Site suitability analysis for urban development using GIS based multicriteria evaluation technique: a case study in Chikodi Taluk, Belagavi District, Karnataka, India

Santosh C*, Krishnaiah C and Praveen G Deshbhandari
Department of Marine Geology, Mangalore University, Mangalagangothri-574199, Karnataka, India
santoshchougale.27@gmail.com

Abstract. Determination of appropriate site location for urban development is critical issue in hilly areas. The present study aims the Geographic Information System (GIS) and Multicriteria Evaluation Technique (MCE) based site selection for urban development in Chikodi taluk, Belagavi district, Karnataka. In this study six thematic layers were considered such as slope, land use/land cover, road proximity, land value, lineaments and aspect, the generated thematic maps of these criteria were standardized using pair wise comparison matrix known as Analytical Hierarchy Process (AHP). A weight for each criterion was given by comparing them with each other according to their importance and all the six maps were converted into raster. Finally with the help of these weights all the six maps were integrated and overlaid for the preparation of site suitability map for the urban development. The final site suitability map was divided into five different suitability categories. The area under very low, low, moderate, high and very high lands stand at 1.81 km², 12.71 km², 37.94 km², 66.88 km², and 22.44 km² respectively. The present study allows the local people as well as planners for the appropriate plans of land use planning in sustainable urban development.

1. Introduction
Due to the population growth and urbanization sprawl, it is desirable to find out site suitability for city development [1-2]. In this study Chikodi urban case study has been selected. Chikodi is rapidly growing taluk in the Belagavi district of Karnataka. Identification of suitable locations for urban development is mandatory for sustainable environment and challenging particularly in the growing real estate market. Because of efficient statistical property many researchers has used Analytical Hierarchy process method [3]. It is one of the most extensively known and it enable the users to find out the weights of the parameter in the result for different problems. Site suitability for urban growth is essential and efficient to move towards better urban growth location and the approach allocate different weight and criteria [4]. To determine the site suitability first need to collect suitable locations of development by using maps of specific area [5]. In urban development for controlling and monitoring changes geographic information system is one of the significant tool and also for its impact on ecosystem [6]. For environmental sustainability geographic information system is best tool and it aims to best location for land suitability [7]. Fechner introduced the pairwise matrix [8] and Thurstone has developed [9]. Saaty proposed the Analytical Hierarchy Process (AHP) method [10]. AHP is one of the efficient process and help the decision maker as well as planners to examine all the data before
final decision [11-12]. Geographic information system and analytical hierarchy process has been integrated to check the importance of criteria and [13].

2. Study Area
It is covering area of 142 sq. km. The geographical extent of the area ranges from 16°20’0” to 16°30’0” N latitude and 74°32’0” to 74°38’0” E longitude (Figure 1). Clay and Loamy soil has been observed in the present study. It receives and annual rainfall of 750mm and it is considered as semi-arid area. It is predominantly underlain by basalt and Agro-climatologically the study area falls under “Northern transitional zone” of Karnataka state.

![Figure 1. Study area](image)

3. Material and Methods
Using the Survey of India (SOI) toposheet (E43U11) base map was prepared on 1:50,000 scales. To study the environmental impact on surrounding villages 5KM buffer zone from existed city was selected for analysis. In the present study six criteria were used for analysis namely land use/land cover, slope, road proximity, land cost, aspect and lineament. Slope map and aspect map are prepared from Shuttle Radar Topographic Mission Digital Elevation Model. Roads are delineated using the top sheet (E43U11) on 1:50,000 scale. Landsat - 8 2017 data has been used for land use/land cover. Weight assigned for all the criteria using the analytical hierarchy process and all the layers were integrated for the preparation of final map.
3.1 Methods
In the study six criteria was selected namely land use/land cover, slope, land cost, aspect, road proximity and lineament. The methodology followed in this study is shown in Figure 2. For the site suitability of urban development it is necessary to give some ranking to each criterion, Saaty’s nine points scale was used for comparison matrix (Table 1). To create ratio matrix different criteria are required and for the input pairwise matrix is considered and for the output weights has been used (Table 4). Once pairwise comparison has finished sum the values of elements in each column and divide every element with their column total and result of the matrix is considered as normalized matrix. Calculate the average of every row of normalized matrix for the criteria weights (Table 5) [14].

To make paired comparisons, just as in thinking, people do not have the intrinsic logical ability to always be consistent [15]. To estimate the consistency, first calculate the weighted sum vector for that multiply pairwise matrix with the weight. After that divide each component by its corresponding component of weightages like first divide by first, second divide by second so on (Table 6). For vector consistency divide the weighted sum by the weights. Once the consistency vector has finished need to calculate the lambda and consistency index. Mean of consistency vector is considered as lambda and consistency index is depending upon the inspection that λ should be equal to the number of criteria or greater than that, λ-n can be considered as a measure of the degree of inconsistency and it is expressed as

\[ CI = (\lambda - n) / (n - 1) \] (1)
CI provides a measure of departure from consistency. For the calculation of C.I. goodness, AHP is compared with Random Index (Table 2) and the output is considered as consistency ratio which is expressed as

\[ CR = \frac{CI}{RI} \]  \hspace{1cm} (2)

If the consistency ratio is lesser than 0.10 then it is reasonable level of consistency in pairwise matrix if the consistency ratio is more than 0.10 then needed to modify in the pairwise matrix. All the layers are converted from vector to raster to avoid the complication [17]. All the maps were overlaid in GIS environment and multiplied with weights for the preparation of final map using the formulae:

\[ \text{Suitability map} = \Sigma [\text{criteria map} \times \text{weight}] \]  \hspace{1cm} (3)

4. Results and Discussion

Slope is a vital criterion for finding the site suitable for urban development. Steeper slopes increase the cost of construction and there will be maximum limit for the floor. The study area ranges from 0-34.95\(^{0}\) and classified into seven. Lower slopes are highly suitable for urban development where higher slopes are not suitable (Figure 3(i), Table 3). Road proximity plays major role for urban development as it connects the settlements and raw materials will be easily transferable. In hilly areas new road construction of new road is very costly. Buffer zone falling under 150m distances is good for suitable site (Figure 3(ii), Table 3).

Land use land cover gives an idea of the present status and in present study there is built-up, agriculture and wasteland. Agriculture is 37.60km\(^{2}\), built-up is 67.86km\(^{2}\) and wasteland is 36.83km\(^{2}\). Once the building is constructed it remains at least for 50–75 years [18]. For the urban development wasteland is highly suitable (Figure 3(iii), Table 3). Lineaments are indicators of weak zone such as joints, fracture and faults. Buffer zone has been created with an interval of 100m and ranges from 0-700m. More than 600m is considered as highly suitable for the urban development whereas 100m is not suitable for the urban development (Figure 3(iv), Table 3).

Land cost varies based on its location and at a given point of time. In the present study area buffer zone has been created for urban city boundary with an interval of 800 which varies from 800-4000m. The area falling below 800m is considered as high land value because in the centre of the city the price is high compared to outside of the city (Figure 3(v) Table 3).

Aspect map indicates the direction to which the mountain slopes face. Aspect of each raster cell grouped into compass directions (Figure 3(vi), Table 3). In Northern Hemisphere, north-facing, ten degree slope receives less solar radiation than south-facing slopes of the same gradient. In the winter, the sun’s highest point above the horizon is an acute angle. The north-facing slopes, when exposed to direct sunlight, receive less solar radiation per unit surface area than do the south-facing slopes. Because the slope faces away from the sun, the solar radiation striking a north-facing slope hits the surface at a shallow, or acute, angle. Consequently, sunlight strikes the slope in a more diffuse pattern, delivering to the surface less-solar energy per unit area [19]. In present study south portion is considered as highly suitable and north is less suitable for residential buildings based on the amount of sunlight available.

Integrated GIS based method for site selection can advocate technically selecting land for sustainable urban development. The advance Analytical Hierarchy Process method is selected to assign the weightages for thematic layers and weighted overlay method is used for integration. The final map is classified in different categories i.e., very low (1.81km\(^{2}\)), low (12.71km\(^{2}\)), moderate (37.94km\(^{2}\)), high (66.88km\(^{2}\)) and very high (22.44km\(^{2}\)) (Figure 4, Table 6). These integrated techniques may be a policy medium for decision makers and urban planners. They can consider a development tool for future scenario of land use planning such as expansion of cities and development in chikodi taluk. Hence, this method may be considered as a development tool for future urban growth.
Figure 3. (i) Slope (ii) LU/LC (iii) Road proximity (iv) Land cost (v) Lineament (vi) Aspect
Figure 4. Final Site Suitability Map

Table 1. Weighting scale nine point

| Scales | Description            | Suitability    |
|--------|------------------------|----------------|
| 1      | Equal                  | Lowest         |
| 2      | Equal to Moderate      | Very low       |
| 3      | Moderate               | Low            |
| 4      | Moderate to Strong      | Moderately low |
| 5      | Strong                 | Moderate       |
| 6      | Strong to Very strong   | Moderate high  |
| 7      | Very strong            | High           |
| 8      | Very to extremely      | Very high      |
| 9      | Extremely              | Highest        |

Table 2. Random Index

| Order Matrix | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| RI           | 0.0 | 0.00| 0.58| 0.9 | 1.12| 1.24| 1.32| 1.41| 1.45| 1.49|
### Table 3. Ranking

| Score | Importance   | Slope in degrees | LU/LC | Road proximity in meters | Land Cost in meters | Lineaments in meters | Aspect |
|-------|--------------|------------------|-------|--------------------------|---------------------|----------------------|--------|
| 7     | Very high    | 0-1              | Wasteland | 0-150 | > 4000 | > 600 | South |
| 6     | High         | 1-3              | -      | 150-300 | 3200-4000 | 500-600 | South, South Est, South West |
| 5     | Moderate high | 3-5              | -      | 300-450 | 2400-3200 | 400-500 | South Est, South West, East, West |
| 4     | Moderate     | 5-10             | -      | 450-600 | 1600-2400 | 300-400 | North, East, North West |
| 3     | Moderate low  | 10-15            | Agriculture | 600-750 | 800-1600 | 200-300 | - |
| 2     | Low          | 15-35            | -      | 750-900 | 0-800   | 100-200 | - |
| 1     | Very low     | -                | Built-up | > 900 | 0-100  | Within city limit | North |

### Table 4. Pairwise comparison matrix

| Criteria | Slope | LU/LC | Road proximity | Land Cost | Lineaments | Aspects |
|----------|-------|-------|----------------|-----------|------------|---------|
| Slope    | 1     | 2     | 3              | 5         | 7          | 9       |
| LU/LC    | 0.50  | 1     | 2              | 3         | 5          | 7       |
| Road proximity | 0.33  | 0.50  | 1              | 2         | 3          | 5       |
| Land Cost | 0.20  | 0.33  | 0.50           | 1         | 2          | 3       |
| Lineaments | 0.14  | 0.20  | 0.33           | 0.50      | 1          | 2       |
| Aspects  | 0.11  | 0.14  | 0.20           | 0.33      | 0.50       | 1       |
| Total    | 2.28  | 4.17  | 7.03           | 11.83     | 18.50      | 27      |

### Table 5. Normalized Matrix and Criterion Weights

| Criteria | Slope | LU/LC | Road proximity | Land Cost | Lineaments | Aspects | Computational criterion weights |
|----------|-------|-------|----------------|-----------|------------|---------|--------------------------------|
| Slope    | 0.44  | 0.48  | 0.43           | 0.43      | 0.38       | 0.33    | 0.42                           |
| LU/LC    | 0.22  | 0.24  | 0.28           | 0.25      | 0.27       | 0.27    | 0.25                           |
| Road proximity | 0.14  | 0.12  | 0.14           | 0.17      | 0.16       | 0.18    | 0.16                           |
| Land Cost | 0.09  | 0.08  | 0.07           | 0.08      | 0.11       | 0.11    | 0.09                           |
| Lineament | 0.06  | 0.05  | 0.05           | 0.04      | 0.05       | 0.07    | 0.05                           |
| Aspect   | 0.05  | 0.03  | 0.03           | 0.03      | 0.03       | 0.04    | 0.03                           |
| Total    | 1     | 1     | 1              | 1         | 1          | 1       | 1                               |
| Criterion          | Weighted sum vector                                                                 | Consistency vector |
|--------------------|-------------------------------------------------------------------------------------|--------------------|
| Slope              | \[(1)(0.42)+2(0.25)+(3)(0.16)+(5)(0.09)+(7)(0.05)+(9)(0.03)\] = 2.47/0.42          | 5.88               |
| LU/LC              | \[0.50)(0.42)+(1)(0.25)+(2)(0.16)+(3)(0.09)+5(0.05)+(7)(0.03)\] = 1.51/0.25       | 6.04               |
| Road slope         | \[(0.33)(0.42)+(0)(0.25)+(1)(0.16)+(2)(0.09)+(3)(0.05)+(5)(0.03)\] = 0.90/0.16     | 5.64               |
| Land Value         | \[(0.20)(0.42)+(0.33)(0.25)+(0)(0.16)+(1)(0.09)+(2)(0.05)+(3)(0.03)\] = 0.52/0.09 | 5.85               |
| Lineamen trait     | \[(0.14)(0.42)+(0.20)(0.25)+(0.33)(0.16)+(0.50)(0.09)+(7)(0.05)+(2)(0.03)\] = 0.31/0.05 | 6.33               |
| Aspects            | \[(0.11)(0.42)+(0.14)(0.25)+(0.20)(0.16)+(0.33)(0.09)+(0.50)(0.05)+(7)(0.03)\] = 0.19/0.03 | 6.59               |

| Suitability categories | Area in km² |
|------------------------|-------------|
| Very low               | 1.81        |
| Low                    | 12.71       |
| Moderately             | 37.94       |
| High                   | 66.88       |
| Very high              | 22.44       |

**5. Conclusion**

In this study integrating analytical hierarchy process and geographic information system has adopted for site suitability. Integrating environmental dimensions into land management practices in urban areas from the earlier stage of the planning process can greatly contribute to the future sustainability of urban region. Based on the result the final map is classified into five very low (1.81 km²), low (12.71 km²), moderately (37.94 km²), high (66.88 km²) and very high (22.44 km²). The conceptual methodology adopted in the present study will help to locate suitable site for land development in other parts of the world. The outcome of the study will help the local people as well as planners to formulate and implement suitable master plan for development of urban region. Further field investigation needed before the final decision is made.

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