# Potential Landfill Site Suitability Study for Environmental Sustainability using RS-GIS & MCDA

**Vishal Ahire**
School of Engineering and Technology, Sandip University
**Manoj Saxena**
National Remote Sensing Center
**Swati Patil**
School of Engineering and Technology, Sandip University
**Mahesh Endait** ( mahesh.endait@sandipuniversity.edu.in )
School of Engineering and Technology, Sandip University https://orcid.org/0000-0001-6303-2630
**Dhiroj Kumar Behera**
National Remote Sensing Center
**Harshitha Poduri**
National Remote Sensing Center

---

**Research Article**

**Keywords:** Landfill, Municipal Solid Waste, Environment Sustainability, RS-GIS, MCDA-AHP.

**Posted Date:** March 19th, 2021

**DOI:** https://doi.org/10.21203/rs.3.rs-213043/v1



---

# Abstract

Because of the increasing population and more waste generation, the area required for the disposal of MSW increases. Sanitary Landfill is one of the important method used for the disposal of MSW. The problem faced during new landfill sitting and availability of land is also increased simultaneously. Optimization of landfill sitting shows the prime importance at the environmental, social, and economic levels. The present work is carried out for the Solid Waste Management plant of Nashik Municipal Corporation (MH) India. As the landfill site is on the verge of the closure period, new landfill sitting identification is essential with consideration of all criteria to reduce environmental degradation and improve the standard of living of people nearby vicinity. This study aims to identify potential landfill sites for the year 2021 and the upcoming 25-year period, using a Remote Sensing (RS) - Geographical Information Systems (GIS) with Multi-Criteria Decision Analysis (MCDA). Fifteen parameters were considered while selecting a potential landfill site i.e., geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, population density used for AHP-MCDA. Airport, water bodies, road, habitation are used for restriction buffer analysis and aspect, while the wind rose diagram used for final site suitability. The weights of the 9 parameters were obtained from a constructed AHP matrix with a consistency ratio of 0.05557.During the study restricted zones were omitted. Afterward, the threshold limit and selection criteria were used for potential site selection. The study revealed several potential landfill sites and their suitability. Furthermore, the landfill area required for upcoming years is calculated based on the projected population, and the result of the potential landfill sites map shows the effectiveness of the proposed method. The results from this work showed the effectiveness of potential landfill site suitability for Environmental Sustainability in the selection process.


# 1. Introduction

The generation of municipal solid waste (MSW) is increasing day by day, which leads to environmental degradation and pollution. In India approximately 1,36,000 tonnes of solid waste is generated per day and which has been forecasted to rise by 33% in the next 15 years (CPCB 2016). Due to the increased population and expansion of cities, the area required for the disposal of solid waste increases and results in a lack of basic infrastructure facilities for MSW disposal by Hannan et al. (2015). The management of solid waste is a difficult task for engineers, especially in urban areas. It includes social, environmental, and financial aspects. The hierarchy of solid waste management includes prevention, minimization, reuse, recycle, energy recovery & disposal. Whereas disposal is the least favorable option for solid waste. Mismanagement of municipal waste directly affects on the environment and human beings. Due to which the risk of pollution and human health adverse impact is increased. Most of the initiatives were taken for the reduction of waste at source and source segregation, but still, the problem is in handling and safe disposal up to the landfill site. Municipal solid waste is used for energy recovery, composting, etc, but the rejected material is sent for landfill.

Finding a new landfill is a crucial task. It involves various environmental, political, social, and financial factors. Where one can use the pre-existing knowledge of geology, hydrogeology, waterbody, topography, sociology of the area? Apart from these, many criteria are to be considered in finding the ideal landfill location, hence becomes a tedious and difficult task.

The landfill identification method involves the conventional method using spatial data, GIS& MCDA techniques. It includes (i) setting up of locational criteria (ii) identification of search area (iii) drawing up a list of potential sites (iv) data collection (v) selection of few best-ranked sites (vi) environmental impact assessment and (vii) final site selection and land acquisition. (CPHEEO Manual on MSW Management Rules,2016)

Geographical Information System (GIS) based on decision analysis tools help in resolving the problem and suggests suitable sites through mapping. Application of GIS using spatial data, attribute data, and Multi-criteria decision analysis (MCDA) is being used by many researchers for analysis of the best possible sites of landfilling. Feo & Gisi (2014), Gorsevski et al. (2012), Moeinaddini et al. (2010). MCDA is a sub-discipline of operations research that explicitly evaluates multiple conflicting criteria in decision making, MCDM methods are convenient to decision-makers for giving the ranking or weights to the sites among the conflicting sites. Commonly MCDM methods able to make the comparison against each criterion given in the legislations and assign the weights to the available existing sites.

MCDM techniques alone and in combination with other techniques have been used by many researchers for waste disposal sites using different criteria. MCDA methods used in the literature are the Analytic hierarchy process, Fuzzy logic, Dynamic modelling, Analytical Network process. A Few important methods are summarized by Gzogala & Rawlik (1989), Zeleny (1982), Gal et al. (1999), Figueira et al. (2005), Feo & Gisi (2014), Kapilan & Elangovan (2018), Aksoy & San (2019). The authors concluded the suitable landfill location of disposal of solid waste by considering social, economic & environmental factors using RS, GIS & MCDA.

AHP technique was demonstrated by Everett et al. (1996) for MSW landfill site in Oklahoma. The author considered various factors of Hydrogeology/geology, land use, and proximity for decision ranking, and sensitivity was checked. Kontos et al. (2005) identified the MSW landfill site in the North Aegean Sea Greece and considered hydrology /hydrogeology, Environmental, Social, & Technical/Economic factors. The same technique was used by Sumathi et al. (2008) using GIS-AHP & overlay analysis model for Pondicherry. Various Factors such as lake and ponds, rivers, water supply sources, groundwater table, groundwater quality, infiltration, air quality index, geology, fault line, elevation, and use, habitation, highways, sensitive sites considered for site selection. Similar to Sharifi et al. (2009) found a landfill sitting in Kurdistan Province, western Iran for hazardous waste from the fifteen landfill sites.

The author focused on geology, hydrogeology, hydrology, climatology, and eco-sociology factors. In continuation with this Moeinaddini et al. (2010) used AHP in combination with the weighted linear method & GIS at Karaj, Iran. AHP & GIS technique was used for inert landfill by Geneletti (2010) at Sarca's Plain, located in southwestern Trentino. The ranking is based on visibility, accessibility, and dust pollution. Tavares et al. (2011) identified landfill sitting for incineration plant in Cape Verde and assigned 75% weight to non-environmental factors and 25% weight to environmental factors.

A fuzzy technique in combination with AHP was used by Kharat et al. (2016) by considering environmental, technical, socio-political, and economic factors for landfill selection. Omar & Qdais (2006) demonstrated a fuzzy intelligent system in the capital city Amman, Jordan. Topography, geology, natural resources, socio-cultural, and economy, and safety factors were considered for landfill siting. The same technique was used by Gemitziet al. (2007) for the landfill sitting of MSW. The author considered physical and socioeconomic factors in the selection process.

Analytical Network process in combination with linear weight & ordered weight average was used by Motlagh & sayadi (2015). The author considered environmental & socio-economic factors and the ANP model was developed. The same method was demonstrated by Khan & Faisal (2008) with ANP super matrix approach and suggested the segregation of waste at the source, so that cost invested in landfills can be minimized and measured.

The overall literature summarizes the methodology for the new landfill disposal site using the RS, GIS & MCDA techniques. Many researchers focussed on the criteria of environmental, social & economical. Very few were considered the socio-economical, political, technical & scientific study of new landfill sitting. Finally, the decision of stakeholders is very much important in landfill identification. In the future, it is very important to consider the technical & scientific study involved in the methodology.

With the help of the RS-GIS and MCDA technique, the landfill site suitability was found for Nasik City (MH) India from the available suitable areas. As the landfill site of Nashik city was established in the year of 2000 and now is on verge of closure period by 2021. It is the need for Nasik city to find the best possible landfill location for the future with consideration of all rules and regulations. The new landfill identification will help city planners in the future from a land acquisition point of view as well. The present study focus on nine thematic layers namely, geomorphology, hydrogeology, distance to road, drainage, lineament, slope, Land Use Land Cover (LULC), distance to water bodies, population density used for AHP-MCDA. For the better results four parameters airport, water bodies, road, habitation used for restriction buffer analysis and aspect. With consideration on account of the direction of the wind, the wind rose diagram was also considered for final site selection. Several important mentioned factors were considered and thematic maps were developed with buffer zones consideration using overlay analysis in GIS. The weights were assigned to different criteria as per their relative importance of each. Based on RS-GIS & AHP technique, four landfill potential sites were identified and found the best possible landfill site. The identified landfill site is as per the government rules and used maximum possible information.

# 2. Study Area

Nashik District is situated in the north-western part of Maharashtra, India, with a total area of 276.19 Sq.km. The city is the third most industrialized city in Maharashtra after Mumbai and Pune. The coverage of Nashik(MH) and Environs Villages is 905.157 Sq.km, which includes Nashik Municipal Corporation (276.19 Sq.km) and 73 Villages in a radius of 15 km. The location map of the study area is shown in Fig. 1. The study area has a population count for the census year 2011 is 18, 32,427 among which 15, 61,809 were residing in an urban area, and 2, 70,618 were in a rural area (census of India 2011), which is projected to reach 26, 90,352 by 2021. The city is located at 19°35’ and 20°50’ north latitude and between 73°16’ and 74°56’ east longitude. As per the Department of Survey of India, the city comes under toposheet numbers of 46-H, 46-L and 47-E, and 47-I.

At present approximately 550 to 600 tonnes of municipal solid waste is collected from 2.9 lakh households, 1806 hotels & restaurants, and 300 commercial establishments of 108 wards of the city through 200–225 GhantaGadi’s. The projected quantity of MSW generation will be 1628 tonnes per day, henceforth total quantity generation 594220 MT per year up to 2031. Out of the generated quantity of MSW,89133 metric tonnes will be sent to a sanitary landfill. Endait & Patil (2020) showed the characterization of incoming Fresh MSW of Nashik city, which contains 11% of non-biodegradable components, and the remaining is categorized as easy, medium, and hard biodegradable components. In recent years there is a need of finding new landfill sites for disposal of MSW for Nasik city with consideration of environmental, social & economic factors.

# 3. Satellite Data & Software Used

Site suitability was identified using the primary & secondary data. primary data required for visual interpretation of satellite imageries and data preparation for LULC mapping using remote sensing data of Resourcesat-2A having 5.8 m spatial resolution, (Table 1.) Primary data procured from CartoDEM of 30m spatial resolution of BHUVAN geoportal, National Remote Sensing Centre,(NRSC) Hyderabad. Secondary data includes Geomorphology, Hydrogeology, and Lineament maps sourced from concern departments of the NRSC, and the windrose plot for Nashik city is sourced from Envitrans, which is processed according to the CPCB and US EPA. The ArcGIS 10.7.1 was used for the preparation of the LULC map, generation of thematic maps, proximity analysis, reclassification, weighted overlay analysis, and preparation of final site suitability maps. The ERDAS Imagine 2018 software was used for image processing.

Table 1
Details of Remote Sensing data used

| Satellite | Sensor | Date of acquisition | Spatial Resolution | Spectral Resolution |
|---|---|---|---|---|
| Resourcesat-2A | LISS IV | 18 October 2018 | 5.8 m | 3 Bands |
| Resourcesat-2A | LISS IV | 18 January 2019 | 5.8 m | 3 Bands |
| Cartosat-1 DEM | PAN | 29 April 2015 | 30m | – |
| Source: www.isro.gov.in/bhuvan.nrsc.gov.in | | | | |

# 4. Methodology

Arc GIS was used for the preparation of thematic maps, which is followed by assigning a weight factor and weighted overlay analysis by Multi-Criteria Decision Analysis (MCDA), and finally, site identification was done. Figure 2 shows the schematic of the methodology followed in this study. Nine thematic layers namely, geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, population density used for AHP-MCDA. Airport, water bodies, road, habitation are used for restriction buffer analysis and aspect, the wind rose diagram for final site selection.

Resourcesat-2A multispectral data of sensor LISS IV having 5.8 m resolution on a scale of 1:10,000, geocoded with UTM projection spheroid and datum WGS 84 zone 43 north received from NRSC's user order processing system. Data acquired on 06 August 2019 for the Rabi and Kharif season of 18 January 2019 and 18 October 2018 respectively. Satellite data is used for LULC data preparation and classification. Prominent features like Built-up, Agriculture, Forest, Wasteland, and Waterbodies were classified based on land use land cover classification used in NRSC's natural resources census project on LULC mapping of the entire country. The CartoDEM with 30 m resolution data is used to extract Slope, drainage density present in the region and aspect. In this study, DEM data is obtained from the NRSC's BHUVAN data portal. The base thematic maps of Nashik and Environ namely geomorphology, hydrogeology, lineament, and road was collected from existing data of the NRSC based on Survey of India, toposheet number (46H/12- 46H/16 & 47E/9, 47E/13) which is on 1:50,000 scale.

The population for the year 2021 was estimated by the geometrical projection method. The population of 2021 was used to create a population density map in the ArcGIS environment. Proximity analysis is done for airport, road, water body, and habitation. Restricted maps were generated with the help of standard defined by the Government of India's environmental agencies like the Central Pollution Control Board, Census of India 2011. The wind rose diagram developed for the wind flow and direction estimation; data required for generation is obtained from the Meteorological Department of India.

All base maps were converted into a raster with a common resolution of 5.8 m and then all the raster maps were reclassified according to the rank of the parameter in all layers. The solid waste potential sites were obtained by overlaying all the thematic maps in the weighted overlay analysis method using the spatial analyst tool in ArcGIS. During weighted overlay analysis, the percentage weights were given to all individual parameters of each thematic map, and weights were assigned according to paired wise consistent AHP matrix. Weighted overlay analysis along with the restricted layer gives the output as a potential landfill area, which further scrutinizes with threshold criteria based on score and area. Raster maps were reclassified according to the highly suitable, not suitable for dumping waste. The aspect layer and wind rose diagram used for the selection of the identification of potential sites for solid waste disposal. (Fig. 20)

### 4.1. GIS-based MCDA for Suitability Score

Multi-Criteria decision analysis is a decision-making tool used for ranking. It is used to help in making decisions and gives the best to the worst ranking of actions. Stakeholders found a compromise solution in the field of decision making. MCDA technique has been used in every sector. In every field where we required deciding between the available alternatives, MCDA gives the best solution in assigning the ranking. Analytic Hierarchy Process, Fuzzy logic, Dynamic modeling, Analytical Network Process, Analytic Neural Network methods have been used by many researchers in Literature for landfill site identification. This paper focused on MCDA techniques with GIS -RS & AHP for landfill site identification of MSW.

The present study of landfill suitability, geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, population density parameters is considered for landfill site selection.SAATY scale was used for a rating on 1 to 9 scale and fixed criteria & subcriteria based on their importance. Afterward, the thematic layer was prepared using the parameters for decision-making using the analytic hierarchy process (AHP).A score of 9 for the most importance and score of 1 for equal importance or least importance as per Saaty (2008), Kumar & Hassan (2013).

### 4.2. Analytical Hierarchy Process (AHP)

Thomas Saaty (1980) introduced the Analytic Hierarchy Process (AHP). AHP analysis is used to build a hierarchy for the decision making analysis. Saaty has explained the pairwise comparison scale in numerical values from 1 to 9 scales. Where 1 is for equal importance and 9 is for extremely important. It shows higher weight gives more importance to the corresponding criterion.(Saaty 2008,Saaty 1980).After the pairwise comparisons, the overall weights are computed for each layer and then compared with every other parameter used by Kumar & Hassan (2013), Kaliraj & Chandrasekar (2015). The consistency index & consistency ratio was checked, to know whether the computed weights were consistent or not. The CR & CI value for the constructed matrix is calculated as follows:

$$CI = \frac{\lambda max - n}{n-1} \quad \text{...... (i)}$$

$$CR = \frac{CI}{RI} \text{.............(ii)}$$

Where;

λmax- is the product between each element of the weight and the column total of the comparison matrix

$n$ - The number of parameters.

RI- the random consistency index (RI)

Saaty (1980) has shown that the consistency ratio should not be more than 10%. If it is more than 10% then the judgments need to be revised.

### 4.3. A criterion for an AHP analysis

A total of 15 criteria were considered while selecting a landfill site in the study area for Nashik and Environ namely geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, population density used for AHP-MCDA, while Airport, water bodies, road, habitation are used for restriction buffer analysis and aspect, the wind rose diagram for final site suitability.

### 4.3.1. Geomorphology

This study map was taken from the NRSC data source by assigning the suitability scores 1 to 9 (Table 2). The geomorphology map used in the study has been classified into six classes namely; moderately dissected, weathered, slightly dissected, waterbody, highly dissected, weathered-canal command, and undissected. Geomorphological features considered in the study that are directly linked to the groundwater percolation. It is an important factor in selection, for which highly dissected area is unsuitable and an undissected area is the most suitable for dumping solid waste. The suitability score for geomorphological parameters reveals that undissected areas having a high score of 9 and water bodies/weathered canal-command attained less score 1 (Fig. 3).

Table 2
Suitability score for selected criteria

| Sr. No. | Name of Thematic Criteria | Reclassified concerning present Study Area | Suitability Score (1- less preferred, 9-extremely preferred) |
|---|---|---|---|
| 1 | Geomorphology | Waterbody/weathered-canal command | 1 |
| | | Weathered | 1 |
| | | Highly dissected | 3 |
| | | Moderately dissected | 7 |
| | | Slightly dissected | 8 |
| | | Undissected | 9 |
| 2 | Hydrogeology | Waterbody | 1 |
| | | Mixed basalt | 3 |
| | | Vesicular basalt | 7 |
| | | Massive basalt | 9 |
| 3 | Distance to Road (meter) | 0-200 | 1 |
| | | 201–300 | 3 |
| | | 301–500 | 5 |
| | | 501–1000 | 7 |
| | | > 1000 | 9 |
| 4 | Drainage Density (Km/sq.km) | > 5 | 1 |
| | | 4–5 | 3 |
| | | 3–4 | 5 |
| | | 2–3 | 7 |
| | | 1–2 | 9 |
| 5 | Lineament Density (Km/sq.km) | > 0.8 | 1 |
| | | 0.4–0.8 | 5 |
| | | 0.4 | 7 |

| Sr. No. | Name of Thematic Criteria | Reclassified concerning present Study Area | Suitability Score (1- less preferred, 9- extremely preferred) |
|---|---|---|---|
| 6 | Slope (degree) | > 20 | 1 |
| | | 10–20 | 1 |
| | | 5–10 | 5 |
| | | 2–5 | 7 |
| | | 0–2 | 9 |
| 7 | LULC | Waterbody | 1 |
| | | Forest Area | 1 |
| | | Built-up | 1 |
| | | Agriculture | 1 |
| | | Wasteland | 9 |
| 8 | Distance to Waterbodies (meter) | 0-250 | 1 |
| | | 251–500 | 1 |
| | | 501–1000 | 3 |
| | | 1001–1250 | 7 |
| | | > 1250 | 9 |
| 9 | Population Density(pop/sq.km) | > 3000 | 1 |
| | | 1001–3000 | 3 |
| | | 501–1000 | 5 |
| | | 251–500 | 7 |
| | | 0-250 | 9 |

### 4.3.2. Hydrogeology

The geology map used in the study gives information about the infiltration rate capacity of the earth's surface. The study area covers three major lithological units as shown in Fig. 4, such as massive basalt, mixed basalt, and vesicular basalt. Infiltration rate plays an important role in landfill suitability study, the rate of infiltration is high for mixed basalt while it is poor for massive basalt. Table 2 shows the massive basalt is highly suitable for site selection so that it has a high suitability score 9 and low score for mixed basalt 3, water body 1.

### 4.3.3. Distance to Road

The India road network data for highways, primary and secondary roads were selected for the Nashik city area to generate the distance to the road map. Disposal of waste in near to the roads can regulate the violation of laws, according to rules and regulations of the Central Pollution Control Board of India (CPCB 2003). As given by the CPHEEO manual, the construction of landfill sites should be 200m away from the national or state highway. By taking the buffer distance as consideration a minimum of 200m is taken as default for a not suitable condition for disposal of waste in the study area. Therefore, places away from the road network received a high score. Table 2 shows the landfill locations within 0-200m are not suitable with a score of 1 and the most suitability score of 9 was given to a more than 1000m of distance, Fig. 5 shows the results of distance to a road map.

#### 4.3.4. Drainage Density

The study map of drainage density shows the stream channels present in the study area. The drainage density study gives information about the surface runoff, in this study Fig. 6 shows the drainage density map resulting from the CartoDEM imagery. The study area has a total length of the stream is 2379.55 Km and a total study area of 905.157 Sq.km, hence, drainage density for the total area is calculated (2.628 Km/Sq.km). Surface and subsurface formation in the study area from drainage density gives the information on surface run-off present in the region. Drainage density values of stream channels from 1–2, 1–3 km/sq.km have fewer chances of surface run-off while drainage density > 5 km/sq.km is having the highest value which tends to higher runoff present in the area. Potential drainage density areas in the study are not suitable for landfills while areas away from the drainage density are most suitable for the landfill site. In this study, a score of 9 for lesser drainage density and score of 1 for the higher drainage density as shown in Table 2.

#### 4.3.5. Lineament Density

Surface fracture intensity can be quantified by lineament density. Figure 7 shows the lineament moments in the direction of NW-SE and NE-SW. It is well understood that less lineament density represents solid rocks with fewer infiltration rates, giving more chances of suitability for waste management landfill sites. The present study area has less lineament density of 0–0.4 km/sq.km and the highest lineament density of > 0.8 km/sq.km. Figure 7 also shows northwest and southern parts of the study area have high to moderate lineament density. Table 2 depicts the weights of the lineament density, showing a suitability score of 7 for less lineament density and a score of 1 for high density.

#### 4.3.6. Slope

CartoDEM satellite data has been used for the preparation of the slope map (Fig. 8). It has been classified into five classes in degrees (0–2°, 2°–5°, 5°–10°, 10°–20°, > 20°). with a suitability score from 1 to 9 (Table 2). The slope parameter plays an important role in the selection of suitable landfill sites. High excavation costs will be required for the higher degrees of slopes and the steep slope with an excess of waste leads to a landslide. The landfill site should be constructed on a flat surface so that the flat surface is most suitable for the study. A high degree of slope attained a suitability score of 1, and the flatter area attained a suitability score of 7, 9.

### 4.3.7. Land Use Land Cover (LULC)

In the present study, Fig. 9 shows the LULC map of the Nashik and environs. LULC data prepared for the study by using LISS IV merged images of Resourcesat-2A satellite, having 5.8 m spatial resolution. LULC map has been classified into Built-up, Agriculture, Wasteland, Forest, and Waterbodies. Among the total area agriculture covered 49.88%, followed by wasteland 20.46%, built-up 17.74%, forest 6.07%, and water bodies 3.86% (Table 4). LULC data indicates the wasteland area is suitable for waste disposal. Table 2 shows the water bodies, forest, agriculture, built-up are not suitable for the landfill with a suitability score of 1 while the suitability score of 9 for the wasteland.

Table 4
Land Use Land Cover Area Statistics for the Year 2019

| Sr. No. | LULC Classes (Level I) | Area_Sq.km_2019 | Area_%_2019 |
|---|---|---|---|
| 1 | Built-Up | 178.66 | 19.74 |
| 2 | Agriculture | 451.48 | 49.88 |
| 3 | Forest | 54.924 | 6.07 |
| 4 | Wasteland | 185.18 | 20.46 |
| 5 | Waterbodies | 34.91 | 3.86 |

### 4.3.8. Distance to Waterbodies

Waterbodies network data used to prepare distance to water bodies map for landfill selection. Disposal of solid waste near to the water bodies can pollute surface and inland water bodies. Therefore, the buffer distance as consideration a minimum of 250m was taken as default for a not suitable condition for disposal of waste in the study area. Buffer distance 250m – 500m was also taken as not suitable for more preservation of water body conditions. 500m – 1000m were taken as moderately suitable and 1000m – 1250m and above are taken as suitable for the disposal of solid waste in the site. Reclassify map of water bodies is shown in Fig. 10

### 4.3.9. Population Density

In this study, Fig. 11 shows the population density map which was considered as the most important parameter in the landfill site selection. Population density map is generated with the help of Census India data. It defines the population per unit area. The population of Nashik and Environ which includes Nashik Municipal Corporation and 73 surrounding villages in the study.Population density map generated for the population of 2690352 for the year 2021. The area covered by Nashik Municipal Corporation is almost saturated by built-up & habitation. Waste management sites within or nearer to these areas will be harmful to people and therefore, population density areas with less habitation are mostly preferred for landfilling sites. The population density data are classified from a minimum of 250 Pop/sq.km and a maximum of above 3000 Pop/sq.km. Table 2 shows the most suitable area with a suitability score of 7, 9 for the least population density, whereas population density more than 3000 pop/sq.km has given the least importance with the suitability score of 1. Sites are away from the municipal corporation with the least density are considered unsuitable due to the expensive waste transportation, results are shown in Fig. 11

### 4.4. A Criterion for Restriction Buffer Analysis

#### 4.4.1. Airport

The airport restriction map was prepared according to the criteria given by the CPHEEO manual (2016). Buffer analysis was carried out by using a distance of 7500m (Table 5) as shown in Fig. 12. The obtained vector polygons were converted into a raster format with a 5.8m spatial resolution. The restricted cell was assigned a value of 0, while a viable cell was assigned a value of 1.

Table 5
Restriction Layers with their Buffer Analysis

| Sr. No. | Restriction Layer | Min. Buffer | Max. Buffer | Analysis Buffer | Reason |
|---|---|---|---|---|---|
| 1 | Airport | 5000 | 10,000 | 7,500 | Solid Waste Regulations/Laws, CPHEEO Manual |
| 2 | Waterbodies | 200 | 500 | 500 | Solid Waste Regulations/Laws, CPHEEO Manual |
| 3 | Road | 50 | 200 | 200 | Solid Waste Regulations/Laws, CPHEEO Manual |
| 4 | Habitation | 500 | 500 | 500 | Solid Waste Regulations/Laws, CPHEEO Manual |
| **All obtained restricted layers were merged into a binary mask layer of value 0, 1, having been combined using a raster calculator tool in spatial analyst. The restricted and non-restricted areas can be assigned a value of 0 and 1, respectively (Fig. 16). | | | | | |

#### 4.4.2. Road

The Road network restriction map was prepared by considering a data of state highways, primary and secondary roads. Buffer analysis was carried out for the road network by using a distance of 200 m (Table 5) as shown in Fig. 13. The obtained vector polygons of roads were converted to raster format with a 5.8 m spatial resolution and the restricted cell was assigned a value of 0 to nullify the zone.

#### 4.4.3. Waterbody

The waterbody network map was exported from the land use land cover map of the study area. The waterbody buffer analysis and restriction process are similar to that followed for distance to road network analysis. The present study area covers the reservoirs, rivers, lakes, canal, etc as the source of the waterbody. According to the solid waste management rules criteria given by the CPHEEO manual, the source of water and catchment area needs to be protected. To avoid the contamination, a 500m (Table 5) restricted zone was prepared for the waterbody network available in the study area. Figure 14 shows the waterbody restriction map in raster format with the available area for landfill suitability.

#### 4.4.4. Habitation

The Habitation restriction process is based on the Population Density mapping, Fig. 11 shows a population density layer. Data were classified into a minimum to a maximum of population per sq.km of the area; a population maximum of above 500 pop per sq.km (Table 5) was restricted for the suitability. Figure 15 shows the most populated area of the Nashik and environs were restricted and another available area is for consideration. The Center of the city area is completely saturated and hence it is restricted for the analysis by assigning the pixel value of 0.

### 4.5. The Criterion for Site Selection

#### .5.1. Aspect

CartoDEM satellite data used in digital elevation model tools to prepared the aspect map. Physical slope features and their directions were indicated by the aspect map data. Figure 17 shows the aspect map where flat surfaces were in grey and its cell value will be -1. Slope directions measured from 0 degrees starting from the north in clockwise and it returns to 360 degrees north. The aspect map was classified into flat surfaces and a total of eight directions and it indicated the south point of view. India completely lies in the north of the equator so that the present study area is located in the northern hemisphere, hence the radiance of sun rays higher on southern slopes. Landfill sites were selected in the directions to get the balance sun exposure so that the fire incidents can also be controllable.

#### 4.5.2. Windrose Diagram

In the present study, the windrose diagram for the year 2018 was considered for the visual interpretation and final site selection. The windrose plot for Nashik city is freely available on Envitrans, which is processed according to the CPCB and US EPA Guidelines. The average wind speed of 6.9 km/h was analyzed and wind direction flowing towards the West is determined. Figure 18 shows the wind flowing towards the west with high speed and other direction observed at a calm position so that West direction is not suitable for the SWM landfill site suitability.

## Results and Discussion

This study analyzed a total of 15 parameters in the selection of potential landfill sites; thematic maps like geomorphology, hydrogeology, distance to road, drainage, lineament, slope, LULC, distance to water bodies, population density used for AHP-MCDA, Airport, water bodies, road, habitation are used for restriction buffer analysis and aspect, the wind rose diagram for final site suitability selection. GIS-MCDA techniques were used to develop the AHP comparison matrix for nine thematic parameters in the present study. The potential landfill site identification & its suitability were calculated using the suitability index. Table 3.shows the AHP comparison matrix and computed weights of each parameter. The consistency ratio of 0.05557 is obtained from the pairwise comparison matrix which is less than 0.1, so it was acceptable. In the AHP comparison matrix, population density, water bodies, and LULC criteria gave the most important to avoid the contamination by landfill disposal sites. Contamination of waste can cause air and water pollution that is not good for the health of human beings. The geomorphology map has given less importance with the obtained weightage value of 0.02015 and population density has a 0.30592 weightage with the most important in the AHP study.

Table 3
AHP Pairwise comparison matrix and computed weights of each parameter

| Factor | A | B | C | D | E | F | G | H | I | Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| Geomorphology (A) | 1 | 1 | 0.333 | 0.25 | 0.2 | 0.143 | 0.143 | 0.125 | 0.111 | 0.02015 |
| Hydrogeology (B) | 1 | 1 | 1 | 0.333 | 0.25 | 0.2 | 0.167 | 0.143 | 0.125 | 0.02528 |
| Distance to Road (C) | 3 | 1 | 1 | 0.5 | 0.333 | 0.25 | 0.2 | 0.167 | 0.143 | 0.03383 |
| Drainage Density (D) | 4 | 3 | 2 | 1 | 0.333 | 0.333 | 0.25 | 0.2 | 0.167 | 0.05188 |
| Lineament Density (E) | 5 | 4 | 3 | 3 | 1 | 1 | 0.333 | 0.25 | 0.25 | 0.08758 |
| Slope (F) | 7 | 5 | 4 | 3 | 1 | 1 | 0.5 | 0.333 | 0.25 | 0.10379 |
| LULC (G) | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0.5 | 0.333 | 0.15395 |
| Distance to Waterbodies (H) | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0.5 | 0.21762 |
| Population Density (I) | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0.30592 |

The restriction analysis is also carried out to get better and accurate results in case of sensitive areas like water bodies, habitation, airport, and road. Buffer analysis was done according to the CPHEEO manual of solid waste management rules by CPCB and MOEFC. The obtained vector polygons were converted into a raster format with a 5.8m spatial resolution. All obtained restricted maps were merged into a binary mask layer of value 0, 1. It has been combined using a raster calculator tool in spatial analyst. The restricted and non-restricted areas can be allotted a value of 0 and 1. A restricted map of selected areas was combined into the ArcGIS environment to generate the total restriction map of the Nashik and environs and the resultant map seen in Fig. 16. To prepared the solid waste management landfill suitability map, weights calculated for the nine thematic parameters were used in the GIS environment for weighted overlay analysis. Figure 19 shows the resultant landfill suitability map which has been classified into not suitable, less suitable, highly suitable. In the present study of Nashik and environs, due to the rapid urbanization & industrialization Nashik Municipal Corporation was mostly saturated, so that the suitable site area obtained in the suitability map of the study was away from the city area.

The population of Nashik and Environs villages was 13, 19,393 in 2001 (Census India 2001), while it was 18, 32,427 in 2011 (Census India 2011). The projected population calculated for the year of 2021 from the geometrical projection method by considering the average growth rate of the last two decades is 3.915 and the estimated population was 26, 90,352 for the year of 2021. According to the CPHEEO, the 2016 manual generation of domestic solid waste per head was considered for the area having both urban and rural as 0.6 kg/day, and the density of compacted waste in landfill sites was accepted as 850 kg/m$^3$. Solid waste produced in the study area for the year of 2021 was calculated 589,187,088 Kg and the waste generation volume thus computed to be 693,161.28 Cubic m. According to Municipal Solid, Waste Management Manual (CPHEEO 2016), the height or depth of landfill site construction changes as per the size and type of waste generated by the population and place and it varies from place to place. i.e. in the range of 5 to 30 m. Sample calculations, called Case 1 and Case 2, are presented here. In Case 1, consider the solid waste landfill constructed at a depth of 5 m, then the coverage area was required as 0.139 Sq.km. Similarly, Case 2 is generated using a 25 m depth, then the coverage area is computed as 0.02777 Sq.km. For final selection, the potential landfill site area is calculated for 5 and 25m depth by considering 50% excess, which is 0.2085 Sq.km (20.85 Ha) & 0.041655 Sq.km (5 Ha) respectively.

Two threshold criteria were applied to the obtained result to identify the most suitable landfill sites in the present study. The landfill site area should be greater than 5 Ha and having weightage greater than the importance value 7. Figure 20 depicts the result of potential landfill sites map for the study area. The final Suitability of sites were screened out by visual interpretation of selection criteria such as aspect and windrose diagram. The aspect map indicates the Nashik and environs area was located in the northern hemisphere and radiance of sun rays higher on southern slopes So, that the sites at North West and North East directions were more suitable, as it comes under considerable condition. While the wind rose diagram shown winds flowing towards the west direction, hence sites available in the west direction were neglected. A set of four potential sites areas were identified (Table 6 and Fig. 20) as the most potential sites for Solid Waste Management. A landfill site that comes under the Four potential zones was classified into three categories; rank 1, rank 2, and rank 3. Rank 1 is found most suitable, rank 2 is moderately suitable, and rank 3 is less suitable. The results of the current methodology were useful in suitable SWM Landfill Site identification and ranking to the site.

Table 6
Identified landfill sites with its parameters in the present study

| Site No. | Rank* | Area | Geographical coordinates (Decimal Degrees) | | Proximity coverage |
|---|---|---|---|---|---|
| | | (Ha) | Longitude | Latitude | |
| 1 | 1 | 782.93 | 73.747061 | 20.088423 | NMC, NNW |
| 2 | 1 | 172.19 | 73.822215 | 20.087985 | NMC, NNE |
| 3 | 1 | 16.37 | 73.812065 | 20.081761 | NMC, NNE |
| 4 | 1 | 175.26 | 73.897152 | 20.025068 | NMC, E |
| 5 | 1 | 18.38 | 73.913631 | 20.039755 | NMC, E |
| 6 | 2 | 16.06 | 73.792236 | 20.112509 | NMC, N |
| 7 | 2 | 10.50 | 73.795009 | 20.130457 | NMC, N |
| 8 | 2 | 8.504 | 73.916110 | 20.035746 | NMC, E |
| 9 | 3 | 16.07 | 73.759957 | 20.130094 | NMC, NNW |
| 10 | 3 | 58.97 | 73.749486 | 20.125957 | NMC, NNW |
| 11 | 3 | 18.90 | 73.718081 | 20.113181 | NMC, NNW |
| 12 | 3 | 102.89 | 73.797219 | 20.139317 | NMC, N |
| 13 | 3 | 22.41 | 73.926918 | 20.029437 | NMC, E |
| 14 | 3 | 13.77 | 73.707690 | 20.051025 | NMC, NW |
| 15 | 3 | 859.59 | 73.722647 | 19.877954 | NMC, SW |
| (Rank*: 1-most suitable, 2-moderately suitable, 3-less suitable) | | | | | |

# 5. Conclusions

The present study identified the potential landfill sites for Nashik and environs. Solid waste management landfill site for the upcoming years from 2021 onwards obtained by considering per capita waste generation. Geospatial technologies RS-GIS provides an optimum result to delineate the potential landfill sites in Nashik and Environ Villages within a 15 km radius. Thematic parameters used for the AHP-MCDA comparison matrix with their calculated weights help in accurate decision making. 15 thematic layers used in the study gave the best scientific and impactful outcomes. The consistency ratio calculated for the AHP study was 0.05557 which was less than 0.10, which contributed to the precision of the selected technique. Integrated analysis of AHP-MCDA and restricted layers in the GIS environment proposed four potential landfill site areas around the study. Obtained potential landfill sites were mostly in the wasteland that was nearby to Nashik Municipal Corporation and away from the populated places, thus eliminating the risk of social conflict. The future scope will include an implementation of a landfill at the given suitable area after ground verification. Awareness and training program for solid waste handling/ disposal and Environmental Impact Assessment / Socio-Economical Assessment study for the potential sites needs to be done. Hence the identified landfill site as per the rules and regulations and the final decision will depend on the stakeholders and related issues.

# Declarations

### Conflicts of Interest:

The authors declare that they have no conflict of interest.


### Acknowledgment :

The authors wish to acknowledge the support from the National Remote Sensing Center, Balanagar, Hyderabad, India


# References


Al-jarrah O, Abu-qdais H (2006), Municipal solid waste landfill siting using intelligent system. Waste Manag 26:299–306. doi: 10.1016/j.wasman.2005.01.026

Aksoy, E., San, B.T. Geographical information systems (GIS) and Multi-Criteria Decision Analysis (MCDA) integration for sustainable landfill site selection considering dynamic data source. Bull Eng Geol Environ 78, 779–791 (2019). https://doi.org/10.1007/s10064-017-1135-z

Central Public Health and Environmental Engineering Organization, 2016.Manual on Municipal Solid Waste Management, First Edition.

Central Pollution Control Board, New Delhi, 2003. Guidelines for the selection of a site for landfilling, Hazardous Waste Management series, HAZWAMS/23/2002–03, 1–11.Government of India.

Endait Mahesh &Patil Swati (2020), Laboratory investigation of compaction characteristics of fresh and degraded municipal solid waste, Waste Disposal & Sustainable Energy, ISSN 2524-7980

Everett JW, Member A, Vieux BE (1996) Landfill siting using geographic information systems: J Environ Eng 122:515–523

Feo G De, Gisi S De (2014) Using MCDA and GIS for hazardous waste landfill siting considering land scarcity for waste disposal. WASTE Manag.doi: 10.1016/j.wasman.2014.05.028,34(11): 2225-2238

Figueira J, Greco S, Ehrogott M (2005) Multiple Criteria Decision Analysis: State of the Art Surveys

Gal, T., Stewart, T .J., Hanne T (1999) MulticriteriaDecisionMaking: Advances in MCDM Models, Algorithms, Theory, and Applications

Geneletti D. (2010). Combining stakeholder analysis and spatial multicriteria evaluation to select and rank inert landfill sites [J]. Waste Management, 30(2): 328–337.

Gemitzi A, Tsihrintzis VA, Petalas C (2007) Combining geographic information system, multicriteria evaluation techniques, and fuzzy logic in siting MSW landfills. Env Geol 51:797–811. doi: 10.1007/s00254-006-0359-1

Gorsevski P V, Donevska KR, Mitrovski CD, Frizado JP (2012) Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average. Waste Manag 32:287–296. doi: 10.1016/j.wasman.2011.09.023

Gzogala E, Rawlik T (1989) Modelling With a Fuzzy Controller With Application to the Control of Biomedical Processes. Fuzzy Sets Syst 31:13–32

Hannan M A, Abdulla Al Mamun M, Hussain A, Basri H, Begum R A., (2015). A review on technologies and their usage in solid waste monitoring and management systems: Issues and challenges [J]. Waste Management, 43: 509–523.

Kaliraj S. Chandrasekar N. (2015). Evaluation of multiple environmental factors for site-specific groundwater recharge structures in the Vaigai River upper basin, Tamil Nadu, India. Using GIS-based weighted overlay analysis [J], Environmental Earth Sciences, 74(5), 4355-4380

Kapilan, S., Elangovan, K. Potential landfill site selection for solid waste disposal using GIS and multi-criteria decision analysis (MCDA). J. Cent. South Univ. 25, 570–585 (2018). https://doi.org/10.1007/s11771-018-3762-3

Kumar S. Hassan M. (2013). Selection of a landfill site for solid waste management; An application of AHP and spatial analyst tool [J], Journal of Indian Society of Remote Sensing. 41(I):45-56

Kontos TD, Komilis DP, Halvadakis CP (2005) Siting MSW landfills with a spatial multiple criteria analysis methodology. Waste Manag 25:818–832. doi: 10.1016/j.wasman.2005.04.002

Khan S, Faisal MN (2008), An analytic network process model for municipal solid waste disposal options, Waste Management 28(9):1500-8

Manoj Govind Kharat, SheetalJaisinghKamble, Rakesh D. Raut, Sachin S. Kamble (2016), Identification and evaluation of landfill site selection criteria using a hybrid Fuzzy Delphi, Fuzzy AHP and DEMATEL based approach, Model. Earth Syst. Environ. (2016) 2:98,DOI 10.1007/s40808-016-0171-1

Moeinaddini M, Khorasani N, Danehkar A (2010) Siting MSW landfill using a weighted linear combination and analytical hierarchy process (AHP) methodology in a GIS environment Waste Manag 30:912–920.

doi: 10.1016/j.wasman.2010.01.015

Motlagh Z K, Sayadi M H (2015), Sitting of MSW landfills using MCE Methodology in FIS Environment, Waste Management,2015.08.013

SAATY TL (1980). The analytic hierarchy process: planning, priority setting, resource allocation, 287p, ISBN 0-07-054371-2. McGraw-Hill, New York

SAATY T L. (2008). Decision making with the analytic hierarchy process [J]. International Journal of Services Sciences, 1(1): 83–98

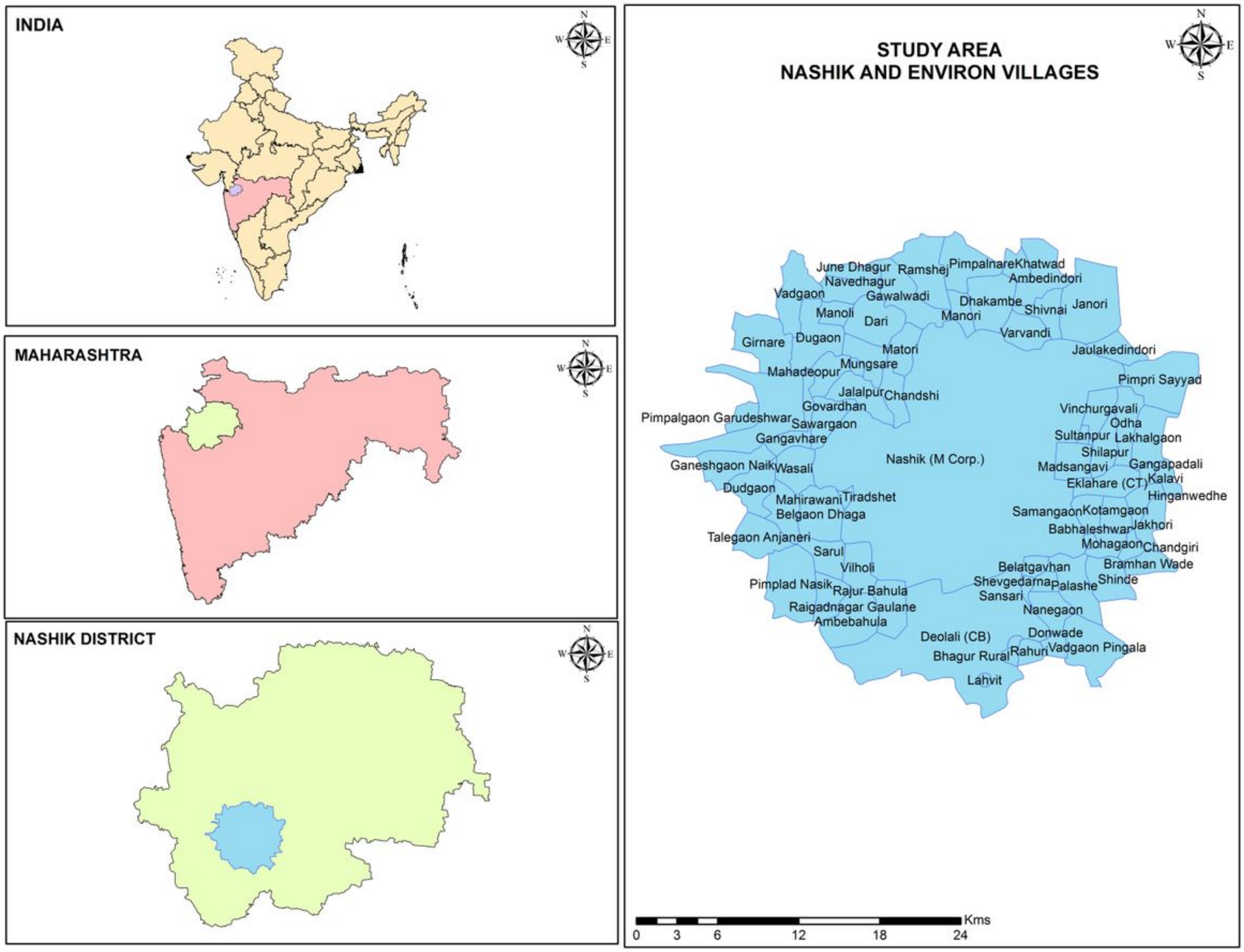
Sharifı M, Hadidi M, Vessali E, Mosstafakhani P, Taheri K (2009) Integrating multi-criteria decision analysis for a GIS-based hazardous waste landfill sitting in Kurdistan Province, western Iran. Waste Manag29:2740–2758.doi: 10.1016/j.wasman.2009.04.010

Tavares G, Zsigraiová Z, Semiao V (2011) Multi-criteria GIS-based siting of an incineration plant for municipal solid waste. Waste Manag 31:1960–1972. doi: 10.1016/j.wasman.2011.04.013

V.R.Sumathi, Natesan, UshaSarkar, Chinmoy. (2008). GIS-based approach for optimized siting of municipal solid waste landfill.Journal of Waste Management, 28. Pp.2146-60

Zeleny M (1982) Multiple criteria Decision making, Tata McGraw Hill, inc, New York

# Figures




## Figure 1

Location map of Study Area

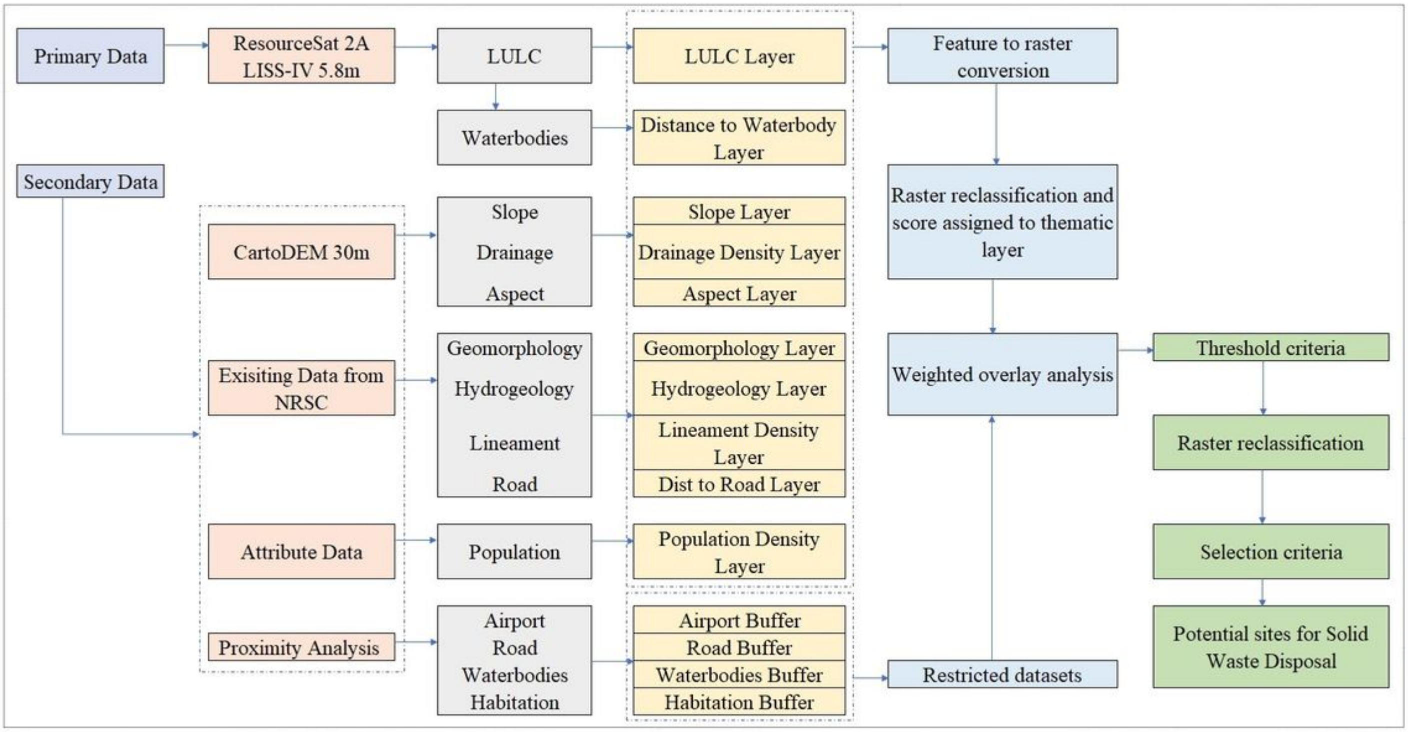
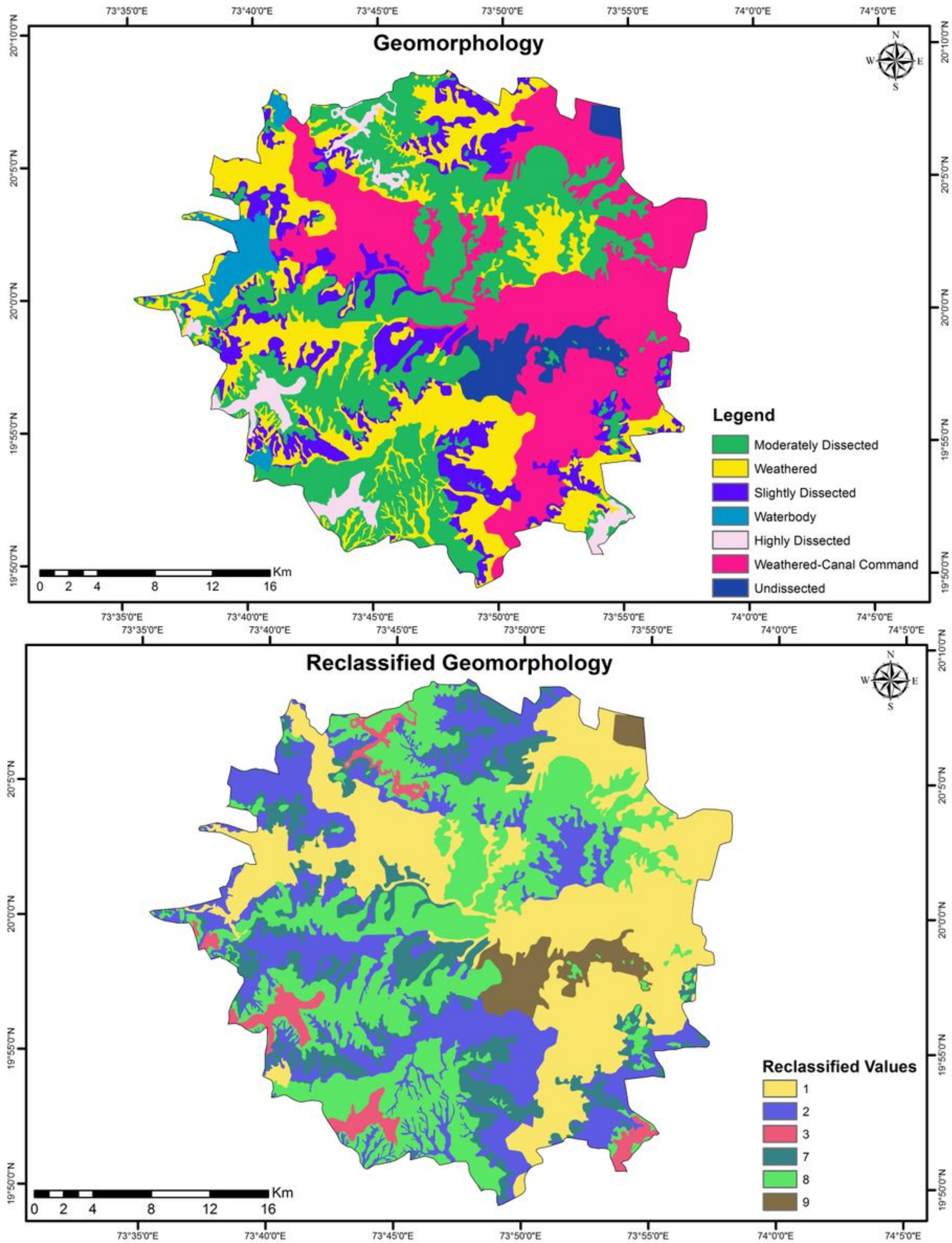


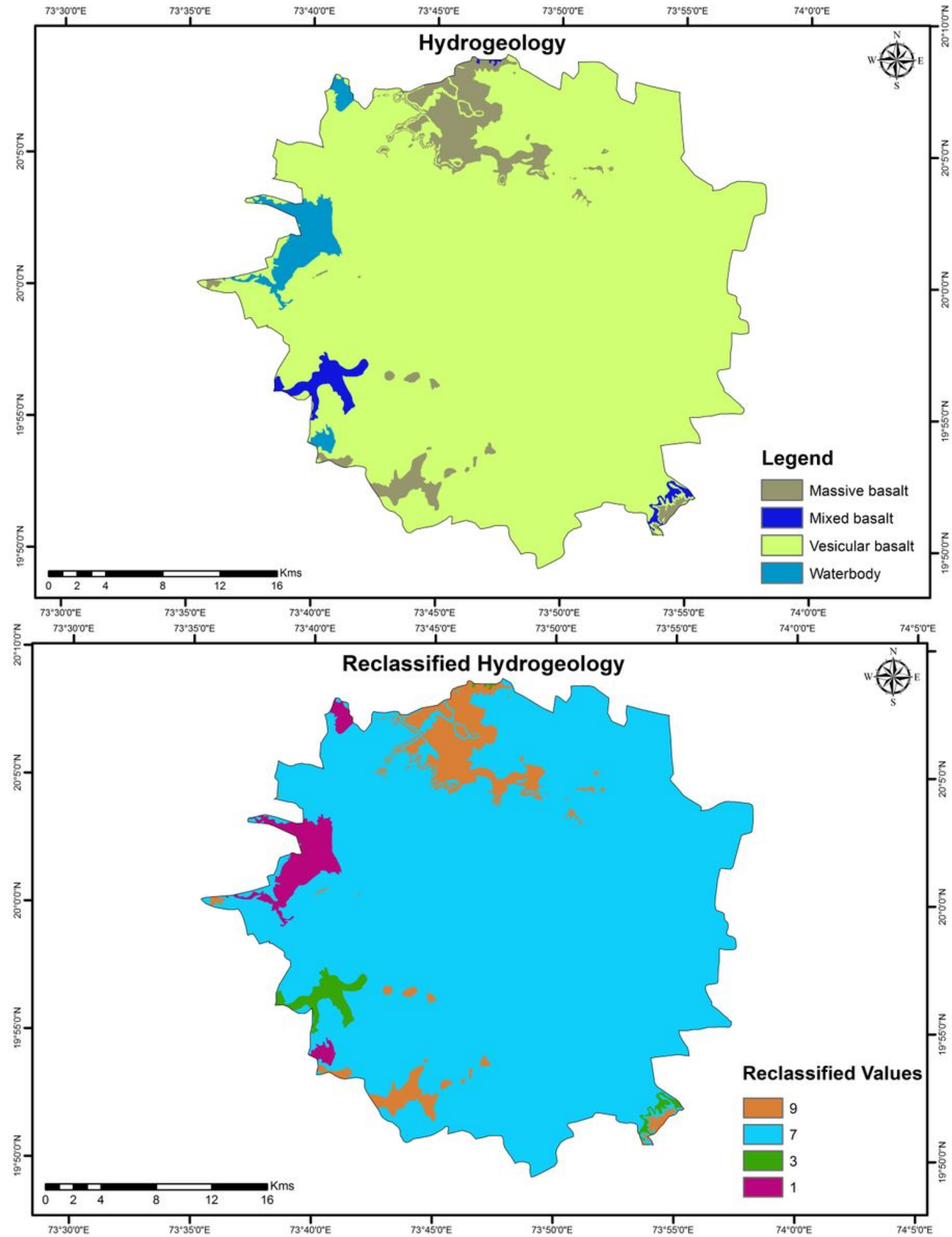

**Figure 2**

Schematic Flow Chart for Methodology



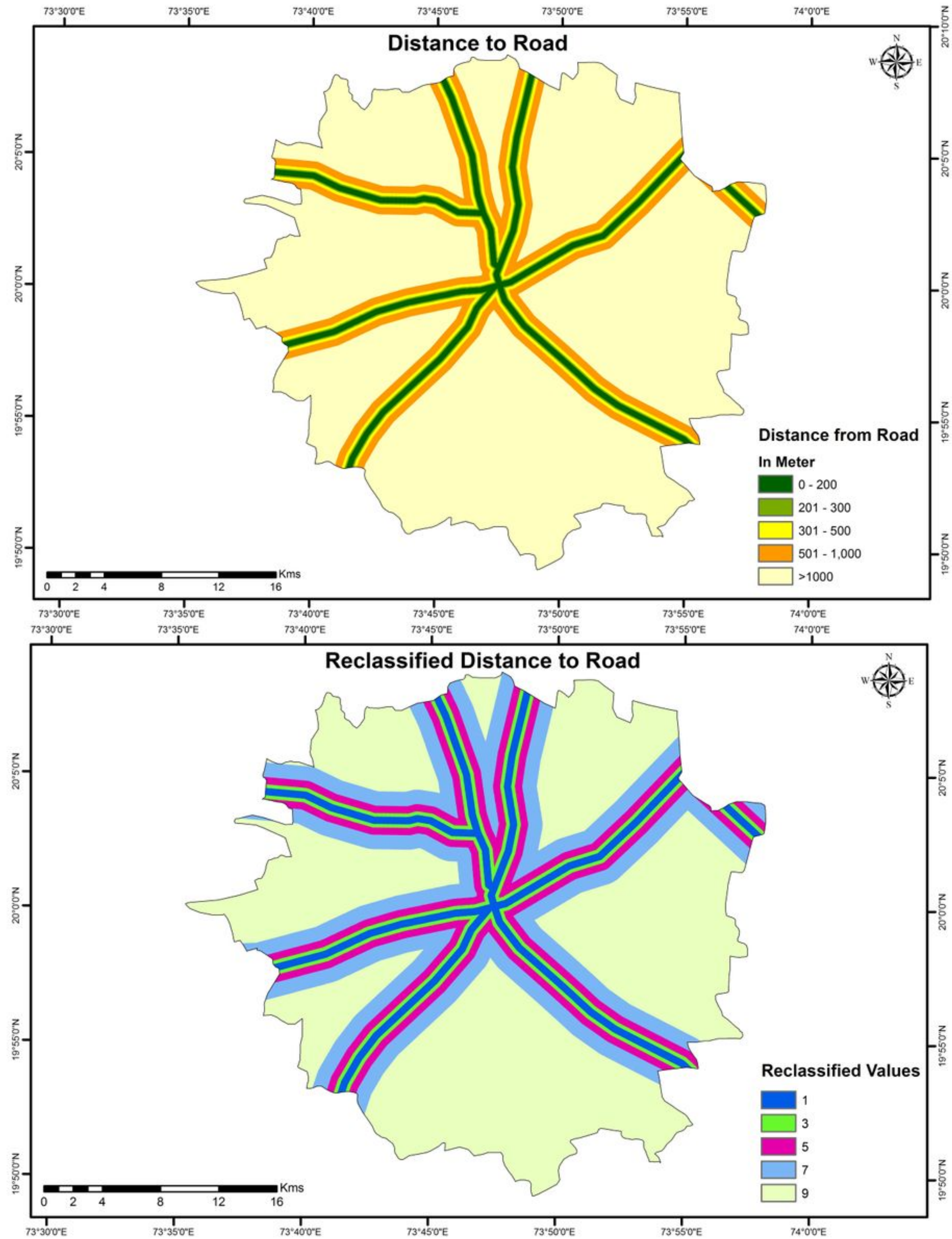

## Figure 3

Geomorphology and Reclassified Geomorphology Map



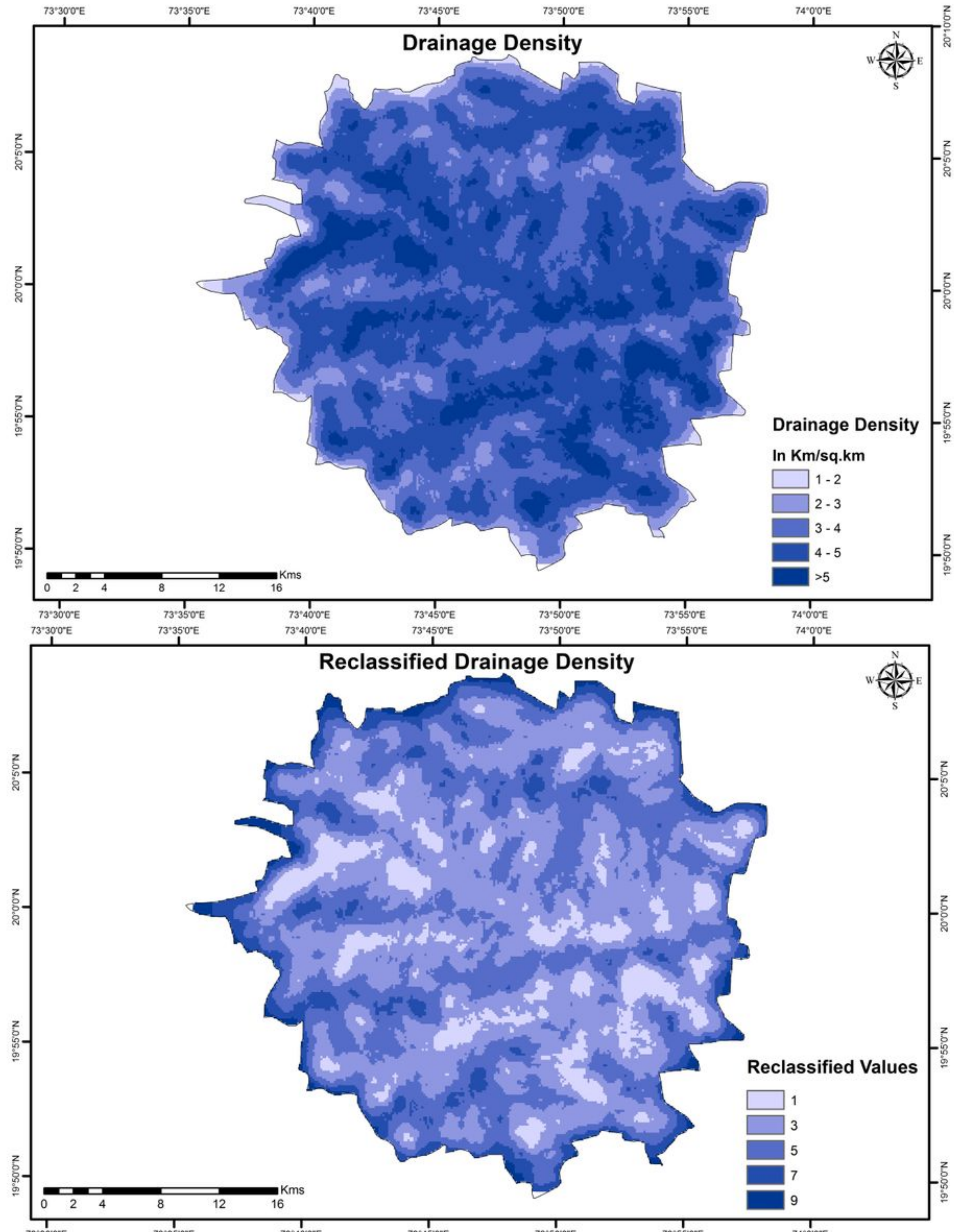

## Figure 4

Hydrogeology and Reclassified Hydrogeology Map



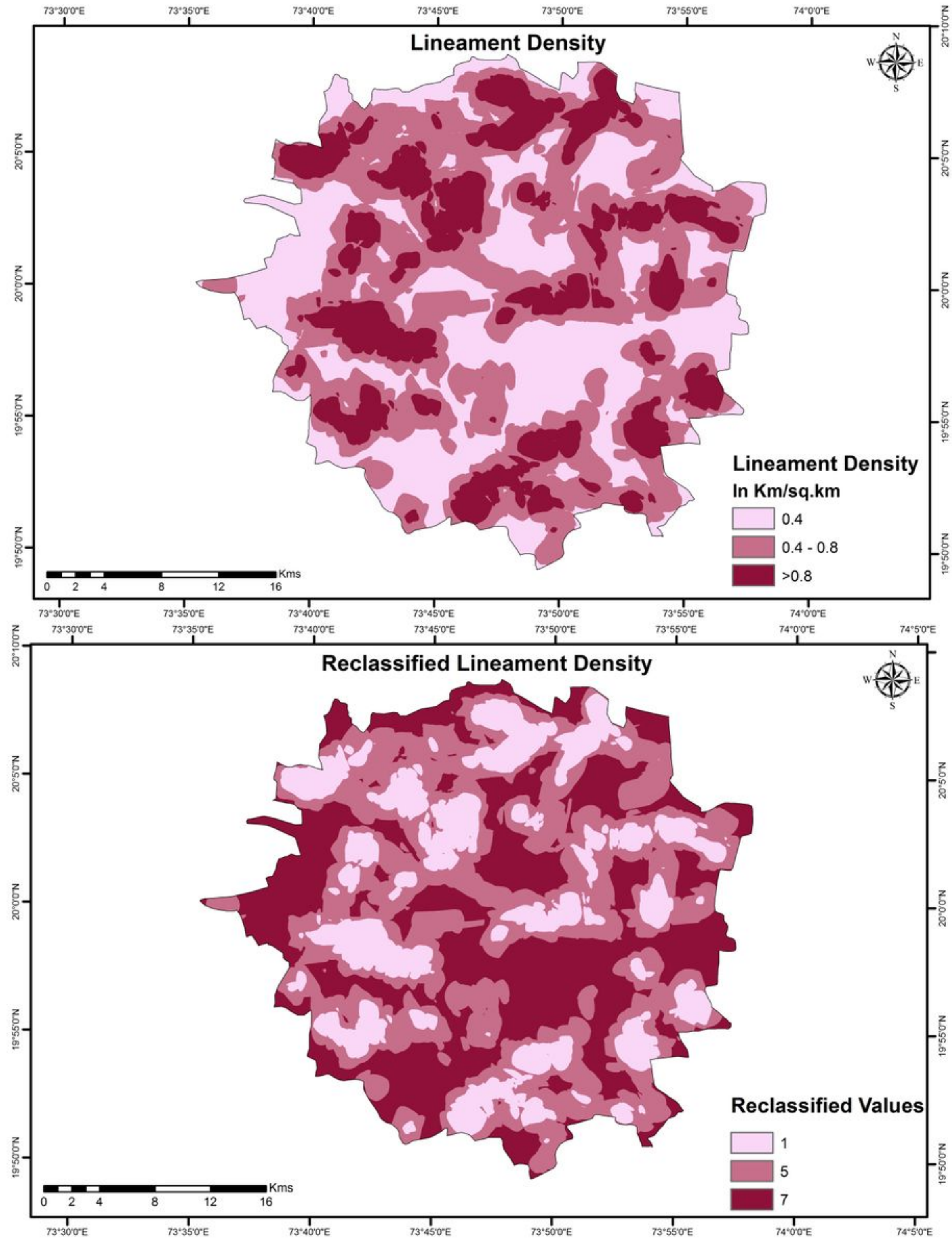

## Figure 5

Distance to Road and Reclassified Distance to Road Map



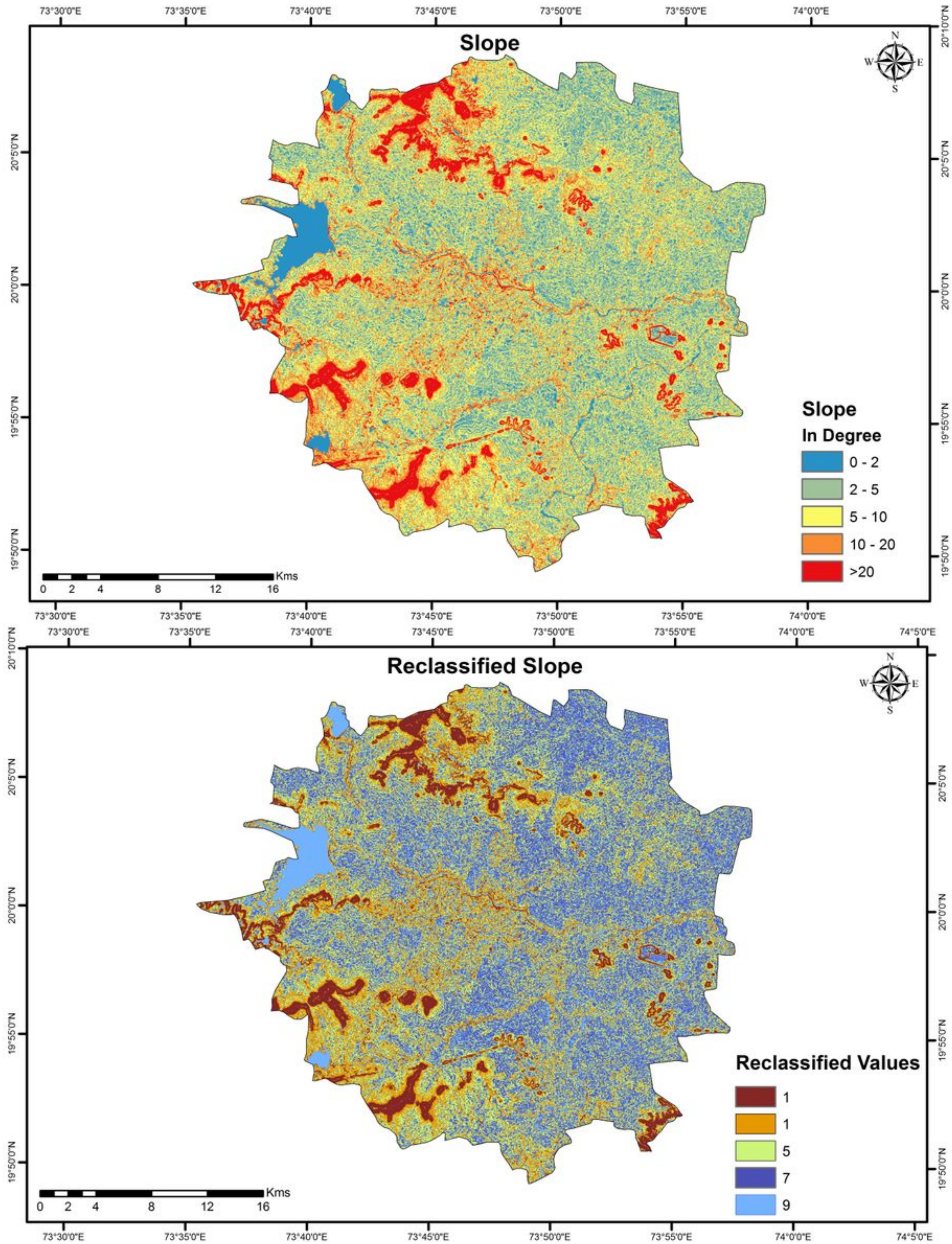

## Figure 6

Drainage Density and Reclassified Drainage Density Map



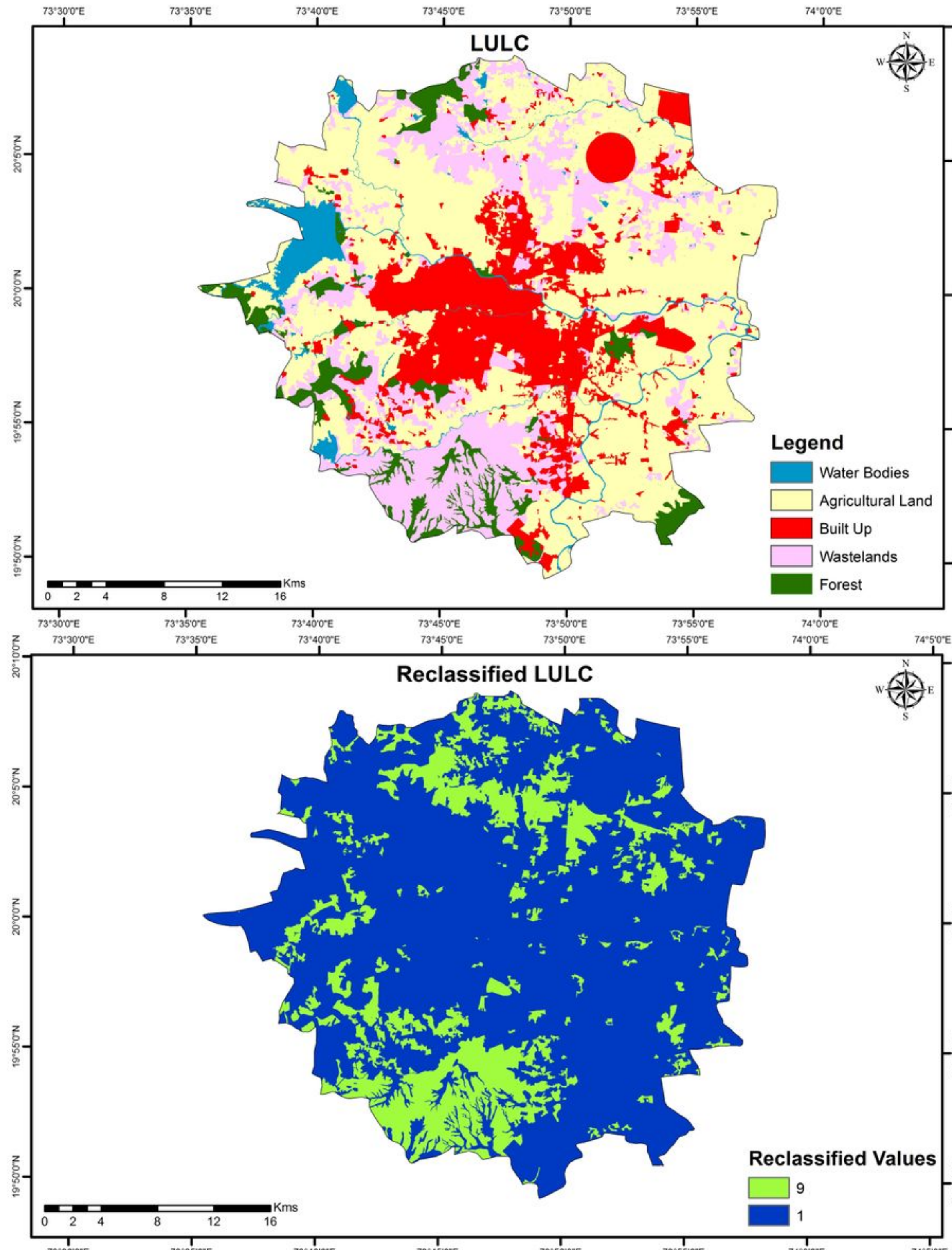

## Figure 7

Lineament Density and Reclassified Lineament Density Map



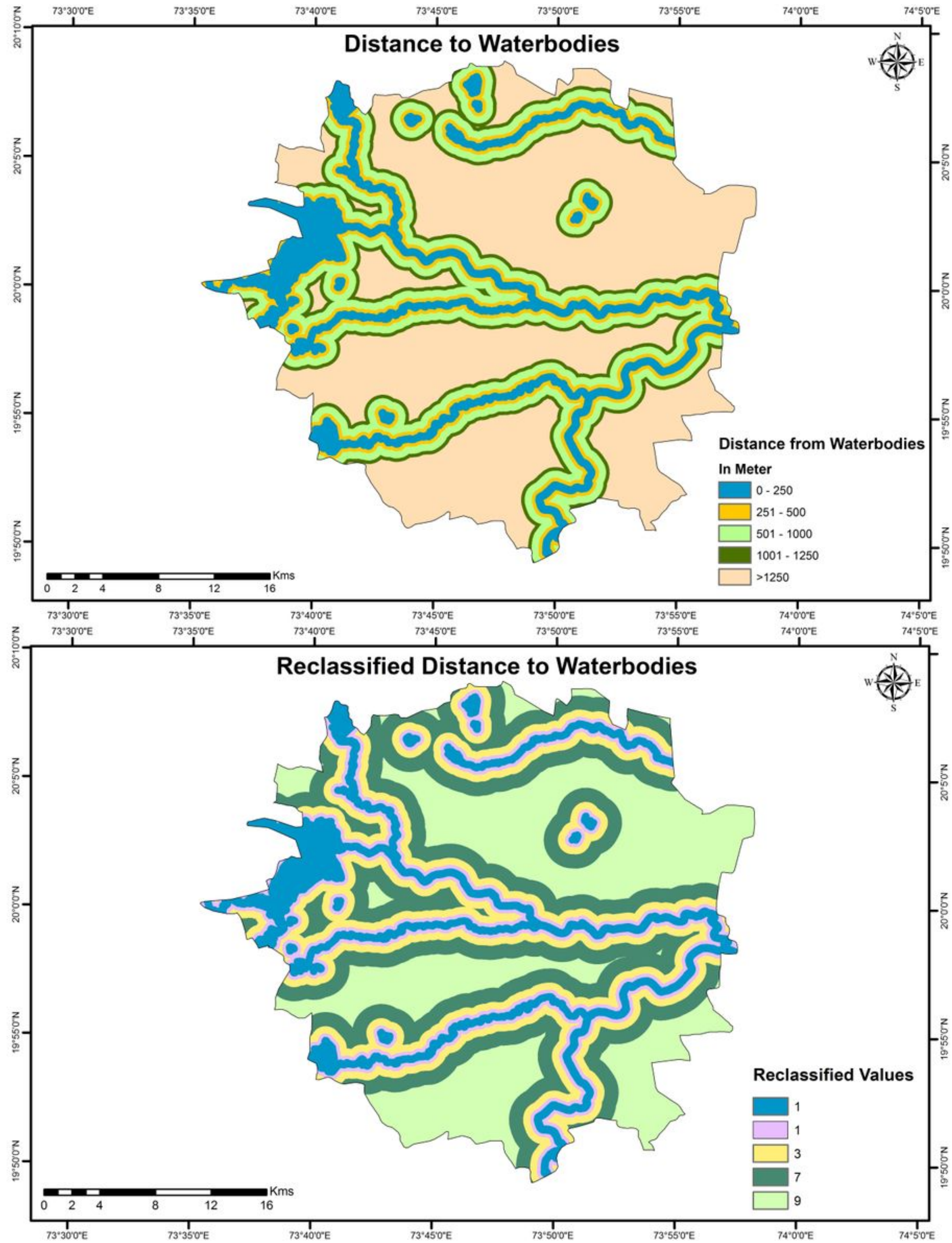

## Figure 8

Slope and Reclassified Slope Map



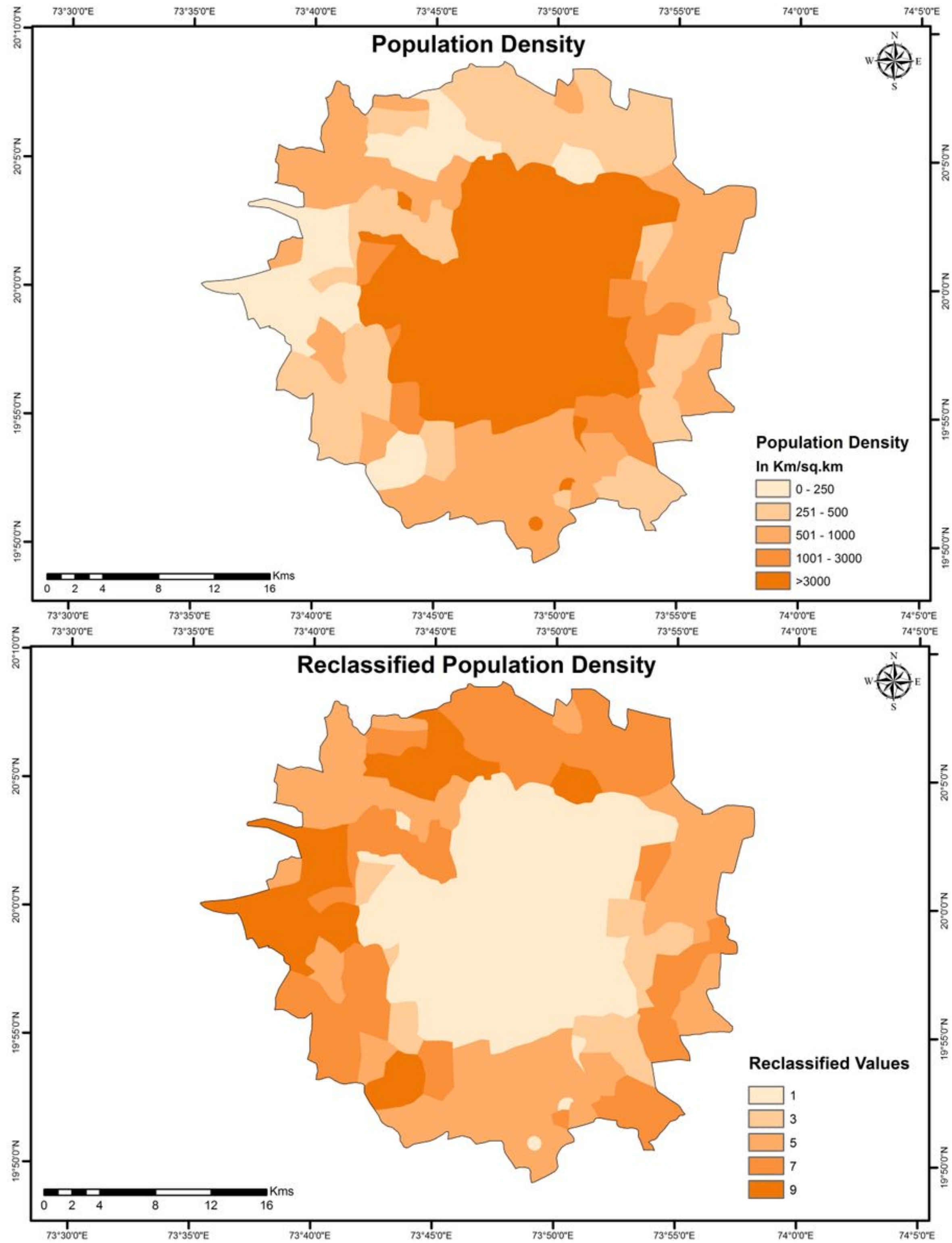

## Figure 9

Land Use Land Cover and Reclassified Land Use Land Cover Map



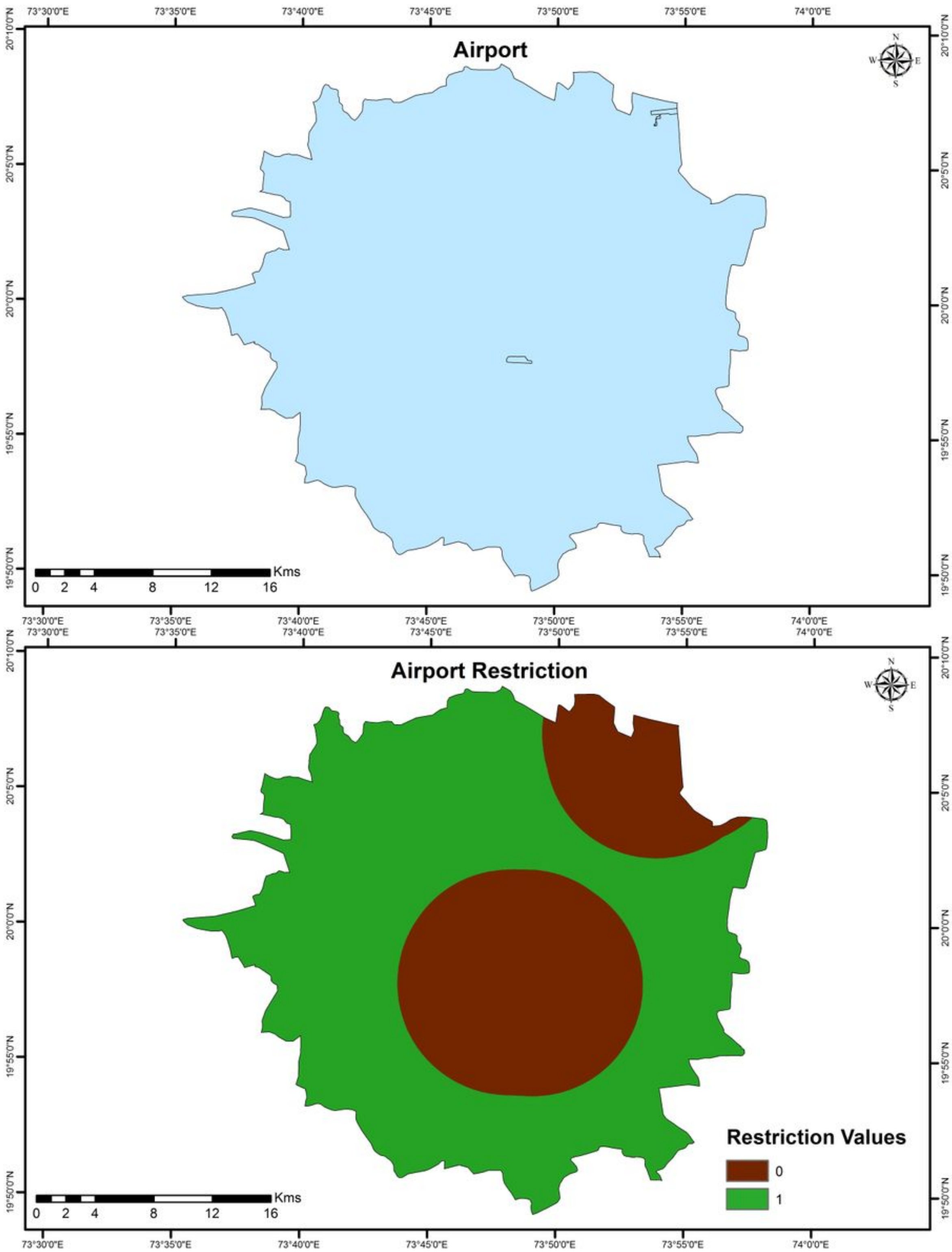

## Figure 10

Distance to Waterbodies and Reclassified Distance to Waterbodies Map



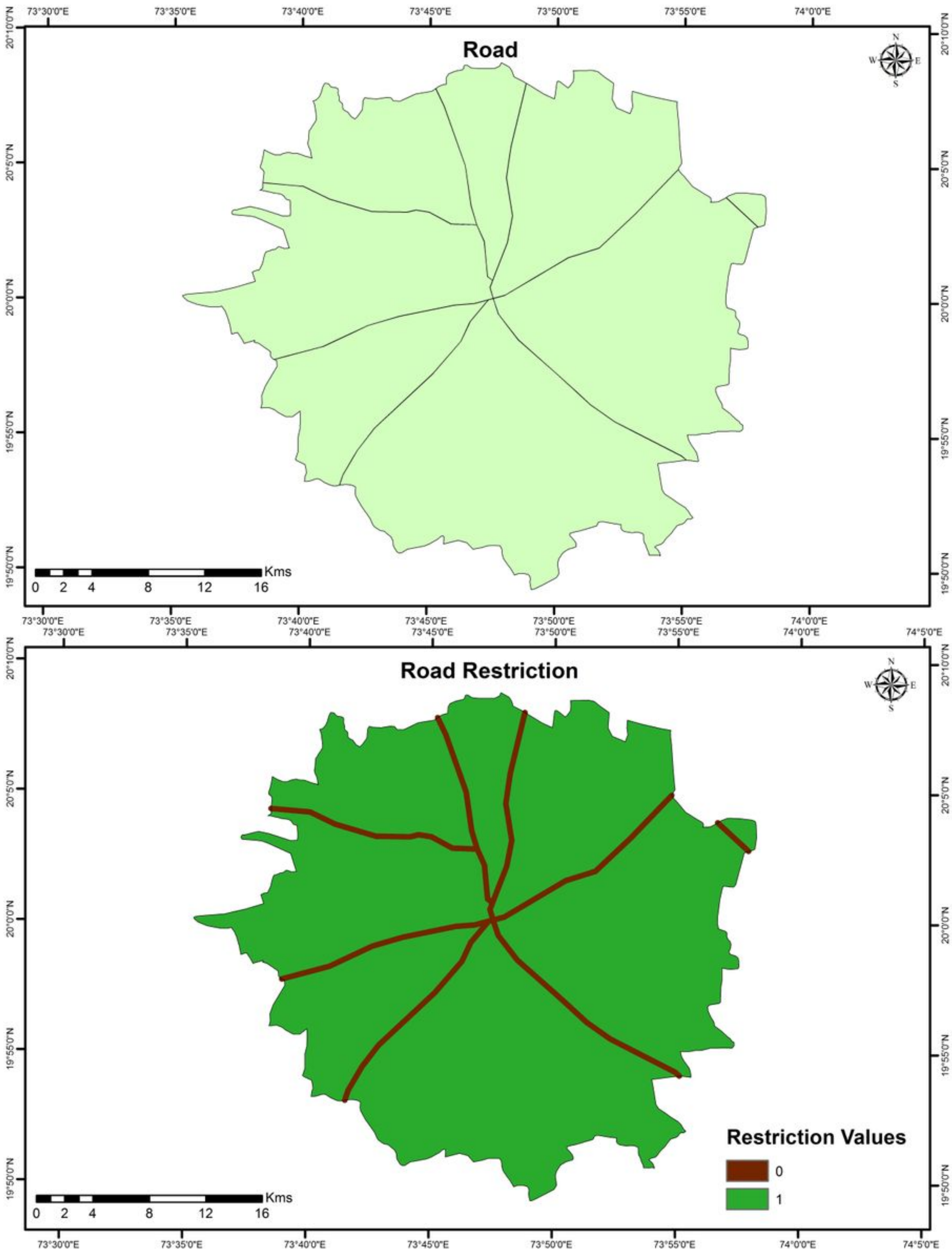

## Figure 11

Population Density and Reclassified Population Density Map



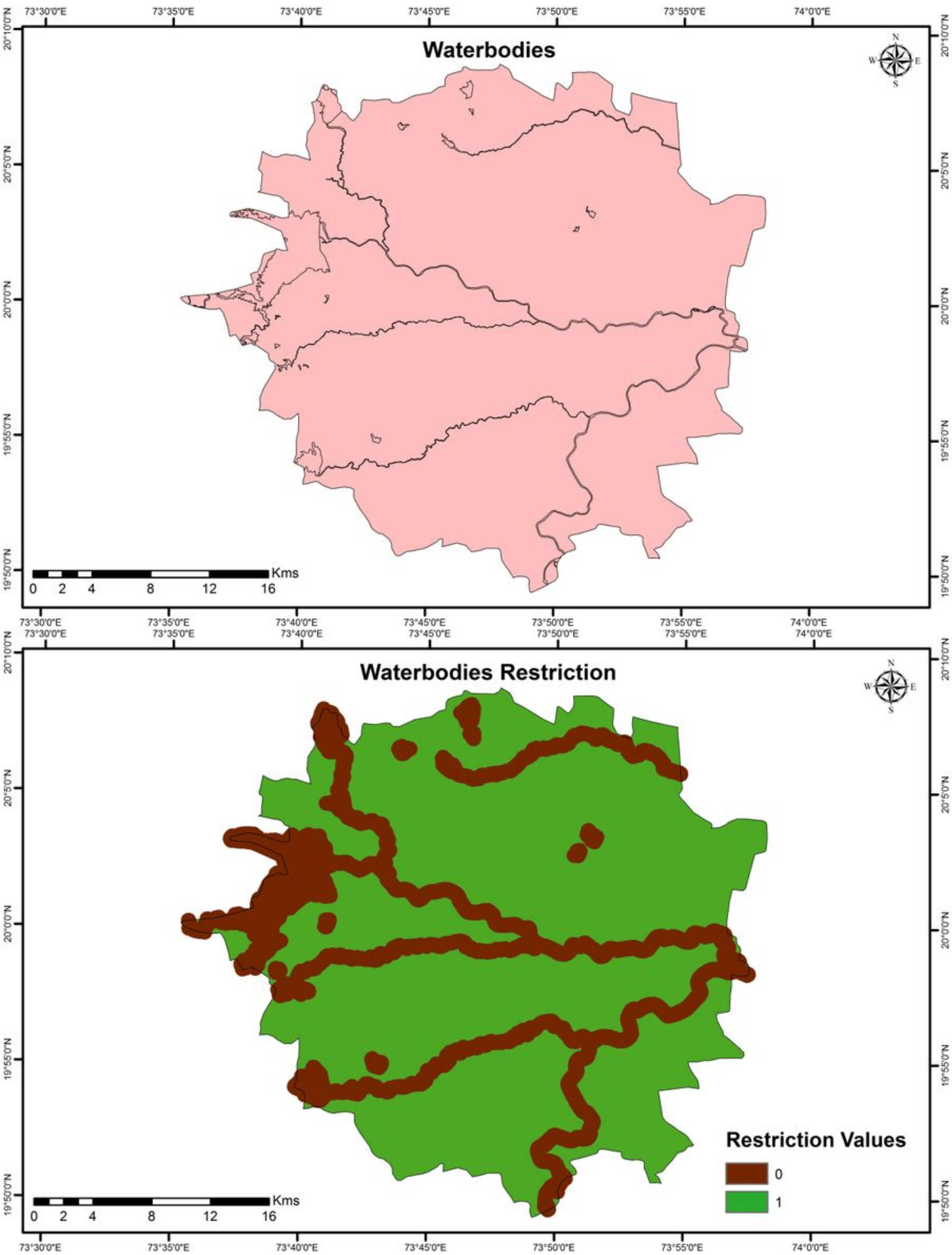

## Figure 12

Airport and Airport Restriction Map



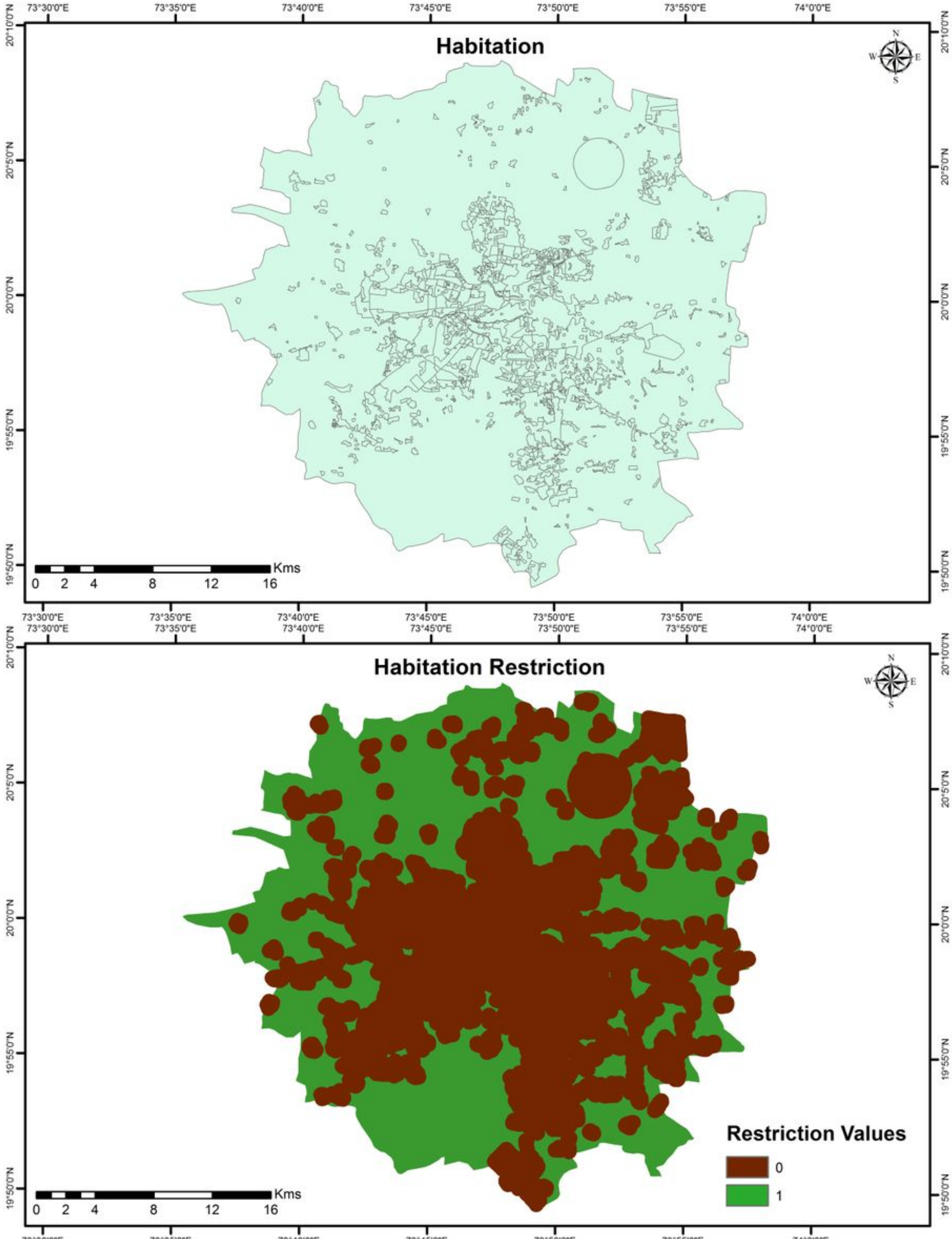

## Figure 13

Road and Road Restriction Map



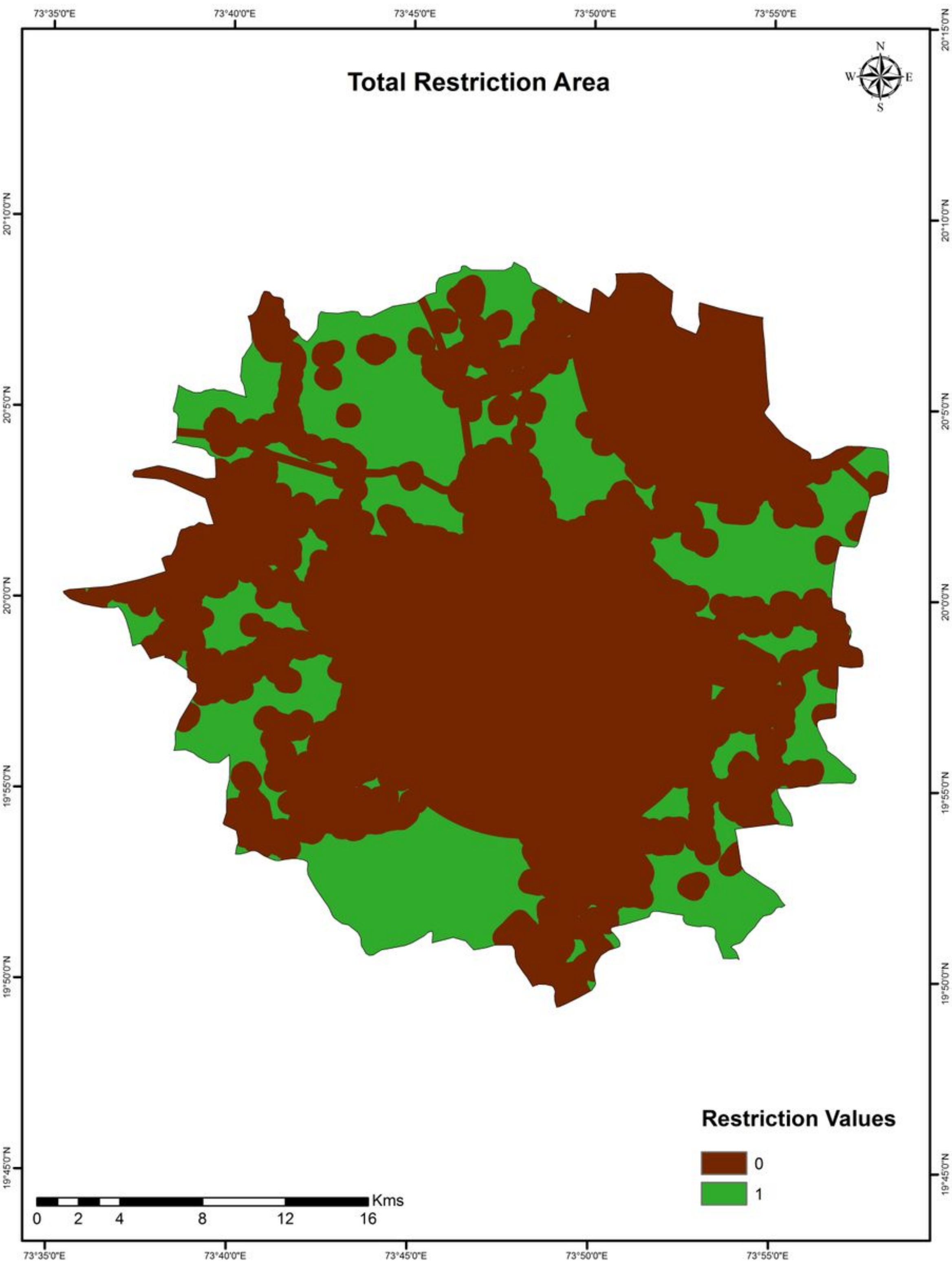

## Figure 14

Waterbodies and Waterbodies Restriction Map



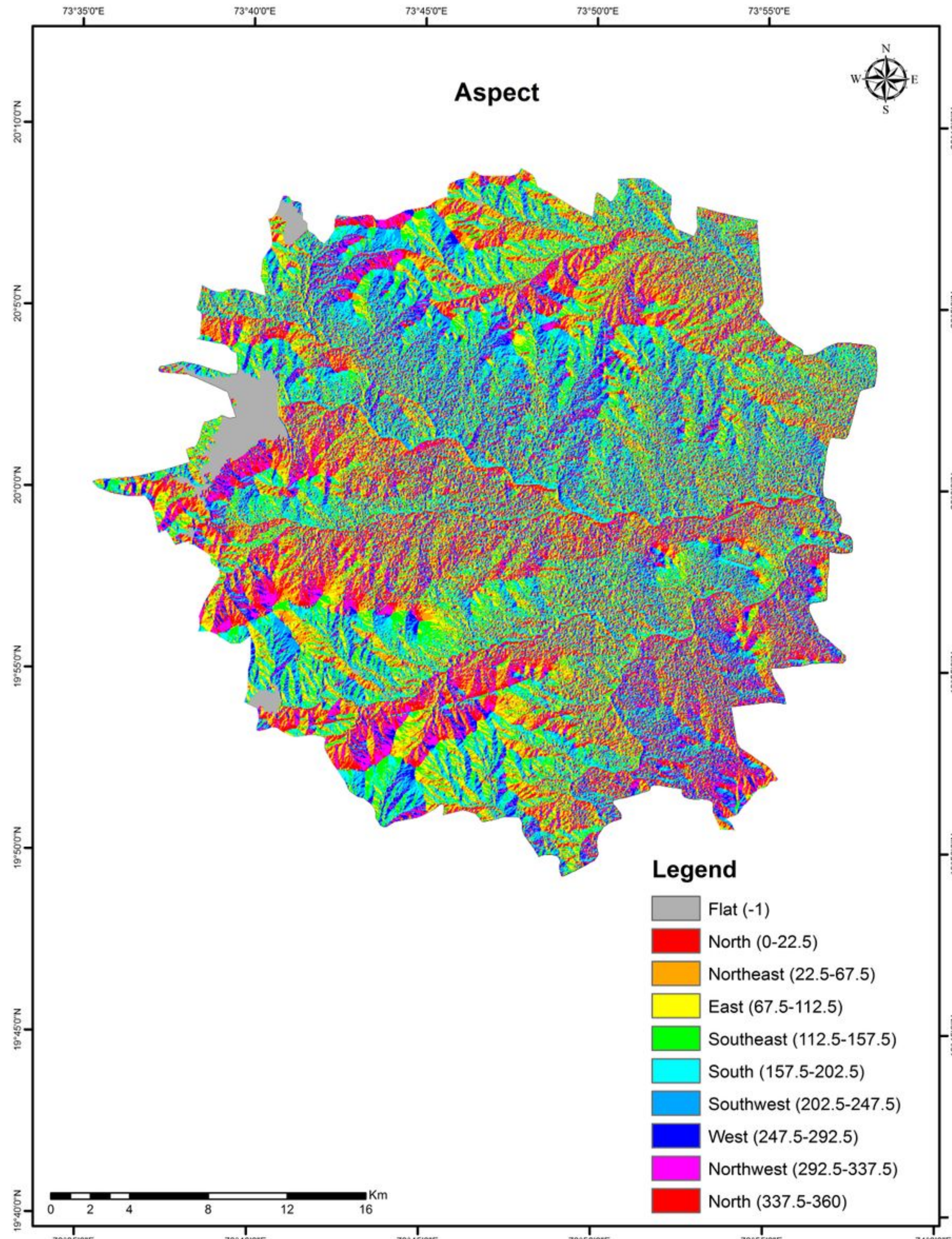

## Figure 15

Habitation and Habitation Restriction Map



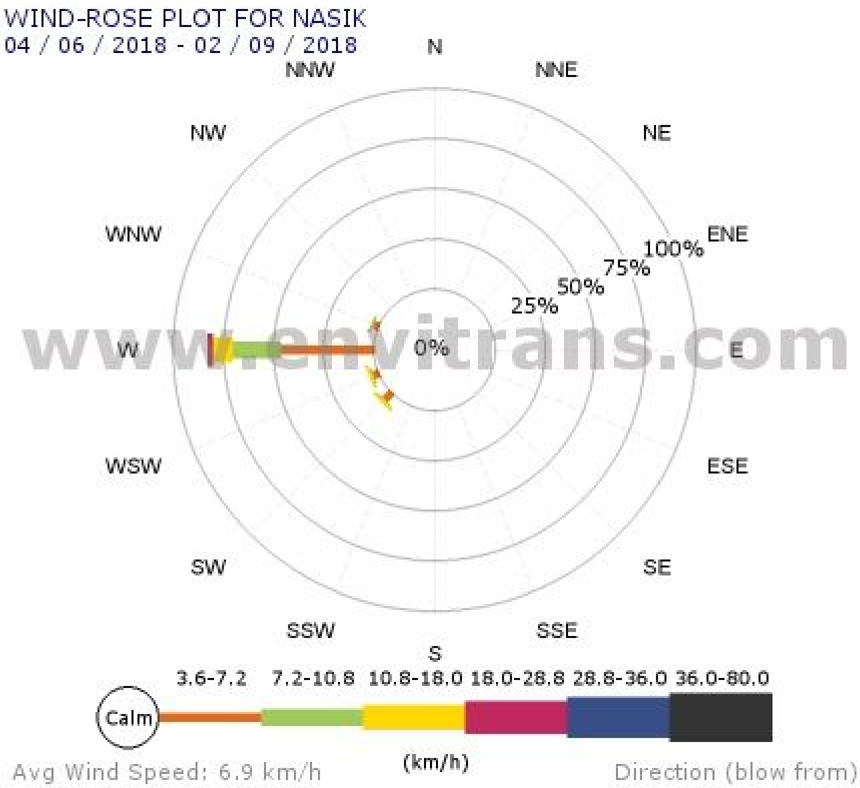

## Figure 16

Total Restriction Area Map



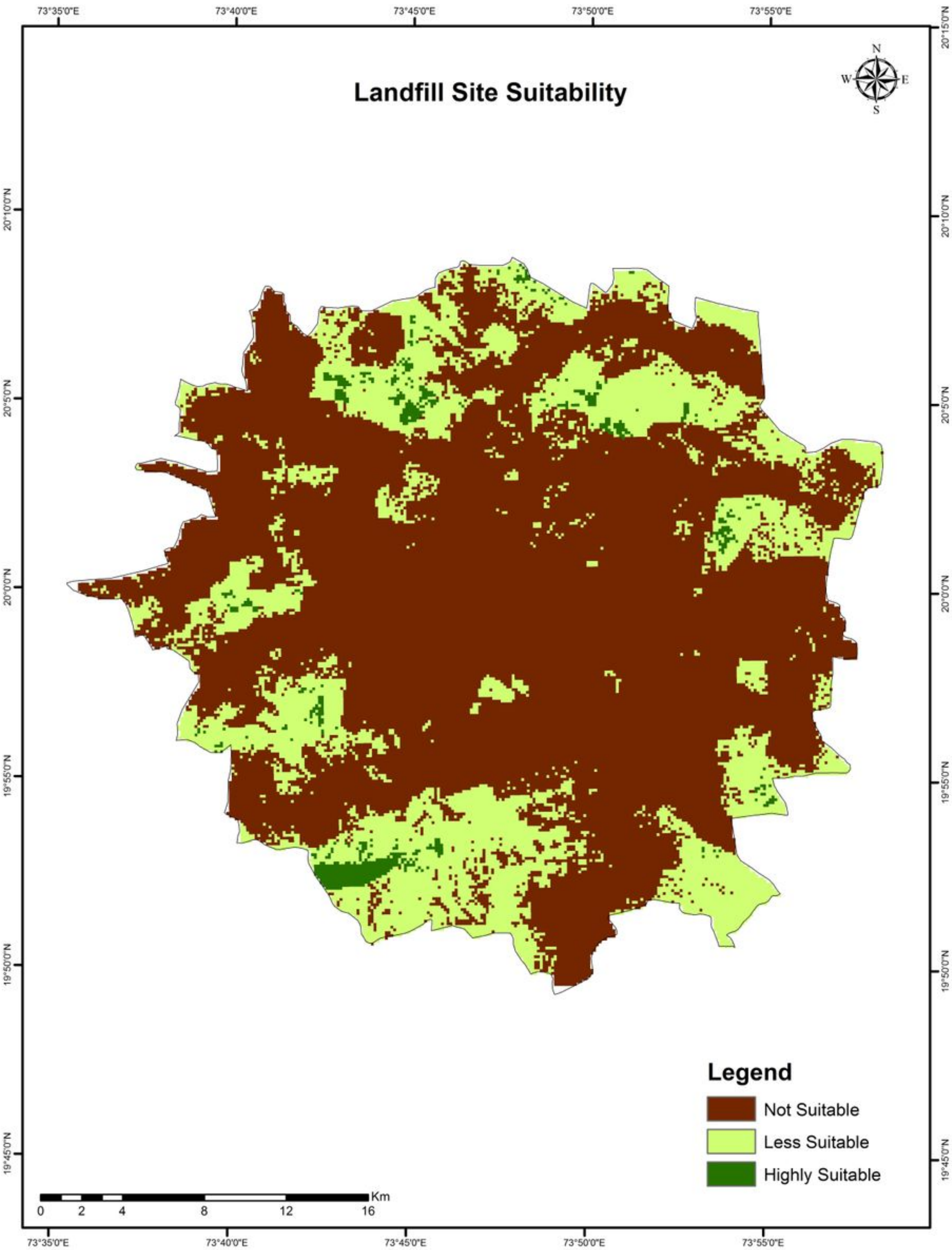

## Figure 17

Aspect Map



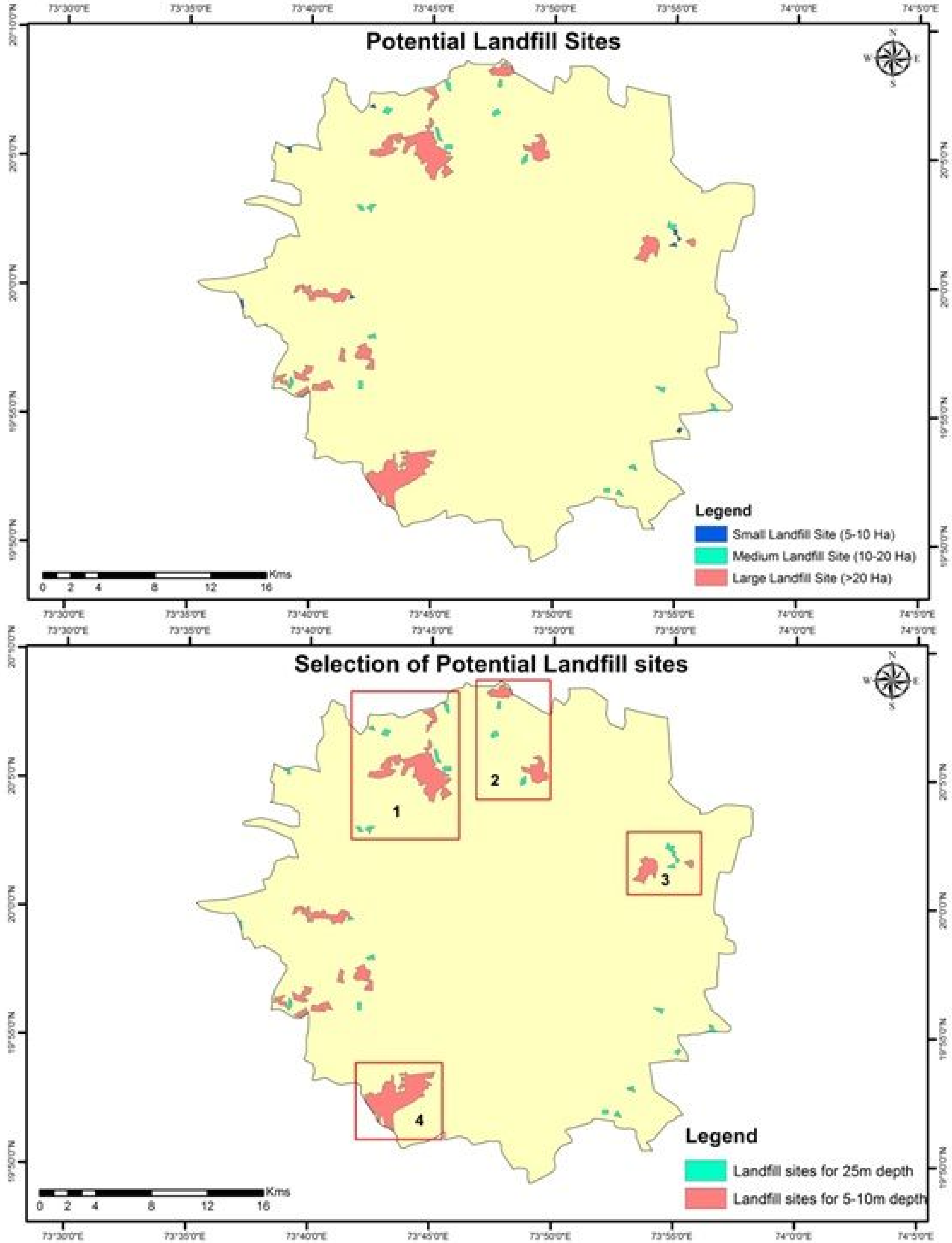

## Figure 18

Windrose Diagram for Nashik and Environs (Source: https://www.envitrans.com/show-wind-rose.php?stn=NDI5MjE=)




## Figure 19

Landfill Site Suitability Map




## Figure 20

Potential Landfill Sites Map