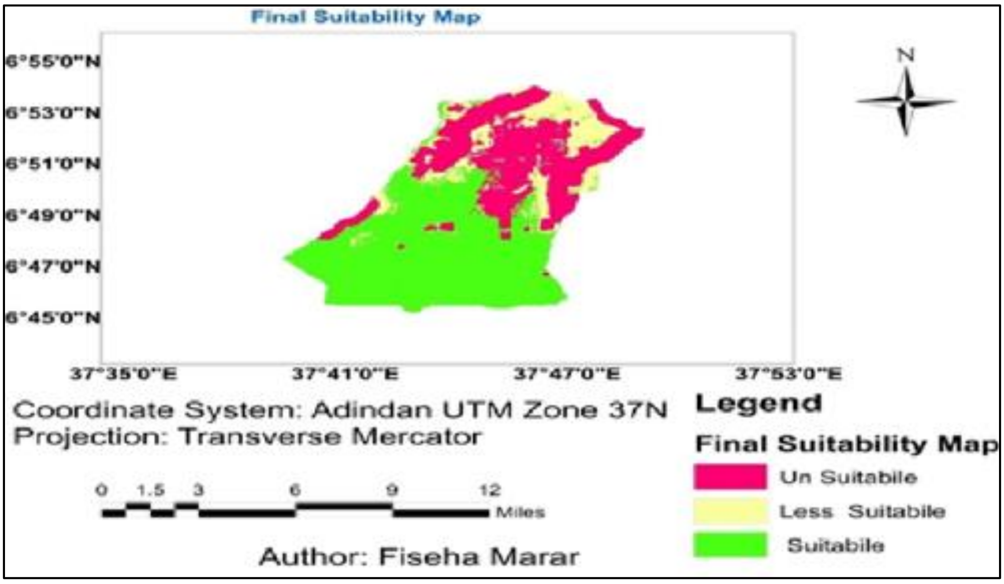

Figure 6 Final suitable site for petroleum station

4. Discussion

A study conducted by **(**Alesheikh A.A and Golestani H.A, 2011**)** and **(**Blamah.N.V. V, 2006**)** in Lagos, Nigeria indicated that, the gas/petroleum station sites generated based on the criteria sets are found to be accessible by road and by consideration of effect of gas station in environment.

This study used various site selection criteria, proximity to road, proximity to river, proximity to school and health care center, slope, elevation, residence, existing PS and proximity to existing built-up area to select potential PF site. The final suitability map has shown that three suitability classes suitable, less suitable, unsuitable from all surface of study area.

The suitable sites are located in South part of the town major and minor road and on the 5 outlet (north-east, south-east, south-west, west and east outlet). The selected sites can be used for future PFS.

The details of the conceptual framework and each processing step are shown in figure :2 MCDA technique is applied to incorporate decision maker's judgment and preferences using the AHP method. This method includes the selection of the criteria for the spatial Multi -Criteria Evaluation (MCE) technique for the suitability analysis for filling petrol station.

The final step involved in AHP is the aggregation of the relative weights obtained at each level of the hierarchy to calculate the suitability index. ArcGIS is used to combine the spatial data with suitability index so that a continuous land suitability map is generated. for this study, using weighted overlay analysis of each input layer or factors such as, road network, slope, and elevation maps, suitable site sensitivity index was arrived.

5. Conclusion

The findings have shown the application of the GIS and AHP, which is a multi-criteria decision-making approach, was developed by Saaty26 and it is widely used to unify multiple criteria in the process of decision-making methods as a viable tool for analyzing the criteria for decision support. The analysis has taken existing gas station, school center, residence, health in state, slope, river, road, built-up area and elevation as determining factor in order to find appropriate site for gas station site.

The integration of multi -criteria decision analysis is a useful tool in solving gas station site selection problem, because it provides efficient spatial data manipulation and presentation. Hence, the capacity to use AHP with GIS technology for effective identification of suitable gas station site will minimize the environmental risk and human health problems. Therefore, the result of final suitability map indicates that 50% of the study area has more suitable for petroleum station site, less suitable 23%, and unsuitable 27% the total of the study area. Selection of PFS need proper selection of site to reduce traffic accidents, congestion and it creates health environment in Wolayita sodo town and surrounding areas in the long term by using suitable area primary for PF site.

Recommendation

From the analysis of the existing situation and inferences drawn of the petroleum stations within the study area have impact on motorist urban dwellers as well as the entire urban as a result, appropriate recommendations for planning of petroleum stations within the study area were made thus.

- The earmark of areas to be devoted for petroleum stations to be located within neighborhood sector and master plan. This is to check the proliferations and haphazard location of gas station are included in various plans.
- A gas station must be 1100m^2 and above for area coverage, but most of the existing Petroleum station is not coverage this much area, and which will give adequate space for services if the area is within the standard.

Planning authorities should ensure that all Petroleum stations are in conformity with the standard and future PFS should consider environmental factors and standards criteria and this may facilitate transportation and reduce the cost transport as well as it creates health living environment.

Compliance with ethical standards

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Disclosure of conflict of interest

All authors declare that they have no conflicts of interest.

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