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Application of the overlay weighted model to determine the best locations for expansion of adigrat town

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Abstract
The objective of this study is to develop Geographic Information System (GIS)-based land suitability analysis model for locating optimal sites for expansion of Adigrat town. In order to determine suitable site, the important factors are incorporated, namely accessibility and topography, land cover, and economic by using overlay weighted method in decision making process. In this paper, Euclidian distance was calculated from roads, streams and existing wells. Aster data was used to classify elevation and slope. Landuse map was prepared using Landsat 8 data. The influence of different factors was given as Elevation 10%, Stream 10%, Wells 10%, Roads 20%, Slope 25% and Landuse 25%. Scale values for criteria were given 1 to 9. Closed distances from wells, Roads, Streams were given higher values. Slope more than 20 degree, Elevation more than 2800 m and Buildup areas were restricted. As a result 3.2 sq. km. of area most suitable and 6.57 sq. km. of area lesser than that was found suitable for urban expansion.

Key words: GIS, Land suitability analysis, MCDA

1. Introduction

The urban areas in Ethiopia have witnessed tremendous changes in terms of population growth and urban expansion. In the absence of proper urban management practice, uncontrolled and rapid increase in population pose enormous challenges to governments in providing adequate shelter to people in urban areas. This has also posed great concern among urban planners. Urban growth due immigration has led to increase in population density.

Urban planning is a complex phenomenon that requires enormous data to support the decision. It is a process of identifying problems and finding solutions using an information system.

Urbanization is a dynamic phenomenon, which keeps on changing with time. Therefore, accurate and timely data is required for proper urban planning. Urban planners use variety of data and methods to solve the problems of urban areas.
With the launch of artificial satellites and availability of remotely sensed data, which gives synoptic view of the planning areas, the urban planners are equipped with new tool. Today very high resolution data such as 1m PAN from IKONOS, 0.6m PAN from QUICKBIRD and 2.5m PAN from CARTOSAT-1 satellites are available at reasonable cost.
This spatial data combined with other data can provide better ability to understand the urban problems clearly and arrive at suitable solutions.
The essence of land evaluation is to compare or match the requirements of each potential land use with the characteristics of each kind of land. The result is a measure of the suitability of each kind of land use for each kind of land. These suitability assessments are then examined in the light of economic, social and environmental considerations in order to develop an actual plan for the use of land in the area. When this has been done, development can begin. Ideas on how the land should be used are likely to exist before the formal planning process begins. These ideas, which often reflect the wishes of the local people, are usually included among the possible uses to be assessed in the evaluation and will thus influence the range of basic data that needs to be collected.
The Geographic Information System has proven practical throughout the world and effective when used for determining suitable lands for a built environment [1]
GIS can take advantage of spatially related factors to influence the built development of the hillsides. In developing a hillside land suitability model, the following criterion has to be considered, i.e. accessibility in terms of road, topography, land cover and economic. Furthermore, hillsides built developments have a big constraint of accessibility because hillsides contain elevation and slope contours [1].
Accessibility provides a key role in the economic development of any region. Consequently, when implementing an unplanned road network, it can be harmful to the natural environment. In this context, an effective route planning considers environmental concerns which take into account a sustainable built development [2].
This can be achieved in the beginning stage with a sustainable development [3]-[4] with integrated GIS-based MCDA approach.
The purpose of integrating the GIS-based land suitability analysis using the multi-criteria evaluation (AHP) approach is that it is the most suitable method for solving complex problems related to land-use planning and any other kind of development. It has also been recognized as an effective multi-criteria decision support system [5].
It is observed, that there have been extensive studies carried out on the land suitability analysis using the GIS-based multi-criteria evaluation (MCE) procedures [6]-[7] land development.

2. STUDY AREA

Adigrat town is located at 14^0 20’ north latitude and 39^0 29’ east longitudes at a distance of about 898 kilometers North of Addis Ababa and 125 kilometers north of Mekelle, the regional capital. The town is an administrative capital of Eastern Tigray Zone and the capital of Gant Afeshum wereda [8]. An area of 28.64 km^2 was selected within and around the town for the present study.

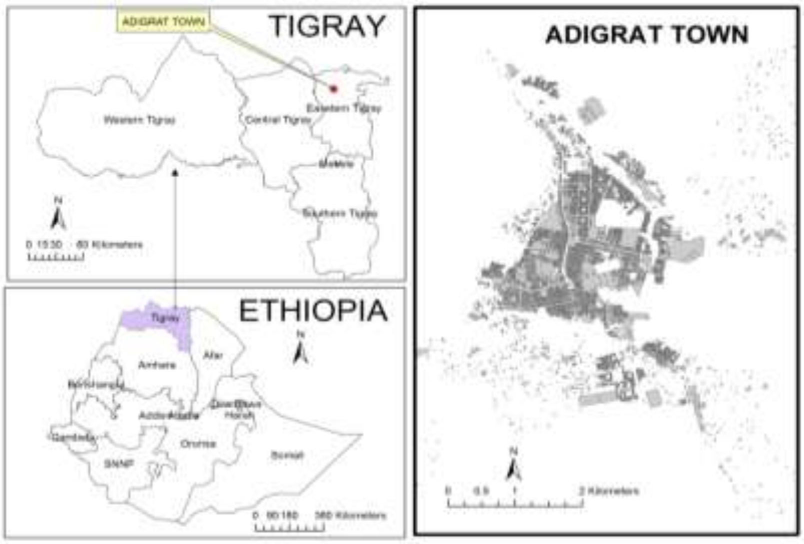

Figure 1

Figure 1 shows the location of study area in Ethiopia.

The population of Adigrat city based on 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA) is 57, 588 [9].

3 METHODOLOGY

3.1 WEIGHTED OVERLAY SUITABILITY MODEL

To meet a specific objective, it is frequently the case that several criteria will need to be evaluated. Such a procedure is called Multi-Criteria Evaluation (Carver, 1991). A "Weighted Suitability Model" is developed using GIS techniques for proposing locations suitable for urnam expansion depending on a number of thematic layers and based on the principle of Multi-Criteria Evaluation. Such models are used for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. Additionally, the factors of the analysis may not be equally important. Each individual raster cell is reclassified into units of suitability and multiplied by a weight to assign relative importance to each and finally add them together for the final weight to obtain a suitability value for every location on the map; this can be interpreted by **Eq. (1)** [10].

$$S= \Sigma\, w_i\, x_i \text{ ……………………………………… (1)}$$

Where,

w_i = The weight of i^{th} factor map

x_i = Criteria score of class of factor i

S = Suitability index for each pixel in the map

In the present study, all the thematic layers were integrated in ArcGIS 10.1 platform in order to prepare a map depicting suitable areas for artificial groundwater recharge. The total weights of each pixel of the final integrated layer were derived from the following equation;

$$S= (SL_f\, SL_c + LE_f\, LE_c + LU_f\, LU_c + DR_f\, DR_c + DW_f\, DW_c + DS_f\, DS_c \text{ ……………… 2}$$

Where,

SL is Land slope,

LE is land elevation,

LU is land uses,

DR is the distance to Road,

DW is the distance to wells and

DS is the distance to streams.

The subscript letter ‘f’ represents the weight of each factor, while ‘c’ represents the weight of each class of the individual factor.

Suitable locations for expansion of Adigrat city, was estimated using **Eq. (2)** for each pixel in the final integration layer and was regrouped into different classes with equal class interval to divide the entire study area into different suitable zones (Chowdhury *et al.*, 2006).

3.2 The conceptual model to create a suitability map

In this study, the main thematic layers are generated as an input for selecting suitable sites for urban extension. A number of processes were performed to prepare these layers for being used as an input in an overlay weighted model. The following sections are going through the main steps which have been done.

3.3 The work plan

To model the spatial problem a diagram of the objectives, process models, and input datasets was created to reach the study goals was drawn, **Fig 2.**

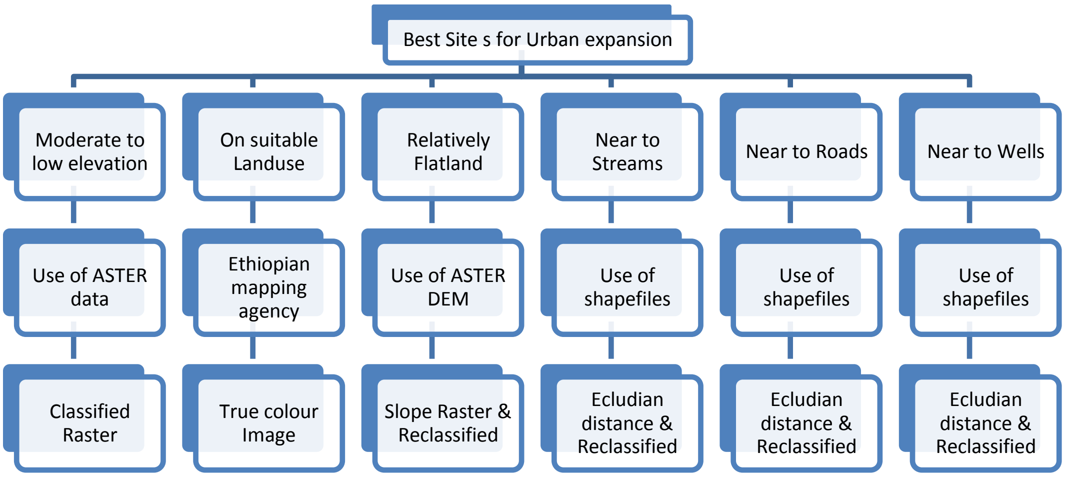

Fig. 2 The work plan for the needed data

As shown from **Fig. 2** there are 6 parameters have been selected to be thematic layers for the overlay weighted model analysis. Each parameter has some classifications and corresponding weight values which affect the model final decision, as will be shown in **Table 1**.

3.4 Landuse and DEM maps

Landuse map was used prepared by Ethiopian mapping agency. To calculate the slope DEM data was projected to projected coordinate system. After adding the DEM and its data to ArcGIS platform the topographic and the slope maps could be generated by the use of the spatial analyst tools, then the study area was clipped according to study area.

3.5 Distances maps

As the study work diagram in **Fig. 2** showed that the distances to roads, wells and streams are some of the important affecting parameters in determining the extension locations, these maps have been generated by using the Spatial Analyst Straight Line Distance function in ArcGIS which creates such maps by calculating the straight line (Euclidean) distance from the main objective site (in this case; roads, wells, and streams).

3.6 Reclassifying the distances maps

All the distances maps have been reclassified to integer values instead of ranges to be used as inputs in the weighted model. To reclassify these maps the reclassify function was applied. A value of 10 was assigned to the most suitable range and 1 to the least suitable range. All the layers should have the same range of classes (1 to 10).

3.7 Weighted Indexing table

Each raster is assigned a percentage influence according to its importance. The weight is a relative percentage, and the sum of the % influence weights must add up to 100. Each cell value is multiplied by their percentage influence then added to create the output raster. A weighted indexing table has been adopted to suggest the ideal location for urban extension using the six parameters, as shown in **Table1**.

Table 1. Weighted indexing table

SN	Raster	Influence (weight) %	Fields	Scale value
1	Landuse	25	Open land	9
			Woodland	3
			Mangrove	6
			Agriculture	5
			Buildup	Restricted
2	Slope	25	1 (Steepest) to 9 (Flat)	High to low values from flat to steep
3	Elevation	10	1 (Highest) to 9 (lowest)	High to low values from lowest to Highest
4	Distance to roads	20	1 (Very Far) to 9 (Nearest)	High to low values from nearest to very far
5	Distance to wells	10	1 (Very Far) to 9 (Nearest)	High to low values from nearest to very far
6	Distance to streams	10	1 (Very Far) to 9 (Nearest)	High to low values from nearest to very far

Source: Study

4 Results

4.1 Land use class

The study area is subdivided into five classes: buildup land, open land, agriculture land, mangrove & woodland. Table 2 and figure 3 shows the existing land use areas of selected study area of Adigrat town:

Areas lying within a buildup land are restricted for expansion, as it is not possible further construction there. On the other hand, open areas are rated with a high value (9) because these areas are readily available for expansion of the town. Agriculture and woodland areas are considered as not good for construction of new buildings.

4.2 The land slope

It was found that very small area of the town is almost flat as the slopes are ranging from 0 to 68 degrees; however 0 degree was given class value 9 as the best land slope. Figure 4 shows slope of Adigrat town.

4.3 The land Elevation

Land elevation of the study areas ranges from 2326 to 2829 m from msl. Very high elevated areas were restricted because such areas are not considered for urban expansion. Similarly very low elevated areas were also assigned lower values because these are flood prone areas. On the other hand low to moderate areas were given high values. The land elevation of Adigrat town is shown in figure 5.

Table 2 Adigrat Town : Landuse

SN	Landuse	Area (sq. km)
1	Agriculture land	18.26
2	Open area	17.93
3	Mixed Grove	0.70
4	woodland	6.03
5	built-up	6.90

Source: Study

4.4 Distances to Roads

The proximity of roads to expansion areas is considered as an advantage because such roads will be used as a source for transportation. Areas lying close to the roads are considered the best and are assigned a class value of 9. Figure 6 shows proximity from the roads in Adigrat town.

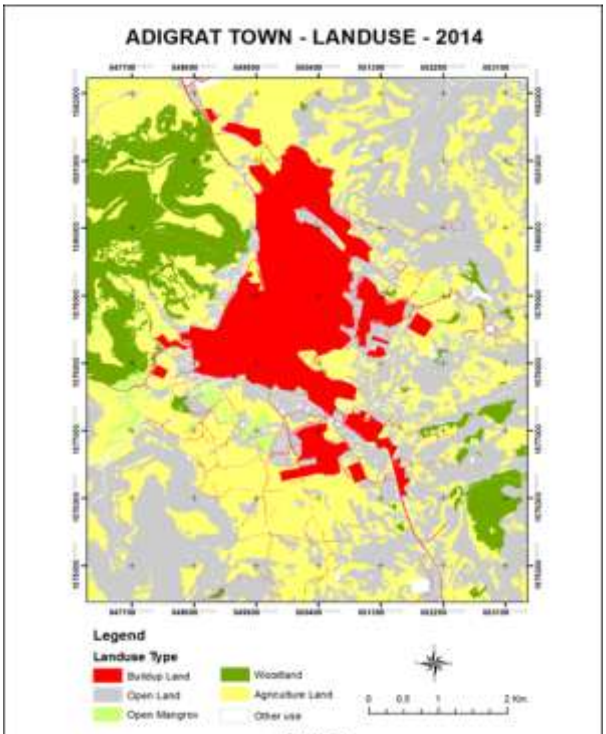

Figure 3

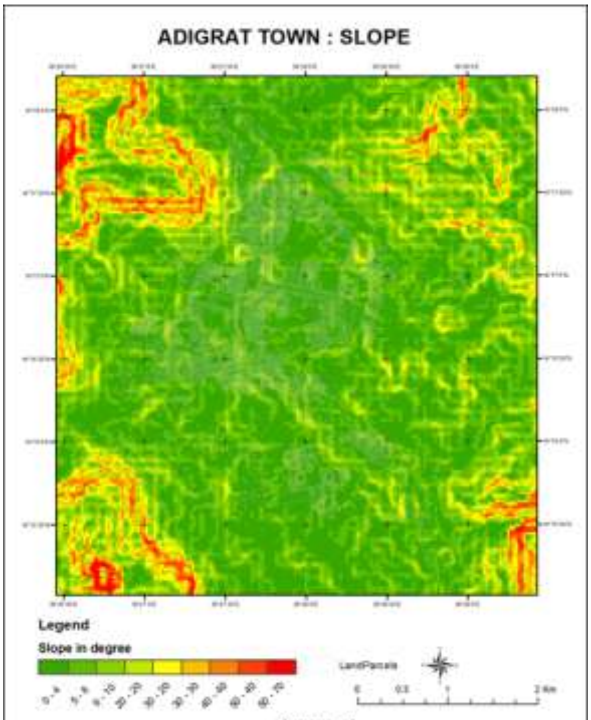

Figure 4

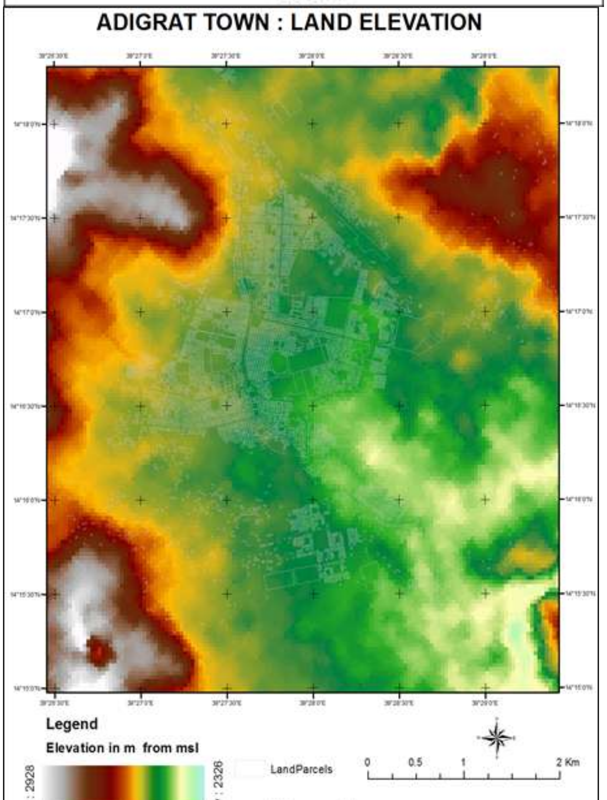

Figure 5

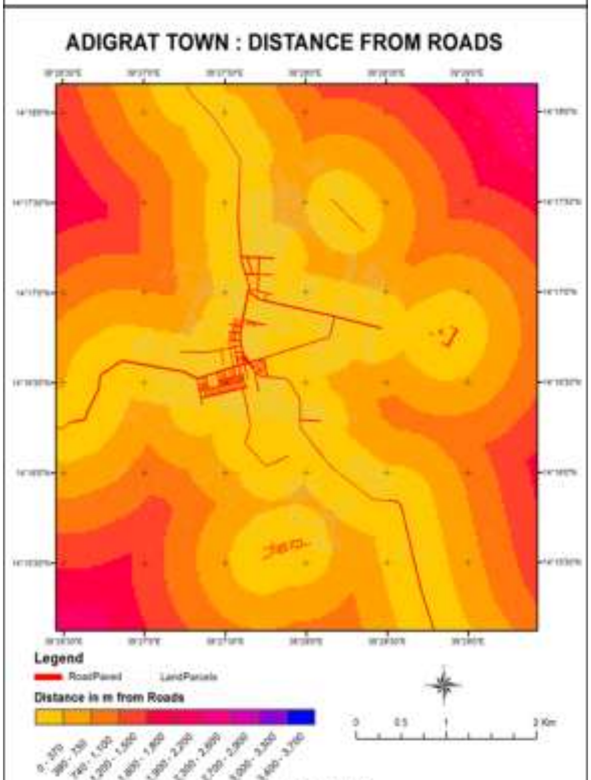

Figure 6

4.5 Distances to wells

The proximity of wells to expansion areas is considered as an advantage because wells will be used as a source for water. Areas lying close to the wells are considered the best and are assigned a class value of 9. Figure 7 shows proximity from the wells in Adigrat town.

4.6 Distances to Streams

The distances far away from streams have been given lower class values than the closer ones to avoid the water scarcity problem in future. Figure 8 shows proximity from the streams in Adigrat town.

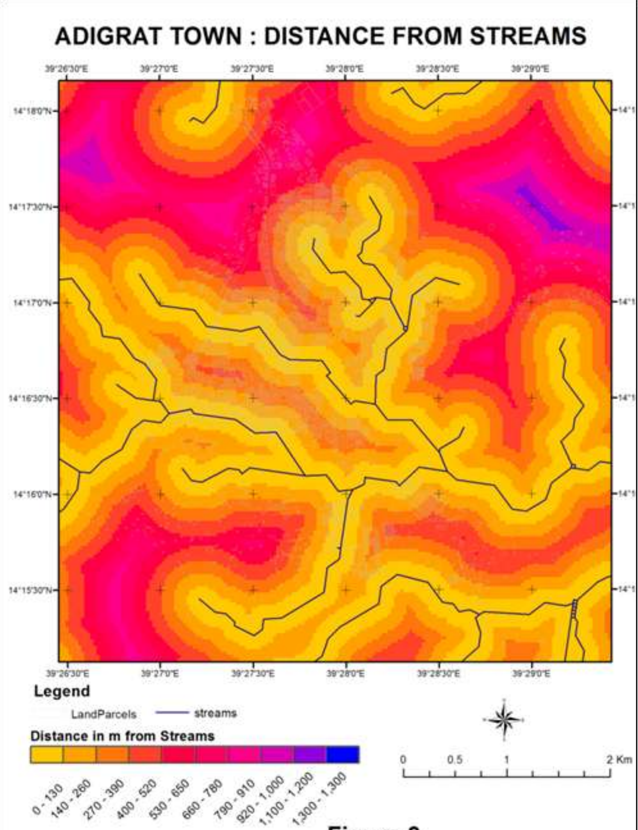

Figure 8

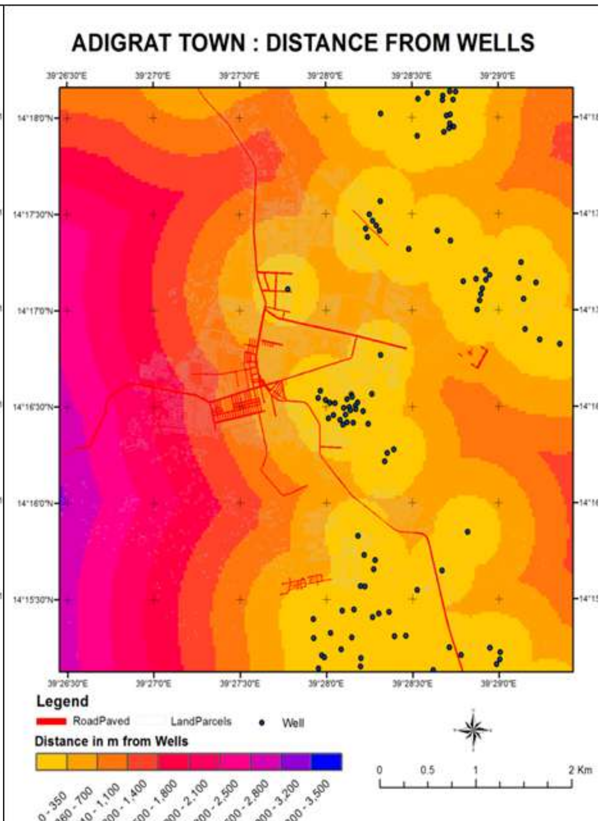

Figure 7

4.7 Suitable recharge locations

After preparing all the thematic layers and the table of weights which were needed for the weighted model, the weighted model could be built and run on ArcGIS, this came up with the most favorable sites selected using the previously mentioned criteria.

One integrated layer from excellent to not suitable land was generated based on the weights assigned to each criterion. Finally most two kind of suitable sites were extracted from this integrated layer as shown in figure 9. First most suitable sites comprise an area of 3.22 km^2 and second most suitable site cover an area of 6.57 km^2.

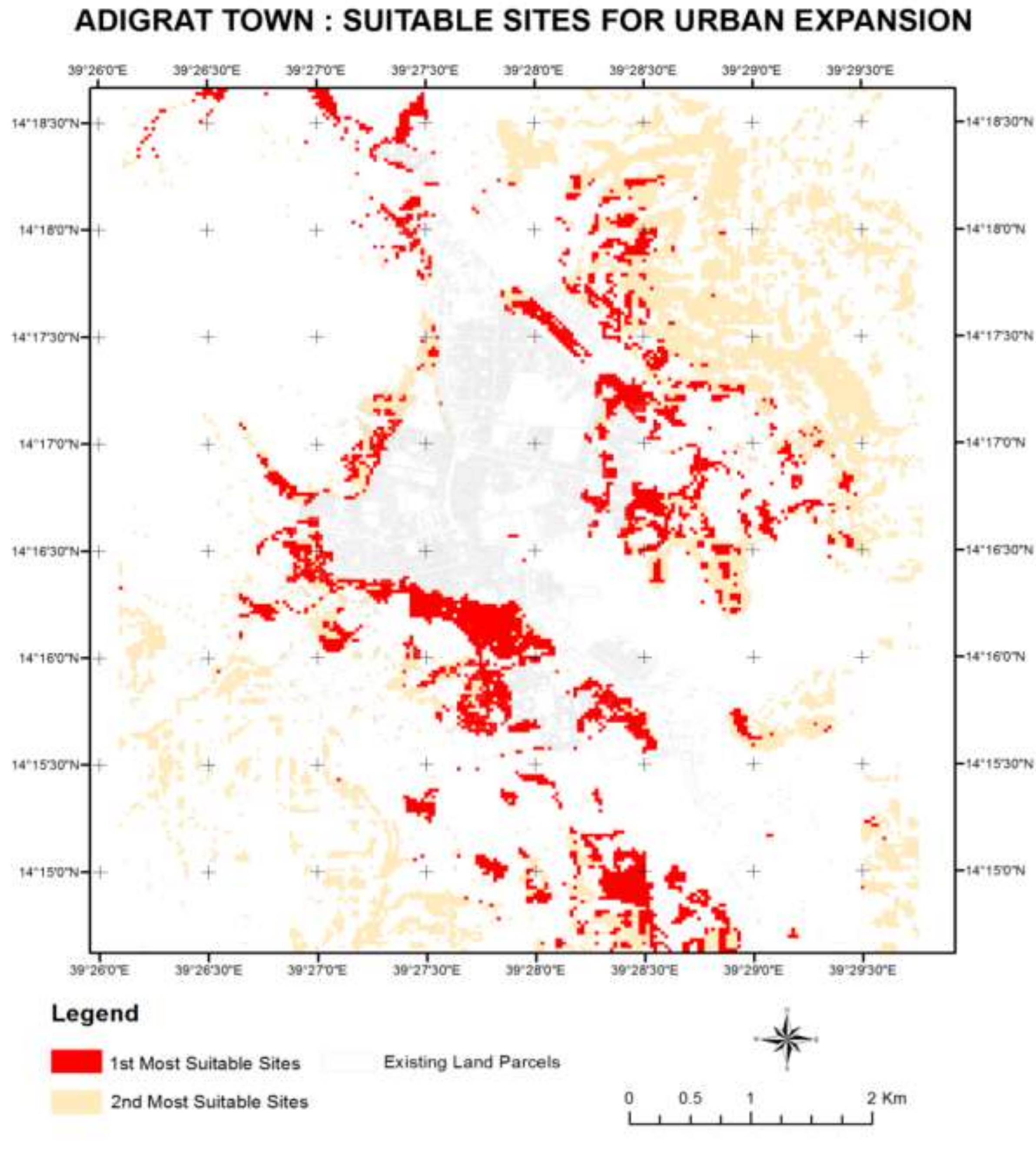
ADIGRAT TOWN : SUITABLE SITES FOR URBAN EXPANSION
39°26'0"E
39°26'30"E
39°27'0"E
39°27'30"E
39°28'0"E
39°28'30"E
39°29'0"E
39°29'30"E
14°18'30"N
14°18'0"N
14°17'30"N
14°17'0"N
14°16'30"N
14°16'0"N
14°15'30"N
14°15'0"N
Legend
1st Most Suitable Sites
2nd Most Suitable Sites
Existing Land Parcels
0
0.5
1
2 Km

Figure 9

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