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Site suitability analysis for urban development using geospatial technologies and AHP: A case study in Prayagraj, Uttar Pradesh, India

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Abstract
During the planning of locating suitable site for urban development is critical and challenging task. This study has been performed to identify suitable site for further development of city using Geospatial technologies and Analytical Hierarchy Process (AHP) method in Prayagraj, Uttar Pradesh, India. Various thematic layers such as LULC, Lithology, Soil, Drainage, Slope, road and river proximity were considered in this study. Selected seven thematic layers and their features were assigned suitable weights on the Saaty's scale according to their relative importance and then normalized by using AHP technique. Finally, the thematic maps were integrated by weighted linear combination method in a GIS environment to produce suitable sites. The final site suitability map was divided into five different Zones. The area under very low, low, moderate, high and very high land stand at 6.81%, 13.27%, 34.54%, 31.28%, 14.08% respectively. The present study depicts the zones in the study area and can be helpful for the better land use planning in sustainable urban development.

Keywords: AHP, geospatial technologies, Prayagraj

1. Introduction

In the developed world, urban development rates are fixed or low due to normal settlement patterns and relatively stable populations. By contrast, developing countries are still in the process of industrialization and urbanization results in ever increasing population of the urban lands and are therefore only beginning to face the additional challenge of making their development sustainable in the long term (Kiamba, 2012) [4]. Unplanned and uncontrolled rapid growth has resulted in serious negative effects on the population and environment of the suburbs (Chadshan and Shankar, 2012) [2]. Unplanned growth of population in any area ultimately causes the slum problems, air pollution, water shortages, energy shortages, traffic congestion, inadequate sewage and sanitation, and inadequate urban and industrial waste disposal capacity. Therefore, much attention has been paid to addressing the issue of urbanization and its negative effects on social, economic and environmental issues. Sustainable development must be practiced by both developed and developing countries (Raddad *et al*., 2010) [8]. The 21st century has brought the direction of "sustainable urban development" and this concept adds new dimensions to urbanization and the urgent need to improve the current level. Smart city concept comes from integrating technology into a strategic approach to sustainability.

In the resent year geospatial technologies is most frequently used approach to understand area by providing systematic view of the large area, quick and spatial information. Remote sensing data is used to create different thematic layers. However AHP technique uses to determine the weights of various thematic layers and their classes to help the decision maker as well as planners to examine all the data before final decision (Trung *et al*, 2006; Bagheri, 2013) [15, 1]. In the past, number of studies has been carried out to identify the suitable site for urban development using geospatial technologies and AHP with successful results (Jain and Subbaiah 2007; Kumar, and Shaikh, 2012; Kumar and Biswas 2011; Kumar and Kumar 2014; Santosh *et al* 2018) [6, 5, 7, 9].

In this paper we have considered Geospatial technologies for selecting suitable sites for urban development in Prayagraj, Uttar Pradesh. Seven criteria were selected namely road proximity, river, land use, lithology, soil, slope, drainage for selection of suitable site. The generated maps of these criteria were standardized using pairwise comparison matrix known as analytical hierarchy process (AHP).

2. Study area

Prayagraj is one of the largest cities of UP (Uttar Pradesh) in terms of area and population. Prayagraj is located at 25°28‘N latitude and 81°54‘E longitude (Fig 1). Elevation of study area is 98 meters from mean sea level. The city may be divided into three physical parts Trans-Ganga or the Ganga par Plain, the Ganga-Yamuna doab (confluence), and Trans-Yamuna or the Yamuna. The general topography of the city is plain with moderate undulations. As per Census of India, 2011, the total area of the city is approximately 70 km^2 and the population is 1,168,385. The City area is divided into 97 wards for administrative convenience.

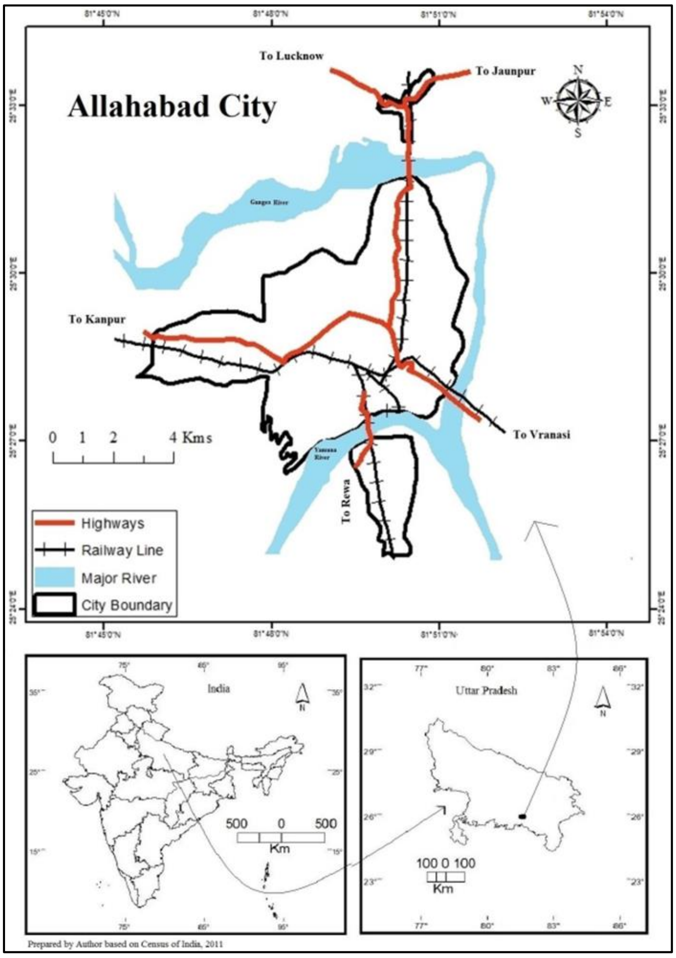

Fig 1: Showing the study area, Prayagraj -India

3. Materials and Methods

3.1 Thematic maps Generation

To identify the suitable site for further development of city seven different layers such as LULC, Road, River, Soil, Slope, Drainage, Lithology were generated using remote sensing, toposheet and Google earth data with the help of ERDAS imagine and ArcGIS software.

The data source used in this study is given in the table1. Landsat data was used to prepared LULC map of study area using supervised classification. However Cartosat-1 Digital Elevation Model (DEM) was used to generate slope of the study area. The lithology map was digitized and prepared in ArcGIS software using the geology map obtained from the Geological Survey of India. Soil map was acquired in vector format from the digital soil map of the world site. Road and river was extracted from toposheet and Google earth data. All the thematic layers were converted into raster format using ArcGIS.

Table 1: s*ource* of different data

Data	Source
Landsat	U.S. Geological Survey website www.earthexplorer.usgs.gov
Cartosat-1	NRSC/ISRO (www.bhuvan.nrsc.gov.in)
Soil	(https://worldmap.harvard.edu).

3.2 Assignment of weight using AHP

In the present study analytical hierarchy process (AHP) developed by Saaty (1980, 1990) [10, 11] was used to assign the weights to different thematic layers. AHP is the most frequently used method for determining weightage for different layer. The AHP method by Saaty (2008) [13] i.e. the pairwise comparison matrix defines the criteria by comparing each criterion against the other criteria which will help in deciding suitable site. A standard Saaty’s 1-9 scale was used to determine the relative importance values for all themes and their respective features, where value ‘1’ denotes “equal importance” between the two themes, and the value ‘9’ denotes the “extreme importance” of one theme compared to the other one (Saaty 1980) [10] shown in Table 2.

Table 2: Scale for pair-wise comparison matrix

Intensity Importance	Linguistic variables
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to the strong importance
5	Strong importance
6	Strong to the very strong importance
7	Very strong importance
8	Very to the extremely strong importance
9	Extreme importance

The following steps were carried out to compute the final weights of all the parameters:

1. Sum the values in each column of the pair-wise comparison matrix using the formula,

$$L_{ij} = \sum_{n=1}^{n} C_{ij} \quad [1]$$

WhereL_{ij} is the total column value of the pair-wise comparison matrix and

$C_{ij}$are the criteria used for the analysis

2. Divide each element in the matrix by its total row to generate a normalized pair-wise comparison matrix.

$$X_{ij} = \frac{C_{ij}}{\sum_{n=1}^{n} C_{ij}} \quad [2]$$

Where X_{ij} = normalized pair-wise comparison matrix

3. Divide the sum of the normalized row of the matrix by the number of criteria/parameter (N) to generate the standard weight by using the following formula,

$$W_{ij} = \frac{\sum_{j=1}^{n} X_{ij}}{N} \quad [3]$$

WhereW_{ij} = Standard weight

4. For calculating the consistency vector values the following formula was used:

$\lambda = \sum_{i=1}^{n} CV_{ij},$

Where λ= Consistency vector ……………………......... [4]

5. Consistency Index (CI) was used as a deviation or degree of consistency which was then calculated using the formula below:

$CI = \frac{\lambda - n}{n-1}$

Where CI = Consistency Index, n = Number of criteria…. [5]

6. Consistency ratio (Cr) is calculated by using the formula:

$Cr = \frac{CI}{RI}$………………………………………………. [6]

Where, RI = random inconsistency (Table 3)

If the value of Consistency ratio is less than or equal to 0.10 then the inconsistency is acceptable.

Table 3: Random inconsistency values (Saaty, 1980) [10]

n	2	3	4	5	6	7	8	9
RI	0	0.52	0.9	1.12	1.24	1.32	1.41	1.45

Where n = number of criteria used and RI = Random Inconsistency

3.3 Assigning criteria weights in GIS

The level two-hierarchy of each layer was represented in GIS in raster form. All the thematic layers were reclassified into different classes and weight was given using the variables and the importance of each layer with respect to their role. The method of the weighted linear combination was applied for the identifying area with growth potential of suitable site. The weights of the factors were multiplied by the weights of features of each factor where all the attributes were calculated in GIS to obtain the Total Scores (TS) (Saaty 1980) [10] by using the following formula:

$TS = \sum W \times R$ ……………………………….…………… [7]

Where, TS = Total Score, W and R, were the weight of the parameters and the weight of the features respectively. The suitable zone is then calculated using rather the star calculator from the spatial analyst tools in GIS using the Equation given below

Suitable site =LU+RO+SW+LT+SO+SL+DR.................... [8]

Where, LU = Land use and Land cover, RO = Road, SW = River, LT =Lithology, SO = soil, SL = Slope, DR = Drainage.

4. Result and discussion

The analysis of identifying area for further growth of city was carried out using the seven parameters which include LULC, Road, and Surface water, Lithology, Soil, Slope and Drainage using AHP. The assignment of the weight and the weight normalization of each parameter with each of its features are represented below:

4.1 Assignment of weights to the thematic layers

In the present study, the pair wise comparison matrix of the seven parameters was computed in the square matrix where each features of the parameters form in the diagonal matrix are always 1. The parameters assigned in this study for pair wise comparison are Surface water (SW), LULC, Road (RO), Soil (SO), Slope (SL), Drainage (DR) and Lithology (LT). In the pair-wise comparison matrix, Normalized pair wise matrix and consistency analysis was calculated using equation 1 to 4 and shown in the table 4 and 5

Table 4: Pair-wise comparison matrix of the thematic layers

	SW	DR	LU	LT	RO	SO	SL
SW	1.00	3.00	4.00	5.00	6.00	7.00	8.00
DR	0.33	1.00	2.00	4.00	4.00	5.00	6.00
LU	0.25	0.50	1.00	3.00	4.00	6.00	7.00
LT	0.20	0.25	0.33	1.00	3.00	4.00	6.00
RO	0.17	0.25	0.25	0.33	1.00	3.00	4.00
SO	0.14	0.20	0.20	0.25	0.33	1.00	3.00
SL	0.13	0.17	0.14	0.17	0.25	0.33	1.00
Total	2.22	5.37	7.93	13.75	18.58	26.33	35.00

Table 5: Normalized pair wise matrix

	SW	DR	LU	LT	RO	SO	SL	Total	Normalized WT
SW	0.45	0.55	0.50	0.36	0.32	0.26	0.22	2.70	0.39
DR	0.15	0.18	0.25	0.29	0.21	0.18	0.17	1.46	0.21
LU	0.11	0.09	0.12	0.21	0.21	0.22	0.2	1.19	0.17
LT	0.09	0.04	0.04	0.07	0.16	0.15	0.17	0.74	0.11
RO	0.07	0.04	0.03	0.02	0.05	0.11	0.11	0.46	0.07
SO	0.06	0.03	0.02	0.01	0.01	0.03	0.08	0.29	0.04
SL	0.05	0.03	0.01	0.01	0.01	0.01	0.02	0.17	0.02

Consistency Analysis

Consistency analysis was calculated by multiplying the pair-wise comparison matrix values and the normalized pair-wise matrix of each feature which is (7*7) matrix and shown in table 6. Therefore, the Consistency vector (λ) which are in the diagonal form are further calculated using the equation 4 which is 6.73 where $\lambda max$is the maximum Consistency vector, *n* is the number of parameters; and RI is the Random Inconsistency Index (Saaty and Vargas, 1993; Saaty, 1994) [12, 14]. Therefore equation 5 & 6 was calculated for the Consistency index (CI) and Consistency ratio (CR) respectively. The value of Consistency ratio (Cr) is found to be –0.03 which is < 0.1, hence the inconsistency is found to be acceptable (Saaty, 1980) [10] where further process can be preceded but if the consistency ratio is >0.1 then the inconsistency is unacceptable which means that further work cannot be preceded

Table 6: Consistency analysis of pair wise comparison matrix and normalized pair wise matrix

	SW	DR	LU	LT	RO	SO	SL	Diagonal value
SW	3.1562	2.512422	2.486633	2.842424	3.192825112	3.556962025	3.914285714	3.1562
DR	1.847558	1.304348	1.201562	1.4	1.784753363	2.063291139	2.39047619	1.3043
LU	1.652711	1.093168	0.908381	0.963636	1.304932735	1.617088608	2.028571429	0.9083
LT	1.076758	0.71118	0.551817	0.509091	0.665470852	0.898101266	1.183809524	0.5090
RO	0.664788	0.46118	0.372084	0.339394	0.376681614	0.477848101	0.673809524	0.3766
SO	0.398103	0.293367	0.248123	0.234574	0.248814862	0.273417722	0.359319728	0.2734
SL	0.209161	0.17713	0.164489	0.161472	0.166773436	0.176537071	0.2	0.2
								λ= 6.73

Here, the value of consistency vector (λ) is calculated as 6.73. Further using equation [5] and [6] consistency ratio was calculated as (-0.03) and found acceptable.

Table 7: Normalized and final weights of different features of eight thematic layers for groundwater potentiality.

Category	Normalized wt	Criteria	Final (wt)
Land use / cover	0.17	Other waste land	0.052
		Scrub land	0.028
		Current Follow land	0.022
		Agricultural	0.023
		Plantation	0.015
		Built-up land	0.018
		Gullied	0.007
		Water bodies	0.007
Slope	0.02	0-1(Low)	0.008
		1-2 (moderate)	0.005
		2-3 (high)	0.003
		3-4 (very high)	0.002
Soil	0.04	Silt loam	0.032
		Sandy Clay	0.008
Lithology	0.11	Clayey sand	0.039
		Sandy clay	0.031
		Gravel Sand. Slit	0.018
		Habitat Mask	0.015
		Water Body	0.006
Surface water	0.39	2500m Buffer	0.154
		2000m Buffer	0.1
		1500m Buffer	0.063
		1000m Buffer	0.05
		500m Buffer	0.022
Road	0.07	1000m Buffer	0.027
		2000m Buffer	0.017
		3000m Buffer	0.013
		4000m Buffer	0.009
		5000m Buffer	0.004

4.1.1 Land use/Land covers of the study area

Land use land cover of this study is categorized as wastelands, Scrubland, Current fallow land, Plantation / orchards Agriculture, Built up land (Urban / Rural), Gullied / Ravines, Water bodies (fig 2). In the study area, major land cover and land use classes were observed to be agriculture followed by current fallow. By applying AHP suitable score is given to different land use land cover. Normalized and final weights of different category of LULC are shown in the table 7.

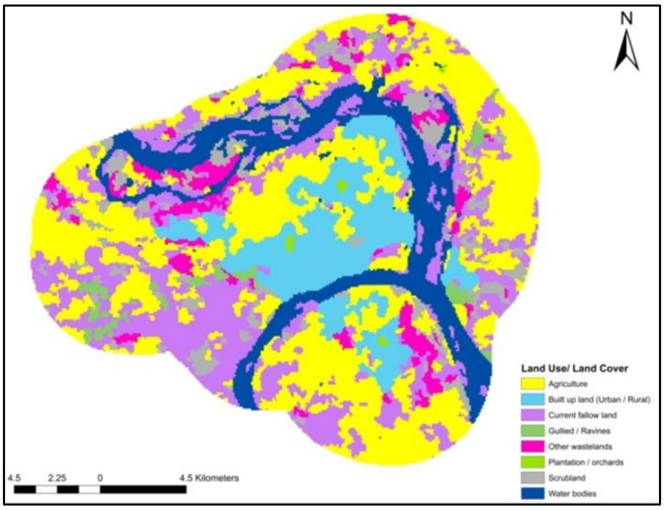

Fig 2: LULC map of study area

4.1.2 Lithology

Lithology of the study area is categorized into Clayey Sand, Sandy Clay, Gravel/Sand, Silt, Habitation Mask and Water Body (fig.3). The AHP method was applied to all layer of lithology to derive normalized weight and final weight which is shown in the table 7.

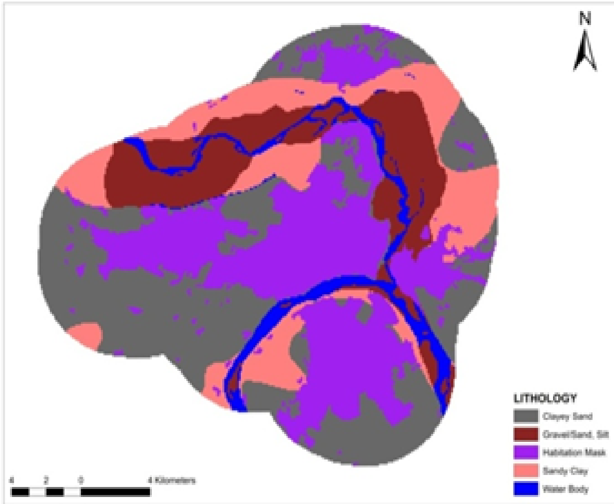

Fig 3: Lithology map of study area.

4.1.3 River

Study area is at the bank of River Ganga and Yamuna. Therefore region is experiencing floods in low-lying areas. The flood plain is an important part of river system. This flood plain is also taking into consideration for selection of suitable site. However being a part of river system these areas are prone to flood during monsoon. Therefore it is very important to select suitable site which is away from the river. The river network for study area was prepared using SOI toposheet and 2017 Satellite image. Five buffer zone was created at 500, 1000, 1500, 2000, and 2500m (fig 4). Final weight for different buffer zone of river is shown in the table7.

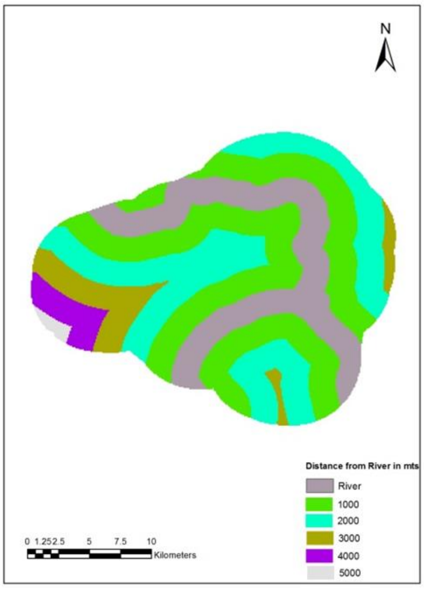

Fig 4: River buffer map of study area

4.1.4 Road
Road also play important role in site suitable for selection of suitable sites. The road network for study area was prepared using SOI Toposheet and Google earth data. Five buffer zones were created at 1000, 2000, 3000 and 4000m (fig.5). The AHP method was applied to the all branch of road to derive the final weights which is given in the table7.

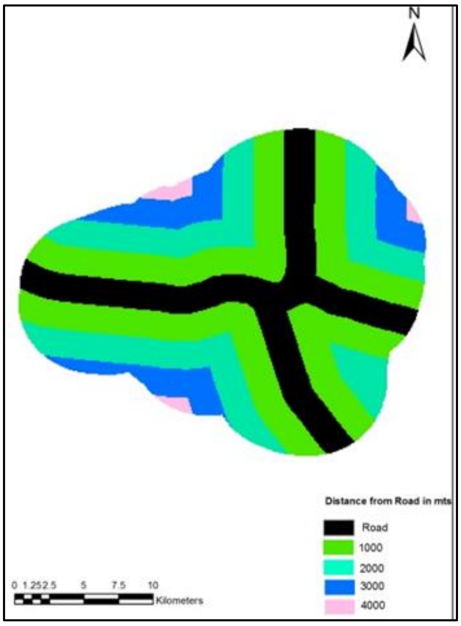

Fig 5: Road buffer map of study area

4.1.5 Slope
The slope of land surface is a crucial factor for selecting suitable sites. Steep slopes will lead to higher costs for development of settlement while flat areas cost less. Therefore, the flatter area gets a higher score in this research work. Map of the study area was prepared using Cartosat-1 DEM data in ArcGIS and was divided into four classes as low (0-1%), moderate (1-2%), high (3-4%) and very high (>4%) shown in figure 6. The final weights of the slope feature are shown in table 7.

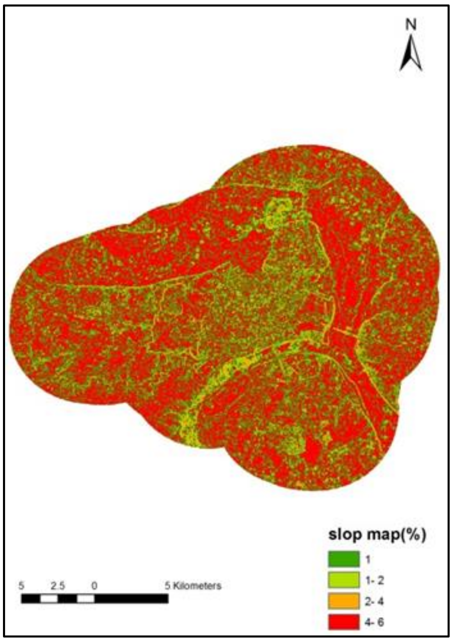

Fig 6: Slope map of study area.

4.1.6 Soil
Mainly two types of soil are found in the study area namely silt loam and sandy clay (fig.7). The AHP method was applied to the soil features to derive the final weights.

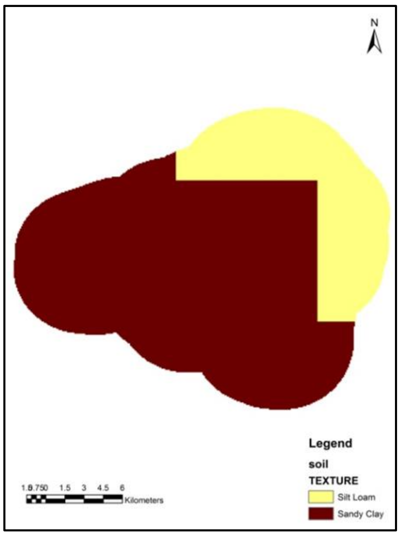

Fig 7: Soil map of study area

4.2 Assessment of suitable site
After computing the final normal weights of all the thematic layers and their individual features, all the thematic layers were converted in to raster format and added with one another using raster calculator in ArcGIS software in order to delineate suitable site in the study area. The very high suitable area occurs about 14.08% of the total area. The next zone is high suitable zone which occupies about 31.28% of the area. The moderate zone is marked by 34.54 % of the total area. Areas with poor zone constitute 13.27% of the total area. Very poor zone consist of 6.81% of study area which is mainly river and closer to river flood zone area.

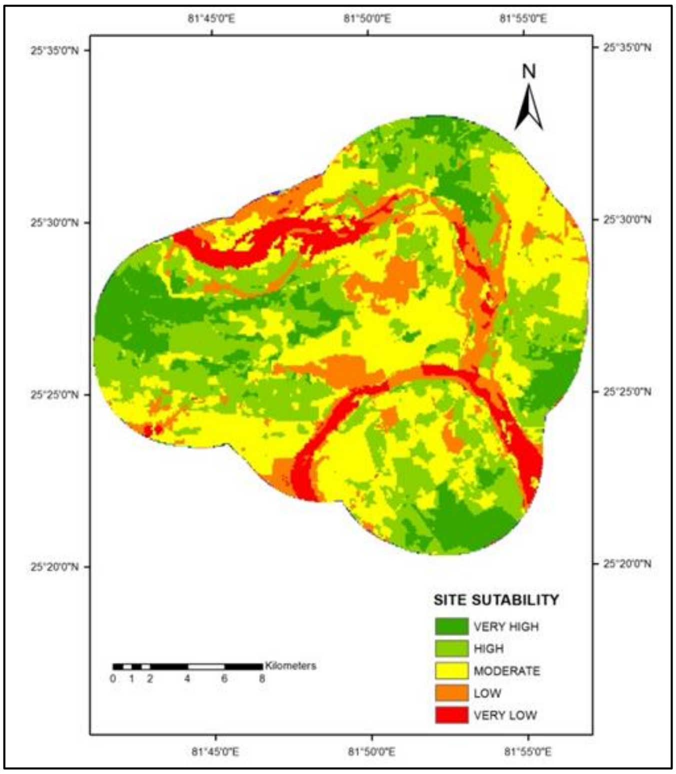

Fig 8: Suitable site index map of the study area

5. Conclusion

Population growth and infrastructure development of any city of India causes LULC change, demand of natural resource, land conflict and traffic jam. However, selection of suitable site for urban development is a strategic process, requiring new approaches, planning, operations, networks and urban project management. Cities such as Prayagraj need a comprehensive reform of social, economic and urban infrastructure. The government of India has launched many plans to achieve the gap requiring the transformation of Prayagraj into a smart city with a great cooperation between city managers, the private sector, academics, and citizens. Population of study area is increasing at a very rapid rate and needed to develop various urban utilities to fulfill the urban need. In this context, urban development monitoring, and utility mapping are necessary to make effective policy for the development of unplanned areas. Remote sensing techniques and GIS tools have become important in the management of the urban environment. The result of the study shows that there are amply of opportunity and areas to develop Prayagraj urban areas. However cooperation between academia, government and the private sector is critical to ensuring the success of sustainable development of urban area. Civil participation and exchange of information are essential. Government leaders need creative and innovative processes and the tools to share data, ideas and gather information, which will help those better shape decisions

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