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GEOSPATIAL APPROACH FOR PETROL PUMPS VALUATION WITH URBAN PREDICTION MODELLING BY CELLULAR AUTOMATA IN CREEDS OF METROPOLITAN EXPANSE

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KEY WORDS: Site Suitability, Analytical Hierarchy Process, Cellular Automata, Prediction Model, Geographic Information System.

ABSTRACT:

The research demonstrated the spatial analysis of site suitability using physical parameters in the Metropolitan expanse that requires environmental safety and sustainability. The location of petrol filling stations that are already developed without following any standard criteria is drastic. This research finds out the level of compliance of petrol pumps to set standards for distances and location in Lahore Metropolitan Corporation. 195 petrol pumps were sampled and eight standard criteria were developed. Which were used to perform site suitability analysis using Analytical Hierarchy Process technique. The results revealed that 88% of petrol pumps in the study area meet the standard criteria while 12 % did not meet the criteria due to improper planning of the management. Furthermore, by incorporating all the essential factors for petrol pumps suitable sites and spatial prediction of urban sprawl using Cellular automata have been developed. Therefore, this study also indicates the LULC pattern of metropolitan area with past and present existence of LULC feature. On the basis of past and present trends the future prediction has been performed using cellular automata modelling to observed the future scenario of urban development's patterns. The prediction of future builtup pattern results are very alarming and need serious concentration regarding future road map. The study showed that geographic information system is essential tool that can assist decision and policy makers for a new development project to take appropriate measures.

1. INTRODUCTION

In the past few years, the growing population is putting immense pressure on the infrastructure, agricultural lands and the natural resources (Jayne et al., 2014). As the 21st century is the era of industrialization and urbanization the use of automobiles is increasing day by day. This increased demand for vehicles resulted in greater fuel consumption that is increasing the development of petrol pumps day by day in all over the world (Jayne et al., 2014). The increased number of petrol pumps is an alarming situation as these are potentially harm towards the environment and sustainability (Patnaik 2018). It has observed from different researches e.g. (Hassanain, Al-Mudhei, 2006; Karakitsios et al., 2007; Nouri et al., 2010) that petrol pumps have a high potential of damage to their surroundings. So, today the major challenge developers are facing is to form such a sustainable approach that does not harm the environment together constructing such development projects (de Siqueira Campos Boclin, de Mello, 2006). A petrol pump is an essential facility but hazardous that needs special attention for site selection that is very important for the success of any development project (Khahro et al., 2014). There are several factors like fire incidences, Traffic Jam and underground storage contaminates the groundwater that leads to the petrol stations damage (Semih, Seyhan, 2011). Thus, the location petrol pump has important role in the survival and productivity of any business. If a site is poorly selected for the petrol stations, then it will lead to the ineffective use of the resources. There are qualitative and quantitative factors that are involved in selecting a suitable site for the petrol stations (Guler, Yomralioglu, 2017). But these factors may remain integral in those conditions when the companies tend to develop their petrol pumps in remote and unsuitable areas due to insufficient space available according to the agreement standards in the metropolitan area (Agade et al., 2019). It is necessary to develop an efficient method for the site suitability analysis that help to locate a viable location for development projects while earlier methods of site suitability do not cover all aspects of an environmental effect and EIA standards. GIS is a tool that has been successfully used for the site selection of any proposed project (Malczewski, 2004) and has proven very supportive to solve the spatial problems (Guler, Yomralioglu, 2017). GIS-Based site suitability analysis using AHP has been used in different studies such as water harvesting reservoir location suitability (Ghayoumian et al., 2007) housing suitability assessment (Malczewski, 2006). Land selection of small gas stations (Aslani, Alesheikh, 2011), Site selection analysis for nuclear waste disposal stations (Huang et al. 2006). Thus, in the present research GIS-based technique adopted to find out how many of petrol pumps in the study area comply standard criteria. Lahore is one of the most populous cities of Punjab because of the education, health and employment services (Waheed et al., 2020) and has immense pressure on the roads due to increased use of automobiles. There are many petrol pumps and service stations are operating in Lahore including Caltex, Shell, Total Parco and the Pakistan State Oil (PSO). These four companies are spread all over in MC having different petrol pump stations in the remote as well as in the CBD areas of Lahore (Tabinda et al., 2019). Previously, Olufayo (2018) also observed the petrol station location and its impact in Nigeria. The study focuses on the situation of the petrol pump stations and the criteria's they are fulfilling to assess the location of petrol pumps that are against the compliance standards. The aim of this research to provide a road map for decision maker and urban planner by using GIS based modelling approaches for cities sustainability can be achieved and the future growth pattern of urbanization determined with realistic scenario. Due to the rapid growth of urban and rural parts there are many serious concerns has been raised on the urban sustainability (Wu, 1996).

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2. MATERIAL AND METHODS

This research has been divided in to the three parts which are as following; In the first part analytical hieratical process (AHP) modelling approach has been used under defined criteria. In the light of developed criteria, the suitability of petrol stations has been observed (Mohammed et al., 2014). To observe the current scenario of petrol stations and its spatial existence and there are many flaws among the randomly selected locations. In the second part of the research past and present LULC scenario has been observed for years 2002, 2012 and 2022. Although, the third part contains the cellular automata based future prediction modelling of LULC to observe the future patterns for the years 2032 and 2042. The urban sprawl has also been extracted from the predicted LULC to observe the future trends for the years 2032 and 2042 to calculate the suitable land for petrol station that will fall within the urban land.

2.1 Study Area

Lahore District located in Punjab, Pakistan was selected for the study (figure 1). The area is bounded by India, Sheikhupura, Kasur and Nankana Shahib from northeast, northwest, south and west (Javed, Riaz, 2019). Lahore is the second most inhabited district with 12,642,000 with the growth rate of 3.72% in 2020. There are numerous small and big settlements exist in the boundary of Lahore with an estimated average density of 7,000 persons/ Sq. Km.

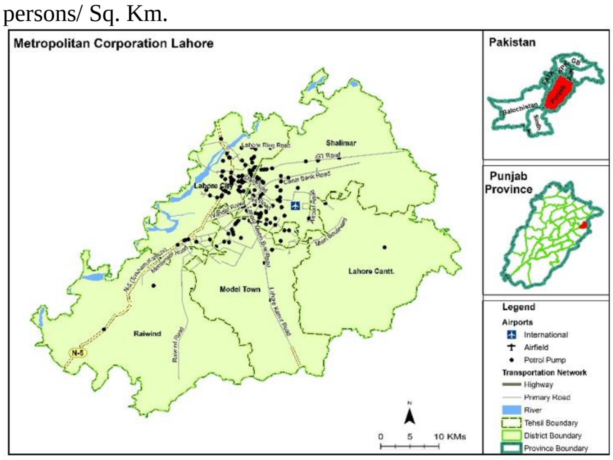

Figure 1. Study Area Map

2.2 Factors for Effective Criteria

Datasets used for the study collected from both primary and secondary sources. Criteria's were selected after a detailed literature review. The selected Criteria's, and their description is given in Table 1.

Criteria	Data Type	Description
Road Network	Polyline	The nearer away, the better
Residential Area	Polygon	The nearer away, the better
Commercial Area	Point	The nearer away, the better
Public Building	Point	The nearer away, the better
Health Facilities	Point	The further away, the better
Religious Building	Polygon	The further away, the better
Petrol Pump	Point	The further away, the better
Water Bodies	Polygon	The further away, the better

Table 1. Standard Criteria and their description

Data layers were prepared according to AHP models using the following steps

- Development of data into the same structure
- Development of distance Maps
- Data Classifications

The first step of data preparation begins with structuring of data that is a major parameter. This step includes the vectorization (conversion in to vector data) of data into the same structure to develop distant map (Semih, Seyhan, 2011). To compare the petrol pump location with standards, distance mapping was done. This step simplifies the data and increases its ability to combine the different layers. Arc GIS used to measure the distances among the petrol pumps using developed criteria. Distance maps were prepared for all the selected criteria shown in Fig 2.

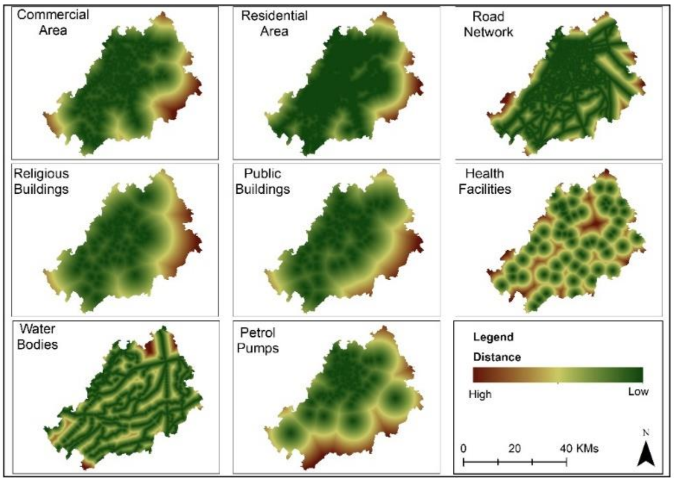

Figure 2. Distance maps of spatial variables

2.3 Data Preparation, Weighting and Criteria Coalescing

After measuring distance, the output rasters were reclassified based on their spatial data priority using Table 2. Each criterion was classified into two classes according to their distances that meet the standards or not as shown in Figure 3.

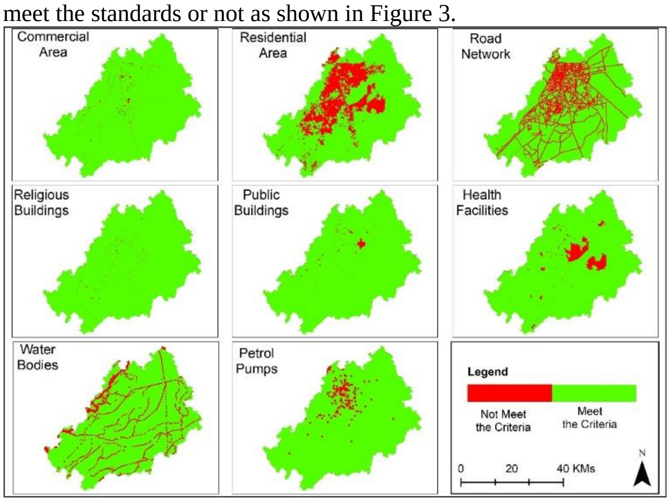

Figure 3. Best site of each Criteria

In the study, AHP technique developed by Thomas was used to calculate the ranking and weights of the selected criteria. This process is a powerful multi criteria decision analysis (MCDA) method that solves the complex problems in a very suitable way by organizing the criteria an into hieratical tree process (Saaty, Vargas, 2012). AHP can judge quantitative criteria along with qualitative criteria (Boroushaki, Malczewski 2008) to make the best decision among several factors as well as on the basis of relevant literature (Khahro et al., 2014; Tah, 2017; Ulasi et al., 2020) and with meeting with urban planners. Also, pairwise comparison approach carried out to measure the relevant importance of the selected factors (Semih, Seyhan, 2011).

Criteria	Distance (Meter)	Compliance	Class
Road Network	<15	Not Meet the criteria	1
	=>15	Meet the Criteria	2
Distance from Residential Area	<20	Not Meet the criteria	1
	=>20	Meet the Criteria	2
Distance from Commercial Area	<10	Not Meet the criteria	1
	=>10	Meet the Criteria	2
Distance from Public Building	<15	Not Meet the criteria	1
	=>15	Meet the Criteria	2
Distance from Health Facilities	<100	Not Meet the criteria	1
	=>100	Meet the Criteria	2
Distance from Religious Building	<100	Not Meet the criteria	1
	=>100	Meet the Criteria	2
Distance from Petrol Pump	<400	Not Meet the criteria	1
	=>400	Meet the Criteria	2
Distance from Water Bodies	<200	Not Meet the criteria	1
	=>200	Meet the Criteria	2

Table 2. Compliance Criteria for Petrol Pumps

A Square matrix was developed by paired comparison of each criterion and a matrix was presented in Matrix (M) with M=(m_{ij}) n"×" n:

$$M= (m_{ij})_{nn} = \begin{bmatrix} m_{01} & m_{02} \cdots & m_{0n} \\ m_{11} & m_{12} \cdots & m_{1n} \\ m_{n1} & m_{n2} \cdots & m_{nn} \end{bmatrix} \quad (1)$$

Where:

n = the number of criteria,

Relative importance of criteria was analyzed and a pairwise comparison matrix is formatted in Table 3.

Now, to calculate the weights of each criteria following equations were used:

Equation 2 was used to normalize the judgement matrix by column.

$$\overline{a_{ij}} = \frac{a_{ij}}{\sum_{k-1}^{n} aij} (i, j = 1,2,3,4) \quad (2)$$

Equation 3 was used to calculate the sum of each row:

$$\overline{w_i} = \sum_{j=1}^{n} \overline{a_{ij}} \, (i = 1,2,3,4) \quad (3)$$

Equation 4 & 5 were used to calculate the weight of Y1, Y2, Y3 and Y4.

$$\overline{w} = (\overline{w_1}, \overline{w_2}, \overline{w_3}, \dots, \overline{w_n})^T \quad (4)$$

$$w_i = \frac{\overline{w_i}}{\sum_{i=1}^{n} \overline{w_i}} (i = 1,2,3,4) \quad (5)$$

Eigenvector of max λ is calculated by using following equations:

$$\lambda_{max} = \sum_{i=1}^{n} \frac{(AW)_i}{nw_i} \quad (6)$$

$$MW = \begin{bmatrix} m11 & m12 & \dots & \dots & m1n \\ m21 & m22 & \dots & \dots & m2n \\ : & : & : & : & : \\ mn1 & mn2 & : & : & mnn \end{bmatrix} \times \begin{bmatrix} w1 \\ w2 \\ : \\ wj \end{bmatrix} \quad (7)$$

Where
W corresponds to eigenvector of max λ,
wi (1, 2, 3…n) is denoting the weight value ranking

Consistency of judgment matrix was certified by using equation:

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \quad (8)$$

Where
CI shows consistency index and
λ max correspond to eigenvalue principal of the matrix and
n is matrix order.

Then, equation 9 was applied to calculate the consistency ratio index

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \quad (9)$$

The CR should be less than 0.10 which shows reasonable consistency. The calculated consistency ration for the selected criteria is 0.076. and weight of each criteria is calculated in Table 4.

After the weightage calculation combining models of GIS-based on various functions were applied to overlay the spatial layers (Bonham-Carter 1994). Weighted overlay model was used to combine all the criteria's by using equation 10.

$$CC = \frac{\sum_{i=I}^{n} Sij_{ij} \quad i}{\sum_{i=I}^{n} W_i} \quad (10)$$

Where:

Wi = ith factor map weight

Sij = ith weight for jth criteria map

CC= The spatial unit in binary base output map, Sij could have zero/one values.

2.4 LULC – Past, Present and Future

The rapid urban growth also causes of many challenges in form of urban infrastructure and urban utilities. Many questions raised and resembled but due to the lack of interest of urban planning criteria inducements the challenges increased rapidly with the growth of city. The temporal LULC pattern identified with supervised classification techniques for the year 2002, 2012 and 2022. The temporal satellite data of Landsat 5 and Landsat 8 with zero cloud cover has been selected after the preprocessing of the acquired satellite data random forest classifier (Kavzoglu, Bilucan, 2022) used to classify the satellite data to observed spatio-temporal pattern of land use and land cover of the area of interest using sample points (figure 4). The main purpose of this work was to observed the dynamic temporal LULC trends how much changes has been occurred due to the urban expansion.

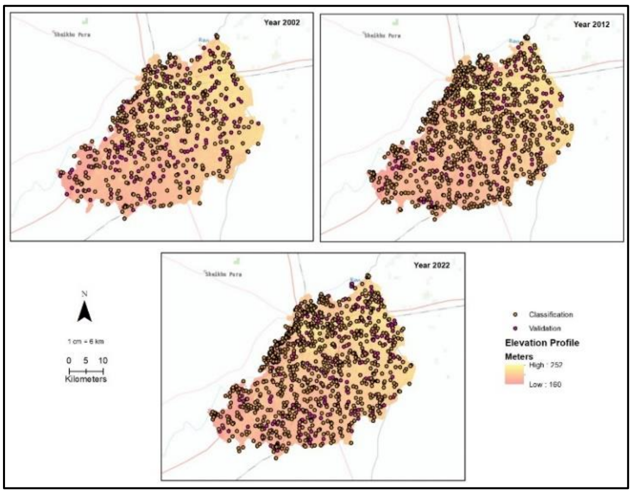

Figure 4. Signatures for Classification and Validation for the year 2002, 2012 and 2022

In the light of temporal satellite observations results and spatial variables the model accuracy of classified data has been checked in the third part using cellular automata-artificial neural network (CA-ANN) modelling using MOLUSCE (Kamaraj, Rangarajan, 2022). As, the cellular automata models are more capable for complex modelling and prediction of urban areas (Santé et al., 2010). Therefore, the accuracy of model checked on known dataset by prediction results using 2002 and 2012 data and predicted the LULC for the year 2022. Which has been compared with already classified dataset for the year 2022.

	Road Network	Distance from Petrol Pump	Distance from Water Bodies	Distance from Residential Area	Distance from Educational Facilities	Distance from Health Facilities	Distance from Religious Buildings	Distance from Public Building	Distance from Commercial Area
Road Network	1	1.00	2.00	4.00	5.00	5.00	6.00	7.00	9.00
Distance from Petrol Pump	1.00	1	1.00	4.00	5.00	5.00	6.00	6.00	7.00
Distance from Water Bodies	0.5	1.00	1	2.00	4.00	5.00	5.00	7.00	7.00
Distance from Residential Area	0.25	0.25	0.50	1	2.00	3.00	5.00	6.00	8.00
Distance from Educational Facilities	0.20	0.20	0.25	0.50	1	2.00	4.00	5.00	6.00
Distance from Health Facilities	0.20	0.20	0.20	0.33	0.50	1	4.00	5.00	6.00
Distance from Religious Buildings	017	0.17	0.20	0.20	0.25	0.25	1	3.00	4.00
Distance from Public Building	0.14	0.17	0.14	0.17	0.20	0.20	0.33	1	3.00
Distance from Commercial Area	0.11	0.14	0.14	0.12	0.17	0.17	0.25	0.33	1

Table 3. Judgment matrix of criteria

The accuracy level of CA model has been observed by comparing the available classified data of 2022 from the prediction results of previous years classified data (Tariq, Mumtaz, 2022) 2002 and 2012. The accuracy of CA-ANN model was observed as 91 % as comparing the result of predicted and classified data of LULC for the years 2022 (known classified data). Then, the future predictions for the years 2032 and 2042 were performed with several spatial variables i.e. digital elevation model (figure 4), distance from roads, river, health facilities, public and religious building as well commercial areas facilities (figure 2).

In this first step the area change and transition potential modelling has been performed with ANN (artificial neural network) then cellular automata simulations were used for prediction. Then, the trained CA model has been used in this research because of this competences and ability of integrated modeling with the spatiotemporal datasets for prediction of the LULC for the years 2032 and 2042. The neural network curve for years 2032 and 2042 shown in figure 5. The simulated results of the CA model (Aburas et., 2016) have also been adopted in this research that will also be beneficent for the urban planners and decision makers to take some necessary measure to words the for urban sustainability.

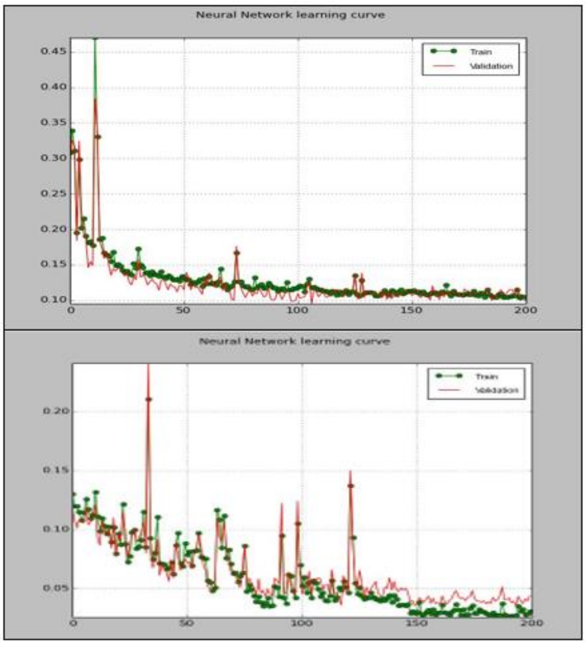

Figure 5. (a)2032 and (b)2042 NN learning curve with 200 Iterations

Criteria	Weight
Road Network	0.256
Distance from Petrol Pump	0.231
Distance from Water Bodies	0.187
Distance from Residential Area	0.113
Distance from Educational Facilities	0.076
Distance from Health Facilities	0.063
Distance from Religious Buildings	0.035
Distance from Public Building	0.023
Distance from Commercial Area	0.016

Table 4. Weights of selected criteria

3. RESULTS AND DISCUSSIONS

3.1 Suitability Assessment

195 petrol pumps were selected across study area to identify their level of competence by use of standards criteria with their suitable distance (Ulasi et al., 2020). Results of criteria assessment are shown in Figure 6. GIS-based suitability model resulted that 23 petrol stations out of 195 do not follow compliance standards shown in red color while 171 petrol pumps shown in Green meeting all the 8 selected standard criteria.

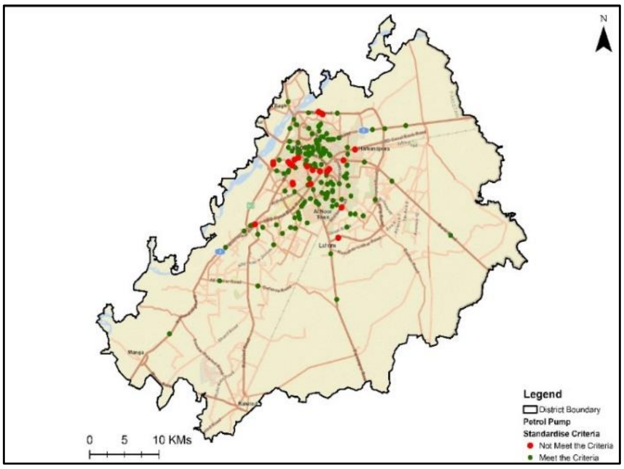

Figure 6. Suitability Map of Petro Pumps

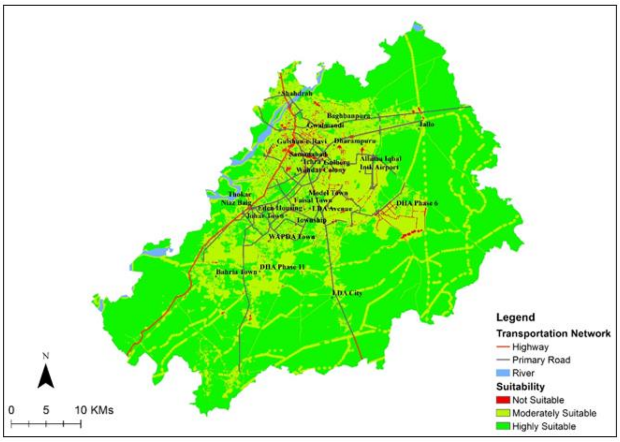

Figure 7. Petrol Pumps Site Suitability Map

There were eight main criteria's to be considered important for installing a new petrol station. All Eight criteria were merged using their weights and develop a land suitability map for the petrol pumps (table 1, 2). Figure 7 is showing the suitable areas in red, yellows and green color indicating Less, Moderate and high suitable areas to install a petrol pump in the study area. It is be attributed from the results that 65% area of Lahore district is highly suitable, while only 9% land is not Suitable to install petrol station.

These suitable maps were merged with urban predicted built-up for 2032 shown in figure 8 (a) to identify the suitable land fall within urban area. It is calculated that 12% highly suitable land would lie within the urban built up where new petrol pump can be installed. Same procedure was applied on predicted Urban built-up 2042 and resulted that 6% suitable land would be available to install new petrol pumps shown in in figure 8 (b) within the Urban Built-up predicted using CA model for year 2042.

3.2 Proximity Assessment

Proximity is criteria based more specific approach to assess the suitability of existing Petrol pumps from various land uses (Khahro, Memon, 2017). It is observed from results shown in figure 9 that all the Pumps are located along the roads while some are found near to health facilities and public buildings. According to Physical planning standard, a petrol pump should not be located less than 15 meters from a road. In a net shell three quarter, 74% of petrol pumps did not meet the set standard of 15 m from the road. Results revealed that in the study area 54% of petrol pumps meet the criteria of 20meter distance from the residential area while 45% do not. The likely reason for this can be heavy traffic on the road in those areas. Again, it was found that many petrol pumps were far away from the commercial area. There are only 11% didn't meet the standard criteria while 89% of petrol pumps are located greater than the 10-meter distance from the commercial area. As per standard criteria, petrol pumps should not be located adjacent to a public or religious building or they must be located 15 m and 100 m away from public and religious buildings respectively. Results revealed that the majority of the pumps meet this criterion. There is only 1% station didn't meet the criteria (Figure 9).

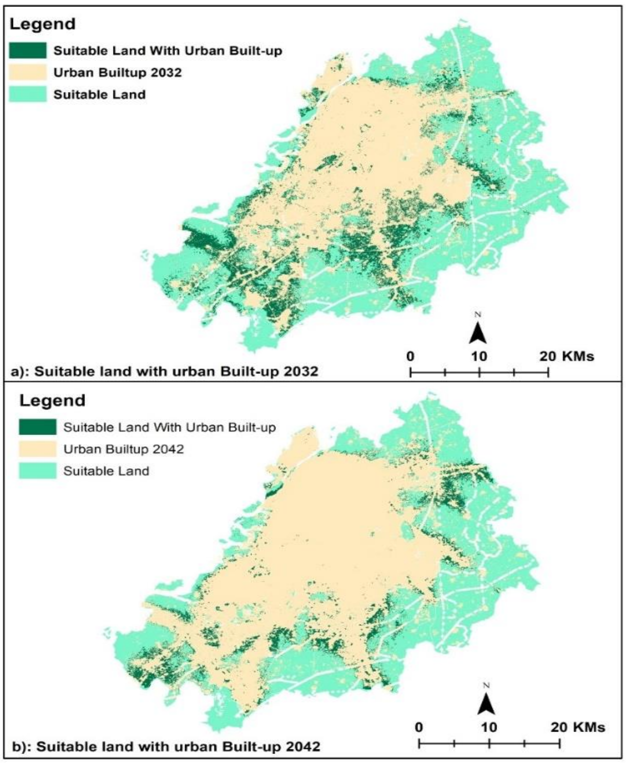

Figure 8. Map of suitable land with predicted urban built-up 2032 (a) and 2042(b)

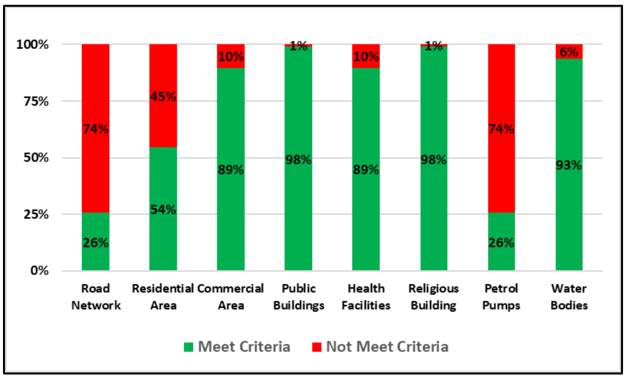

Figure 9. Petrol pumps suitability graph

The distance of stations from health facilities is a major criterion. A petrol pump must have to maintain a minimum distance of 100 m from health facilities. A comparison was developed between the existing petrol stations and their distance from health facilities. The results indicate that 89% of petrol pumps meet this set criterion. Only 11% station couldn't meet this standard. It is observed from the table that there must be a minimum of 400 m distance between neighboring petrol pumps. There were only 50 petrol pumps found located 400m away from the neighboring station, apart from these 50 petrol stations, the mean distance between reaming 144 neighboring stations was found about 40 meters. Results showed that more than half of the station was located less than 400m from their neighboring station. The shortest distance of 10 m was observed between two filling station with no road separation. However, there is only 26% station that meets 400m distance criteria from their neighbor station while 74% do not.

3.3 LULC Distribution (Past - Present - Future) and Accuracy Assessment

The research results determined that the dynamic temporal LULC changed intensively as well the urban area also expanded drastically. Figure 10 is showing the results of random forest algorithm based supervise classification of LULC of Lahore. Whereas, figure 10 is also showing the temporal LULC changes graph where increasing trend was reported in built up and decreasing trend reported in other classes i.e. vegetation, water and barren land. The classification accuracy has been accessed using confusion Metrix process and the gained accuracy for the year 2002, 2012 and 2022 were as 82%, 89% and 92 % respectively (Table 5). Whereas the kappa coefficient was as 0.74, 0.85 and 0.87 for years 2002, 2012 and 2022 respectively. The predicted results of cellular automata for the years 2032 and 2042 are seen in figure 11. Table 6 is showing the area of classes used for assessment in past, present and future scenario. The neural network-based transition potential modeling performed with 200 iterations and the current validation kappa was 0.66 and 0.87 for year 2032 and 2042 respectively.

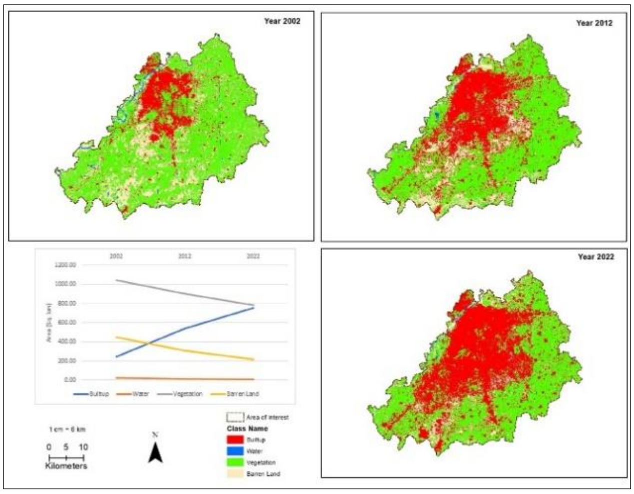

Figure 10. LULC Map for the year 2002, 2012 and 2022

	Classes	User	Producer	Overall	Kappa
2002	Builtup	82.92	73.91	82	0.74
	Water	77.27	65.38		
	Vegetation	81.6	93.42		
	Barren	84.61	81.48		
2012	Builtup	87.71	87.71	89	0.85
	Water	85.18	82.14		
	Vegetation	91.07	92.72		
	Barren	89.23	89.23		
2022	Builtup	94.73	92.64	92	0.87
	Water	85.71	88.88		
	Vegetation	89.47	94.44		
	Barren	89.36	85.71		

Table 5. Accuracy assessment of Land use land cover classes for years 2002, 2012 and 2022

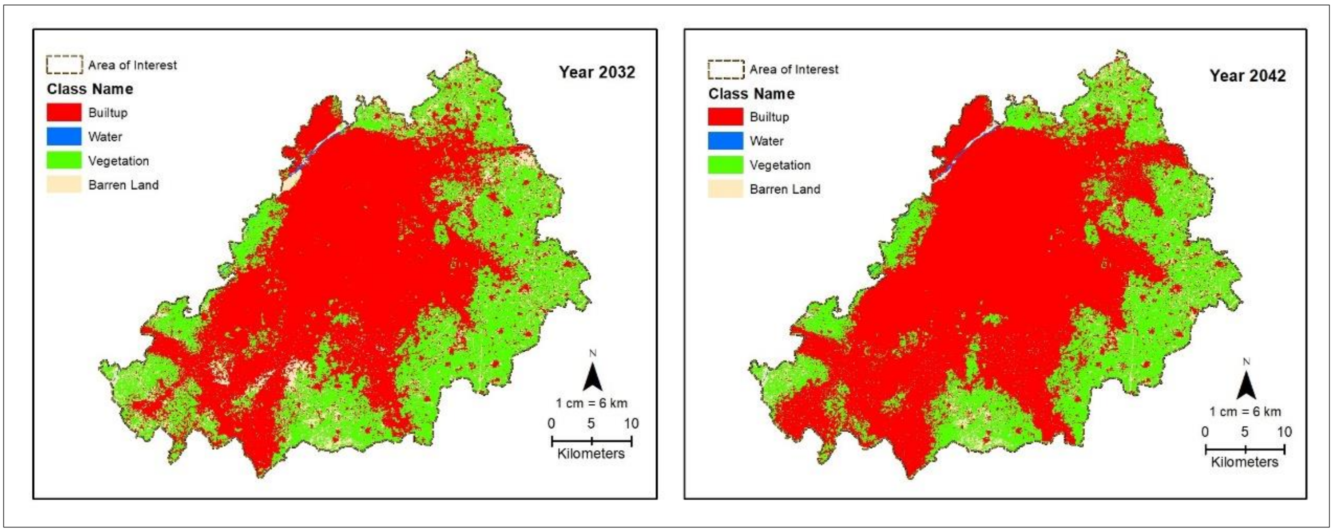

Figure 11. Predicted LULC map for the years 2032 and 2042

3.4 Population Trend and Urban Sprawl

The builtup of Lahore is increasing rapidly with population growth (table 8). The Landscan population (https://landscan.ornl.gov/) distribution map of Lahore showing in figure 12. Whereas, in the table 7 census of 1998 and 2017 results showing the population of Lahore which has been increased with the growth rate of 3.0 every year (Source: Pakistan Bureau of Statistics). The population data has also been used to observe the rate of change in population. Figure 13 is showing the past, present and future pattern of urban sprawl of Lahore with respect to valuated patrol stations and future trends of sprawl for the years 2002, 2012, 2022, 2032 and 2042. The increasing in population also observed in the population distribution data as shown in figure 12.

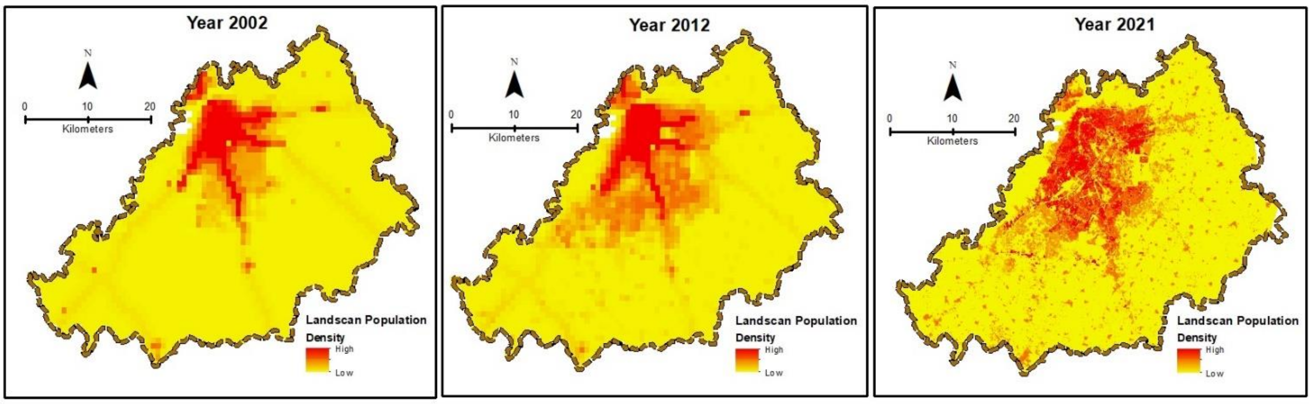

Figure 12. Landscan population distribution 2002, 2012 and 2021

Id	Classes	2002	2012	2022	2032	2042
1	Builtup	246.27	540.08	753.03	1009.62	1142.97
2	Water	24.18	10.96	8.75	3.36	3.12
3	Vegetation	1043.38	903.00	782.99	597.04	520.08
4	Barren	446.92	306.71	215.97	148.34	91.95

Table 6. Past, Present and Predicted Land use land cover classes area in Km^2

No.	Population Census		
1	Year	1998	2017
2	Population	6,340,114	11,119,985

Table 7. Population census results for the years 1998 and 2017 (Source: Pakistan Bureau of Statistics)

Class Name	2002-2012	2012-2022	2002-2022	2022-2032	2032-2042	2002-2042
Builtup	293.81	212.95	506.76	256.59	133.35	896.70
Water	-13.22	-2.21	-15.43	-5.39	-0.24	-21.06
Vegetation	-140.38	-120.00	-260.39	-185.95	-76.96	-523.30
Barren Land	-140.21	-90.74	-230.95	-67.63	-56.39	-354.96

Table 8. Increase/Decrease (+, -) trends of Land use land cover in Km^2

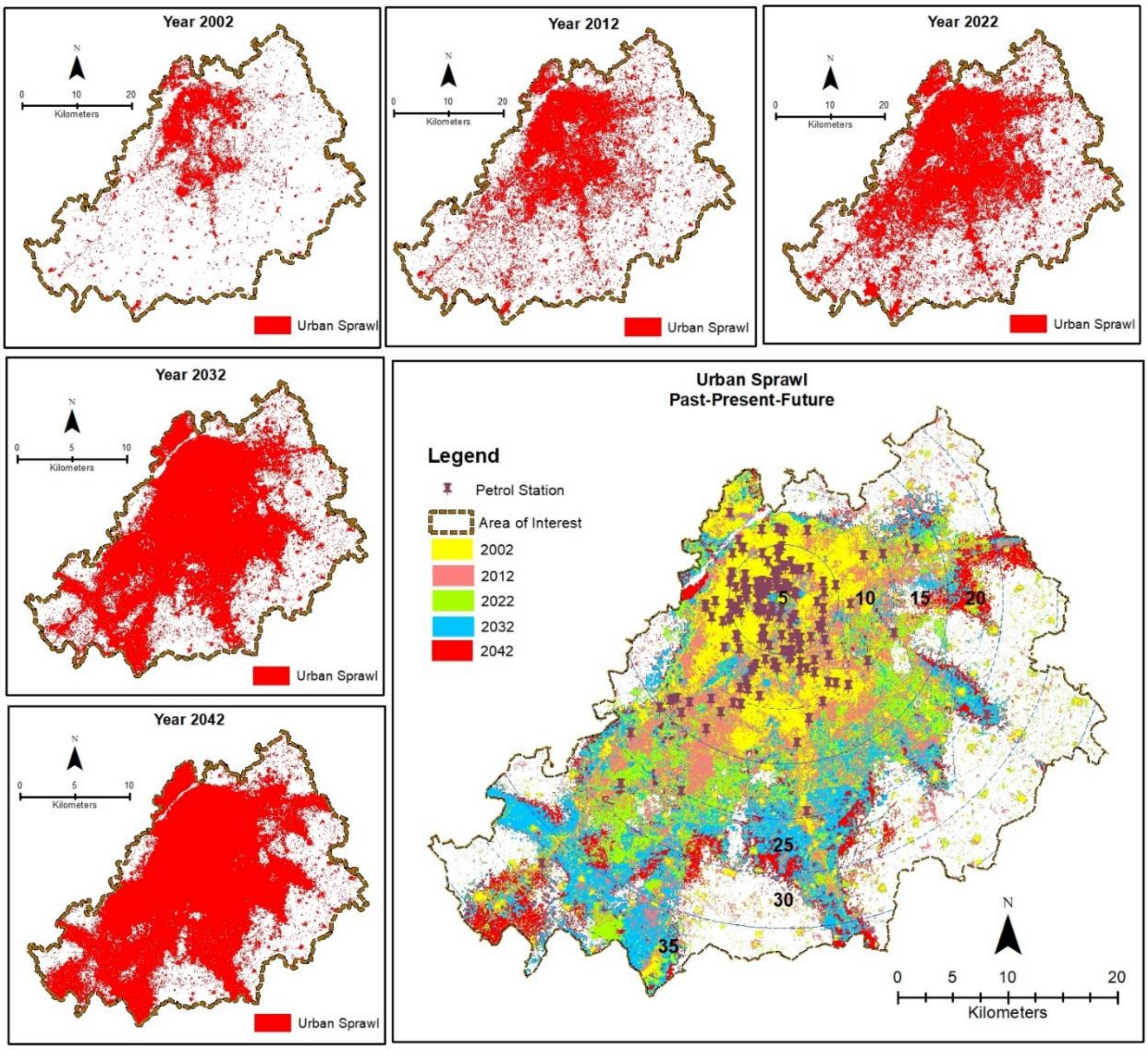

Figure 13. Past, present and predicted urban sprawl with petrol station and buffer zoning of growing builtup

The evaluation of this study may helpful for planner and decision maker for improvement of city infrastructure and provided facility for improvement of city infrastructure as well as sustainable future development purposes. Therefore, in this research the some randomly selected petrol station locations identified and valuated with defined criteria. The location of stations is also shown in figure 13.

Also, the trend of past, present and future trend of temporal LULC changes especially increasing urbanized trend observed that need serious consideration for cities sustainability especially in the case of developing country where serious consideration much required.

4. CONCLUSION

The study showed that geographic information system is essential tool that can assist authorities to ensure the best locations for new development project and take appropriate measures under the consideration of rapid urbanization growth. It is concluded that 88% of existing pumps are located in suitable areas while 12% did not in satisfactory range. The study highlights the gaps of existing petrol pumps land suitability issues and provides the way-out for the future to deal with such problems in efficient manners. Whereas developing countries like Pakistan already facing many problems regarding urbanization. Therefore, some necessary measures will be much useful to overcome the issues cause by urbanization as discussed in this study with past present and future perspective of builtup changes. If, the rate of change in urban pattern continuously increased as observed in this study in the light of different criteria's then it will be a serious concern for land suitability of patrol pump. Therefore, the timely management & planning will be much beneficent and fruitful. This research also demonstrated the use of GIS in siting the spatial problem of petrol pumps locations suitability by applying spatial analytical techniques. The Study highlights the gaps of existing petrol pumps land suitability issues and provides the way-out for the future to deal with such problems in efficient manners.

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