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Optimization of Wind Farm Location Planning with GIS Methods

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Abstract: ***Wind energy is one of the most important renewable energy sources in India and plays a key role in generation of energy and climate policy targets of the India government. However, a further formation of wind farms involves strong spatial implications that refer to various adverse effects on landscape (onshore wind), noise level, and wildlife. Negative environmental impacts caused by the sometimes suboptimal sitting of wind farms have induced an increasing gap between the social acceptance of this technology on the global and local levels. Particularly on the local level, siting processes of wind farm projects often trigger public protest. The objective of this project is to improve the siting assessment for wind farm by providing a holistic multi-criteria decision making approach that includes techno-economic, socio-political, and environmental criteria, which are defined in a way that social acceptance-related issues are specifically emphasized. GIS-based Analytic Hierarchy Process approach is used, where different factors that affect the location of wind farm siting is considered, Government policies and restricted area is also taken into consideration for proper location of wind farm. The results obtained classifying the area into six different classes based on suitability of area for wind farms (0 being not suitable and 5 being most suitable). Spatial Decision Support System (SDSS) assist in strategic decision-making activities considering spatial and temporal variables, which helps in regional planning. WEPA is a SDSS designed for assessment of wind potential spatially. A wind energy system transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Wind energy can diversify the economies of rural communities, adding to the tax base and providing new types of income. Wind turbines can add a new source of property value in rural areas that have a hard time attracting new industry. Wind speed is an extremely important parameter for assessing the amount of energy a wind turbine can convert to electricity: the energy content of the wind varies with the cube (the third power) of the average wind speed. Estimation of the wind power potential for a site is the most important requirement for selecting a site for the installation of a wind electric generator and evaluating projects in economic terms. It is based on data of the wind frequency distribution at the site, which are collected from a meteorological mast consisting of wind anemometer and a wind vane and spatial parameters (like area available for setting up wind farm, landscape, etc.). The wind resource is governed by the climatology of the region concerned and has large variability with reference to space (spatial expanse) and time (season) at any fixed location.***

1. Introduction

Electrical energy is essential for economic growth and wellbeing of human populations. The increasing concern with pollution result from the use of fossil fuels creates the pressure to use renewable energy sources to produce electricity, One of such resources can be wind energy which comes under renewable energy. Now siting of new wind farm require a proper study which should include various factors that should be taken into account while choosing the site for wind farm.

This study focuses on adopting a geographically referenced method to assess land suitability for location of wind farm in Karnataka State of India. All the factors that must be taken into consideration while installation of wind farm is considered and finally the sites with high potential for wind turbine installation are evaluated.

Accompanied by the spatial diffusion of wind farm sites in India, one of the most important associated issues is the social acceptance of this technology. Several surveys (e.g. Bell et al., 2005; Devine-Wright and Howes, 2010; Huber and Horbaty, 2012; Kann, 2009; Wolsink, 2007) show that there is a gap between global and local attitudes towards wind energy.

The siting procedure for wind farms in India is most commonly based on an exclusion approach, which is derived from legal and factual aspects. Thus, areas are excluded which lack sufficient average **wind speeds**, as well as areas where wind farm siting is **restricted**, such as residential areas, natural resources areas, water bodies, highways and other roads. Further a buffer is created around the above mentioned factors to avoid the restricted areas set under government policy's, these buffers also take into consideration various distance from roads water bodies or other type of landforms. These buffer zones are flexible and their area has to be justified case-by-case by the planning authority. After the consideration of all restrictions, and the associated exclusion of those areas, the remaining areas are examined individually. Minimum distances between wind turbines and residential areas, for instance, may vary substantially across the sixteen federal states of India.

Many research has already been done with the same objective but with different approach, main factors that differentiate one method with the other is the selection of restriction area criteria set by local of central authority of that area finally the method applied to add up all the consideration gives out the final result.

The present study aims at providing a more precise and differentiated pre-assessment approach. The suitability of potential sites is evaluated by means of a **multi-criteria decision making (MCDM)** method, including techno-economic, socio-political, and environmental criteria.

Solar energy falling on the earth produces large-scale motion of the atmosphere, on which is superimposed, local variations caused by several factors. Winds are caused by rotation of the earth and heating of the atmosphere by the sun. Due to the heating of the air at the equatorial regions, the air becomes lighter and starts to rise, and at the poles the cold air starts sinking. The rising air at the equator moves northward and southward. Differential heating of sea causes more minor changes in the flow of air. The nature of the terrain, ranging from mountains and valleys to more local obstacles such as buildings and trees, also has an important effect on the wind [2].

The power in the wind is proportional to the cube of the wind speed or velocity. It is therefore essential to have detailed knowledge of the wind and its characteristics, if the performance of wind turbines is to be estimated accurately. Various parameters need to be known of the wind energy are mean wind speed, directional data and velocity variations periodically daily/yearly/monthly and height of the anemometer. These parameters are used to assess the performance and economics of the wind plant.

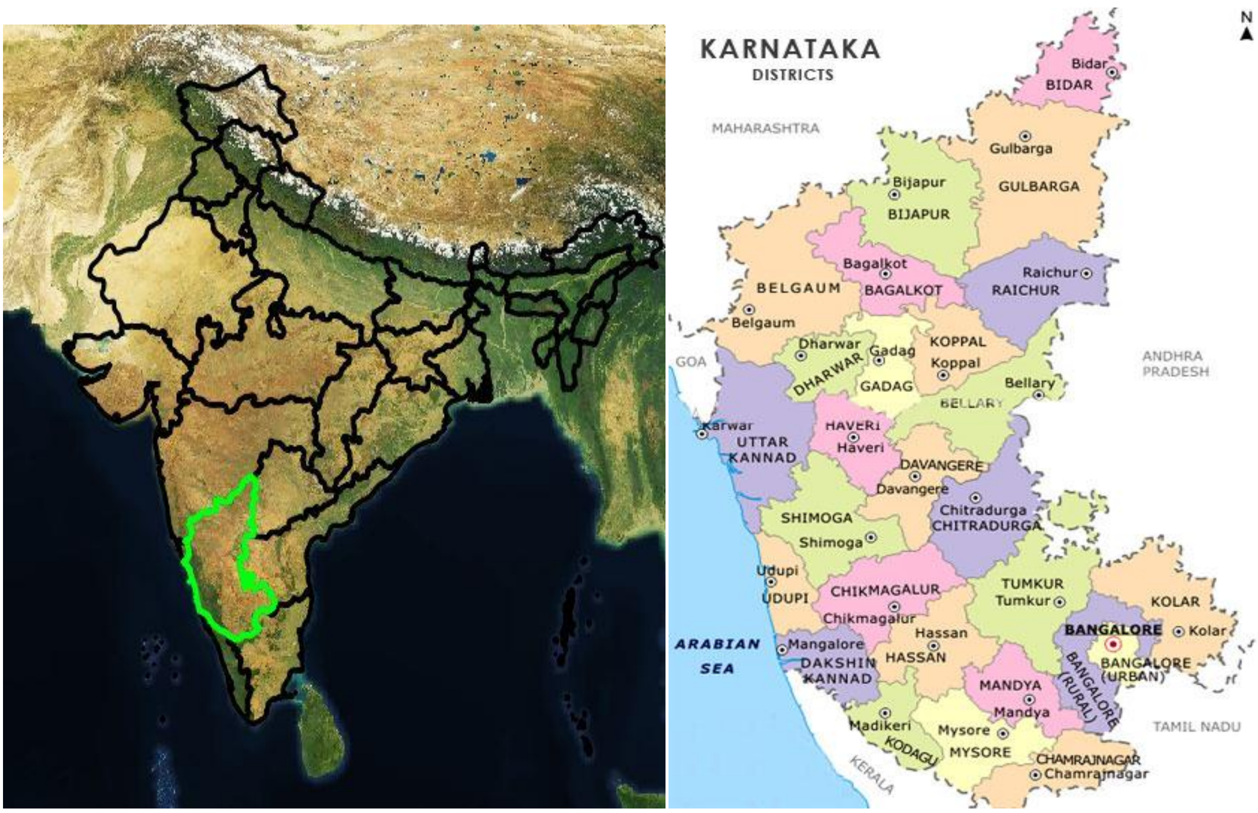
Harnessing of wind energy could playa significant role in the energy mix of a region. Windmills have been used for centuries to grind grain and pump water in rural areas. Wind energy is renewable and environmentally benign. It has the advantage of being harnessed locally for applications in rural and remote areas. Wind driven electric generators could be utilized as an independent power source, and for purposes of augmenting the electricity supply from grids. In densely populated taluks, decentralized production of electricity would help local industries, especially seasonal agro-processing industries, etc.

The extent to which wind can be exploited as a source of energy depends on the probability density of occurrence different speeds. To optimize the design of a wind energy device, data on speed range over which the device must operate to maximize energy extractions are required, which requires the knowledge of frequency distribution of the wind speed. Data on mean monthly and annual wind speeds for a long time (30 - 50 years) are available at meteorological observatories and the data on frequency distribution is available from various locations. Various parameters need to be known of the wind energy are mean wind speed, directional data and velocity variations periodically - daily / yearly / monthly and height of the anemometer. These parameters are used to assess the performance and economics of the wind plant.

2. Study Area

Karnataka (Karnāṭaka) is a state in the south western region of India. It was formed on 1 November 1956, with the passage of the States Reorganisation Act. Originally known as the State of Mysore, it was renamed Karnataka in 1973. The state corresponds to the Carnatic region. The capital and largest city is Bangalore (Bengaluru).

Karnataka is bordered by the Arabian Sea to the west, Goa to the northwest, Maharashtra to the north, Telangana to the northeast, Andhra Pradesh to the east, Tamil Nadu to the southeast, and Kerala to the south. The state covers an area of 191,976 square kilometres (74,122 sq mi), or 5.83 percent of the total geographical area of India. It is the sixth largest Indian state by area. With 61,130,704 inhabitants at the 2011 census, Karnataka is the eighth largest state by population, comprising 30 districts. Kannada, one of the classical languages of India, is the most widely spoken and official language of the state alongside Konkani, Marathi, Tulu, Tamil, Telugu, Malayalam, Kodava and Beary. Karnataka also contains some of the only villages in India where Sanskrit is primarily spoken.



Software Used

- Arc Map 10.3
- Quantum GIS 3.4.4
- Google Earth
- Arcpy

Data Used

Open Street Maps:

- Road Data
- Place Data
- Waterways
- Railway
- Transmission Lines

3. Literature Review

Distance from road network

This is an important factor that should be taken into consideration while locating an area for wind farm; there are several restriction that are set by government based on the type of road. Factor which is responsible for this restriction is the tightness of soil near roads which sometimes saves the money while making a new wind farm. Only the major Roads and highway are taken into consideration and a buffer of 100m is created around them, this 100 m buffer is the restricted area where no new turbine can be build.

Distance from electricity grid

This is also one of the most important factors while locating a wind farm as whenever a power house is built it needs to be connected to any electricity grid and this connectivity is done with the help of transmission lines which can be very costly if the electric grid is far from wind farm. Transmission line with the capacity of 220kv,400kv,765kv is used in the study, a buffer of 100 m is created which indicated area not suitable for location of new wind turbine.

Slope of terrain

Steep slopes of a surface can reduce the accessibility of cranes and trucks and increase building costs moreover other climatic problem are also encountered when working with high altitude.

Distance from places of interest

A wind turbine cannot be placed at some specific areas such as inside a city,village or a hamlet due to various issue caused either by local people or someone else moreover a turbine is always located away from public places , Monuments , etc.

The exclusion procedure is implemented in ArcGIS. The BUFFER tool is used to establish a buffer zone around a given type of area, where a ‘no building zone’ is required according to German legislation. Then all feature datasets are converted into a raster dataset with a cell size of 10 m. In a next step, based on Boolean logic, the IS NULL and CON tools are used to assign a true or false value to the criteria. All restricted areas are denoted as false and, therefore, get a value score of 0. The last step of this stage is to ‘multiply’ all restrictions to make sure that an area which is excluded in one criterion will also be excluded in the entire analysis. Since the MULTIPLY tool in ArcGIS only multiplies two rasters and the function is equivalent to finding the local minimum, the CELL STATISTICS tool is used. Finally, the exclusion area map will illustrate the maximum land technically available for the development of wind energy.

AHP criteria and rated area

In the next step of the analysis, key criteria for finding optimal wind farm sites are defined. The criteria used to determine the suitability of areas are listed in Table 6. These criteria are briefly described in the following. Subsequently, value scores are assigned to each criterion in order to allow for a spatial rating of potential locations.5 As mentioned before, the rating scheme of the criteria was developed with a specific focus on social acceptance-related issues. Finally, after the assignment of the criteria’s value scores, those are multiplied by the relative importance calculated using the AHP approach.

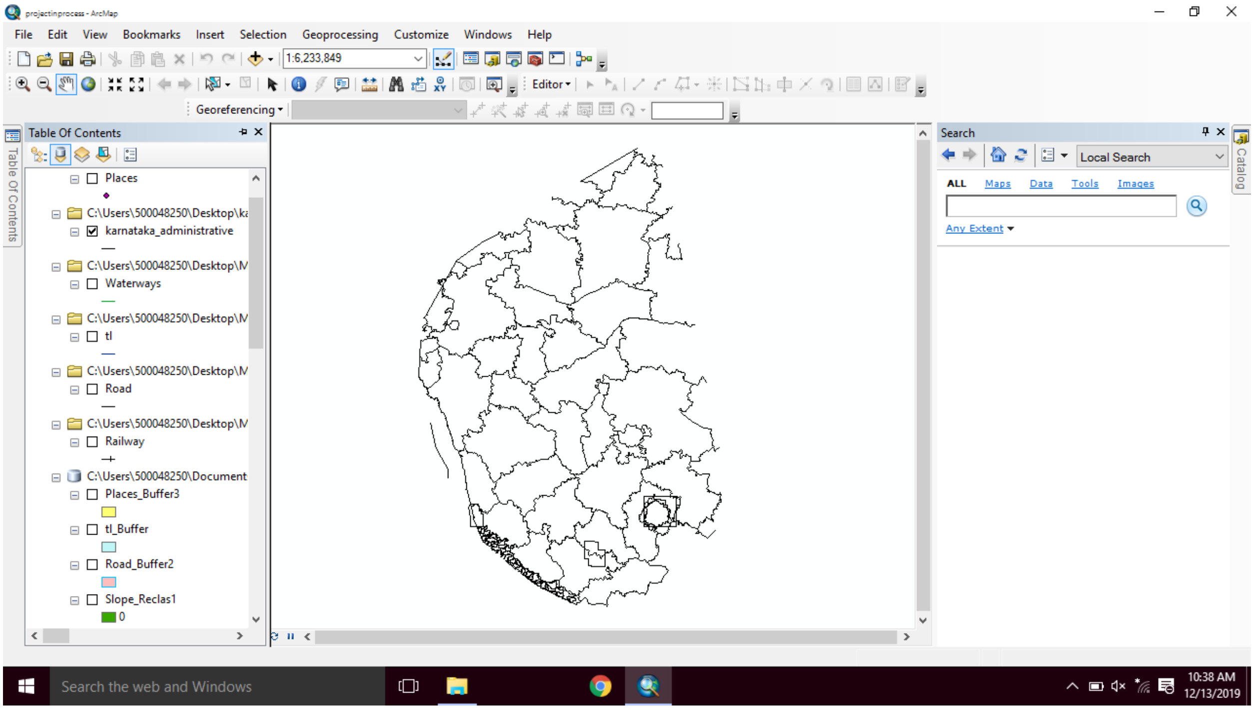
Regarding the implementation in ArcGIS, the first step is to calculate the distance ranges of distance-dependent criteria. For this purpose, the EUCLIDEAN DISTANCE tool is used. Then, the RECLASSIFY tool is employed to assign the value score to the criteria. In order to produce the suitability scores, we applied the RASTER CALCULATOR, which enables the construction and execution of a single map algebra expression in Python syntax. By doing so, we created the weighted overlay function in order to combine the assigned value scores for each criterion with their relative importance.6 Accordingly, the rated area map will display the distribution of value scores across the study area, considering each criterion’s individual weight.

Multi-Criteria Decision Making

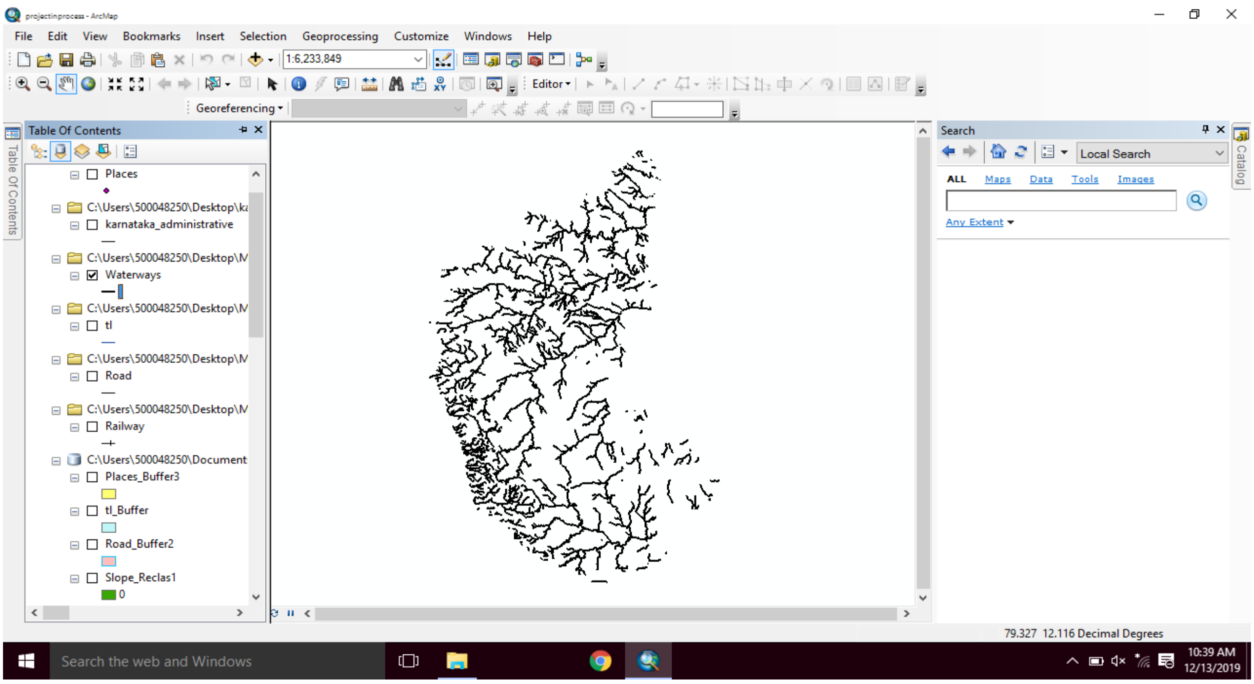
Finding suitable sites for wind farms is a complex decision-making problem, involving several, sometimes conflicting, criteria and multiple objectives. MCDM methods provide a logical framework to investigate, analyze, and solve such problems. MCDM methods are usually categorized in multi-object decision making (MODM) and multi-attribute decision making (MADM).

In general, the AHP approach is a systematic procedure of evaluating the relative importance of a set of criteria and sub-criteria in order to achieve a certain goal. In this context, the subjective importance of the criteria and sub-criteria is quantified and aggregated in order to reach a decision. AHP is based on four axioms; the reciprocal axiom, the homogeneity axiom, the synthesis axiom, and the expectation axiom.

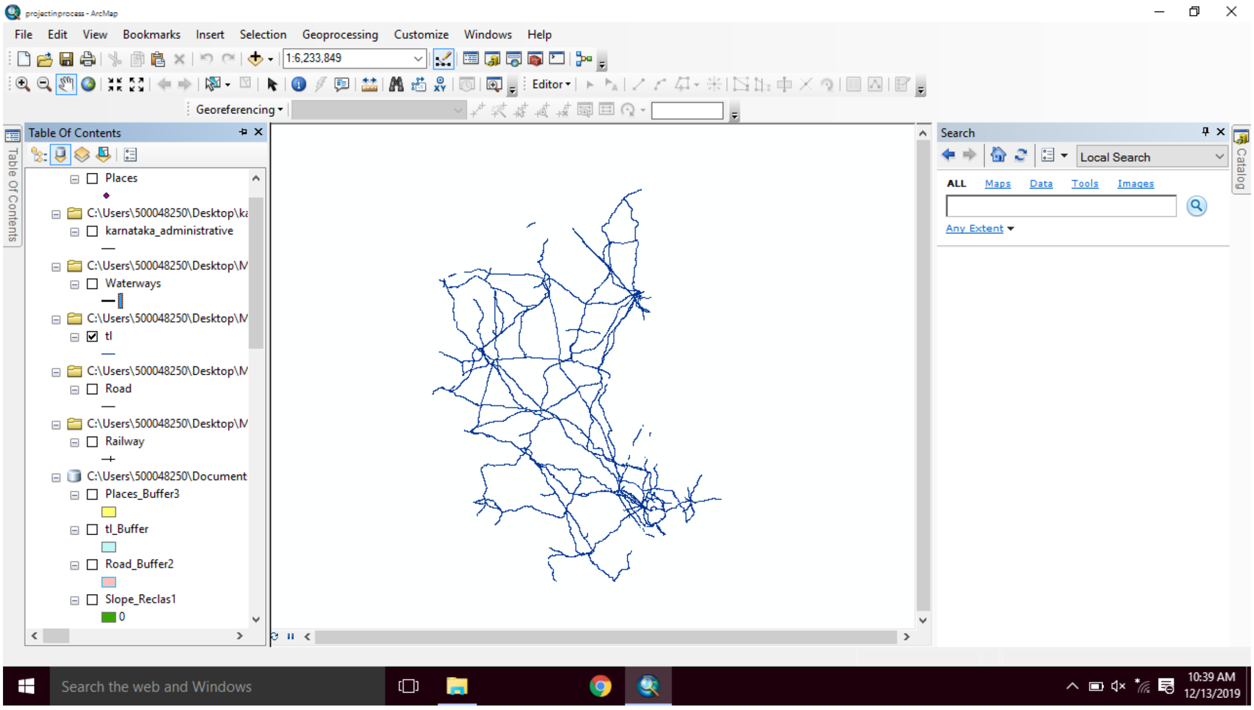
4. Methodology

1. 

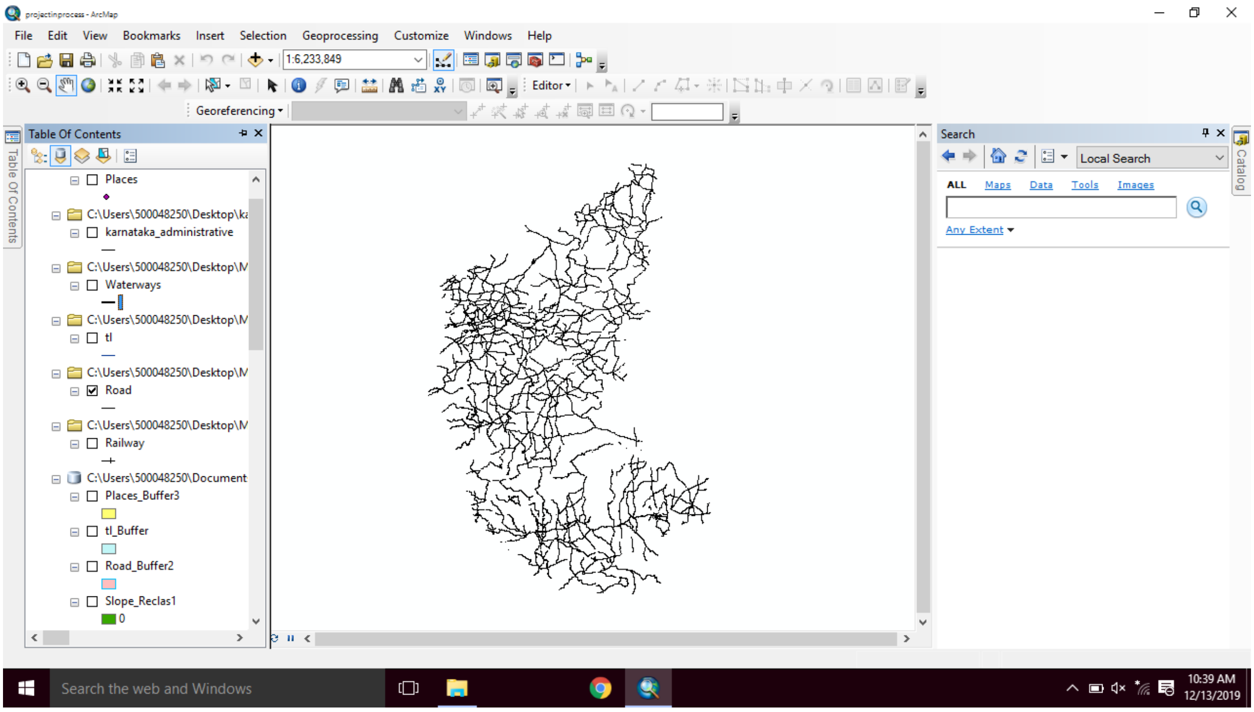
Karnataka Administrative area

2. 

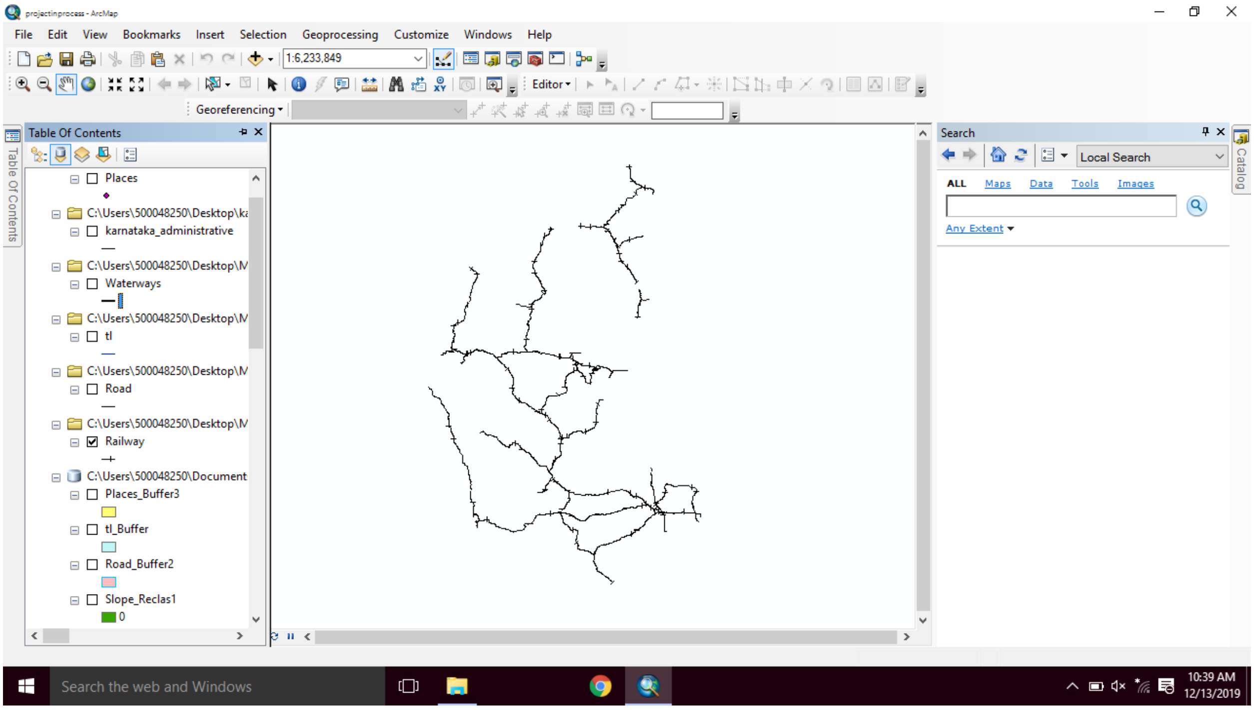
Waterways

3. 

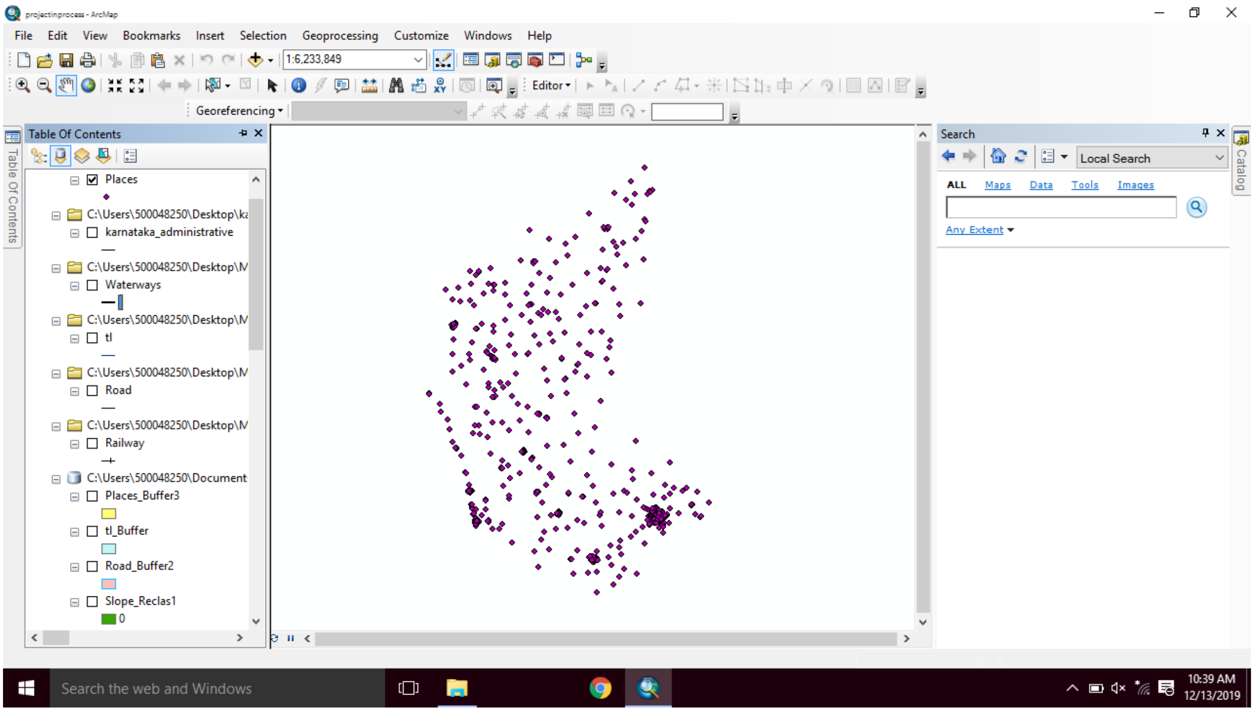
Transmission lines

4. 

Roadways

5. 

Railways

6. 

Places of interest

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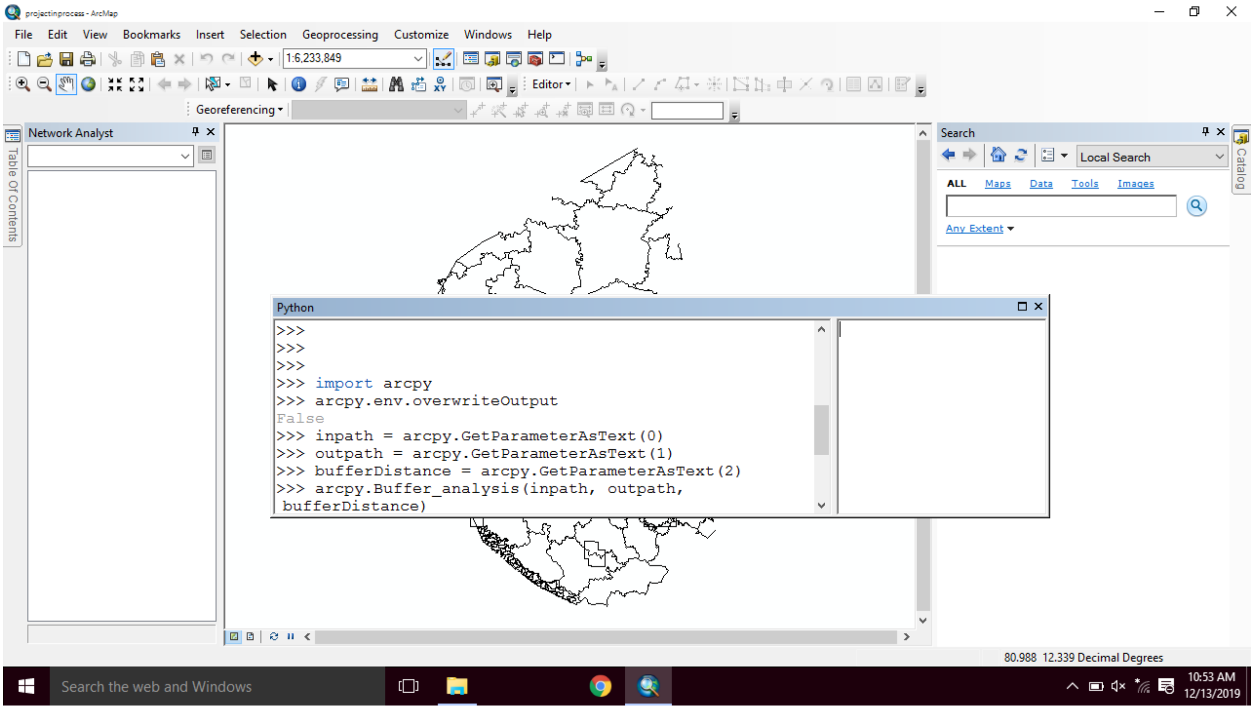
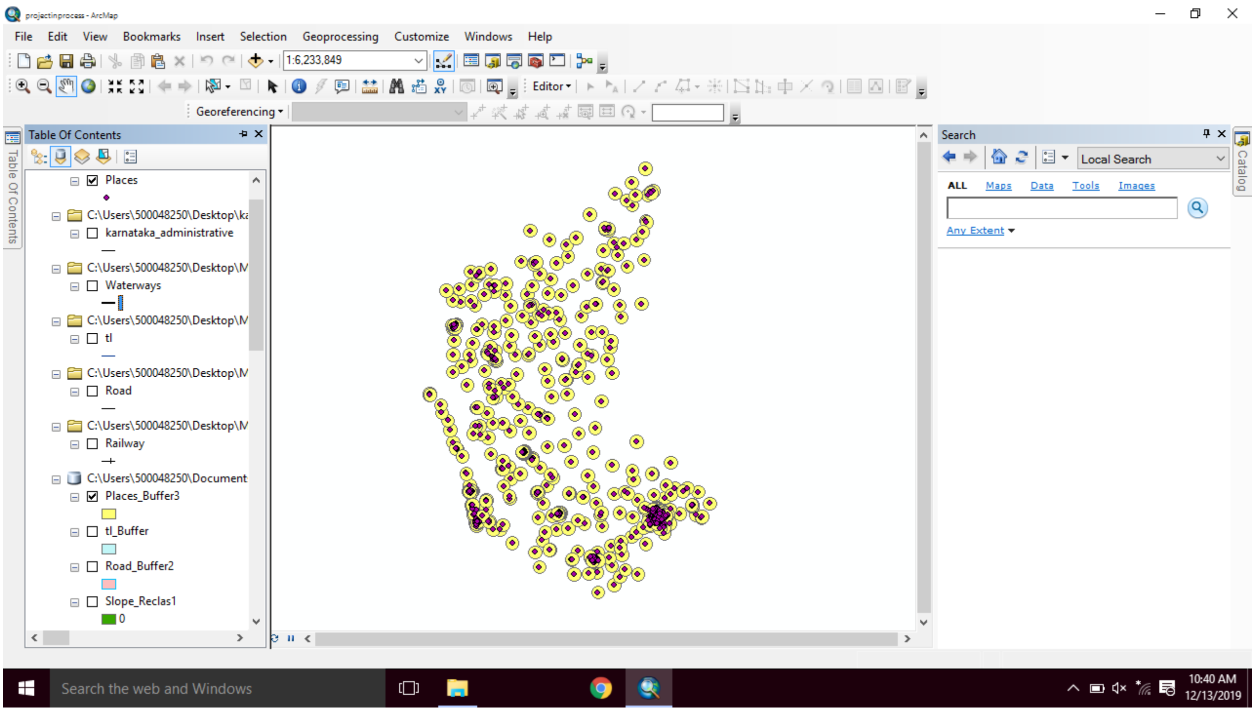
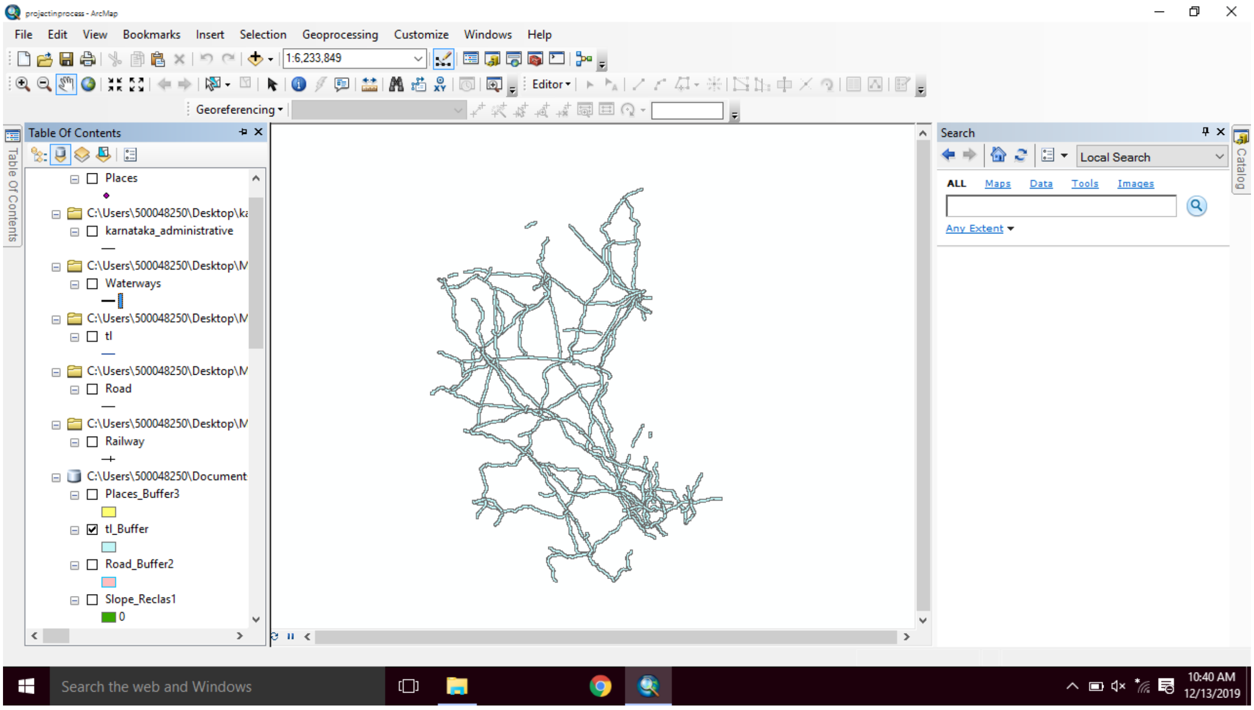


Python basic program for buffering

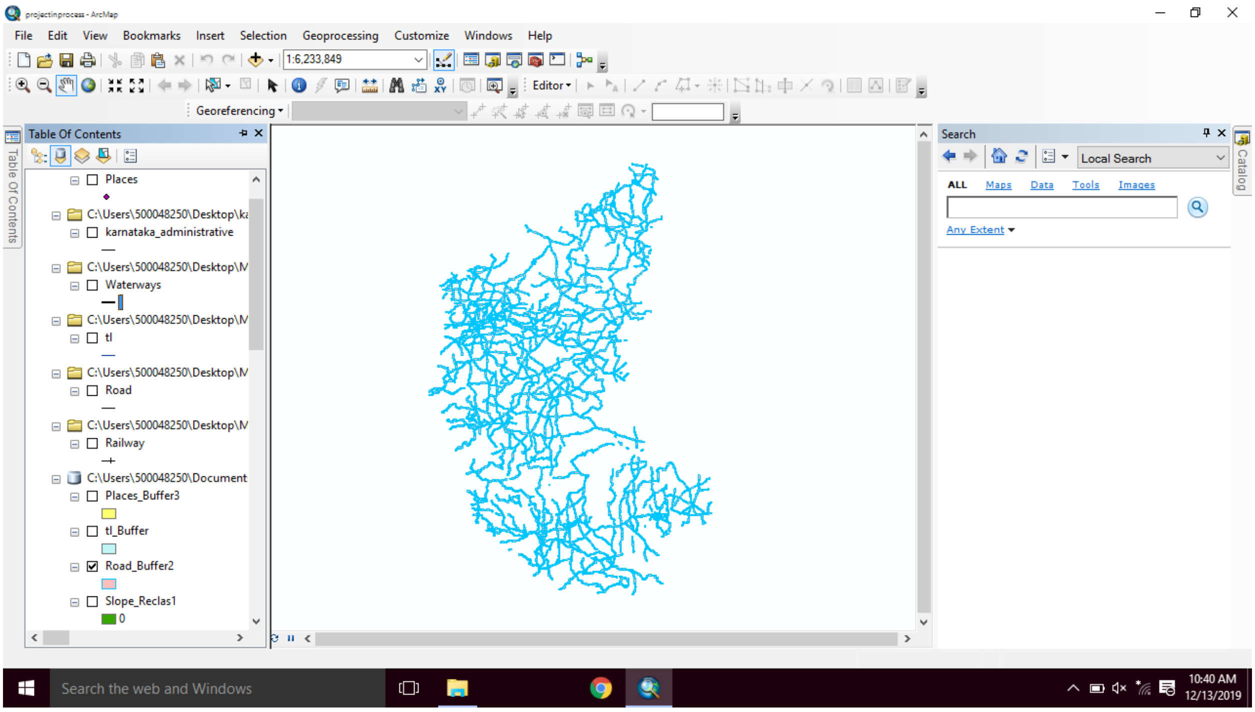
8


Buffer zones around the places of interest



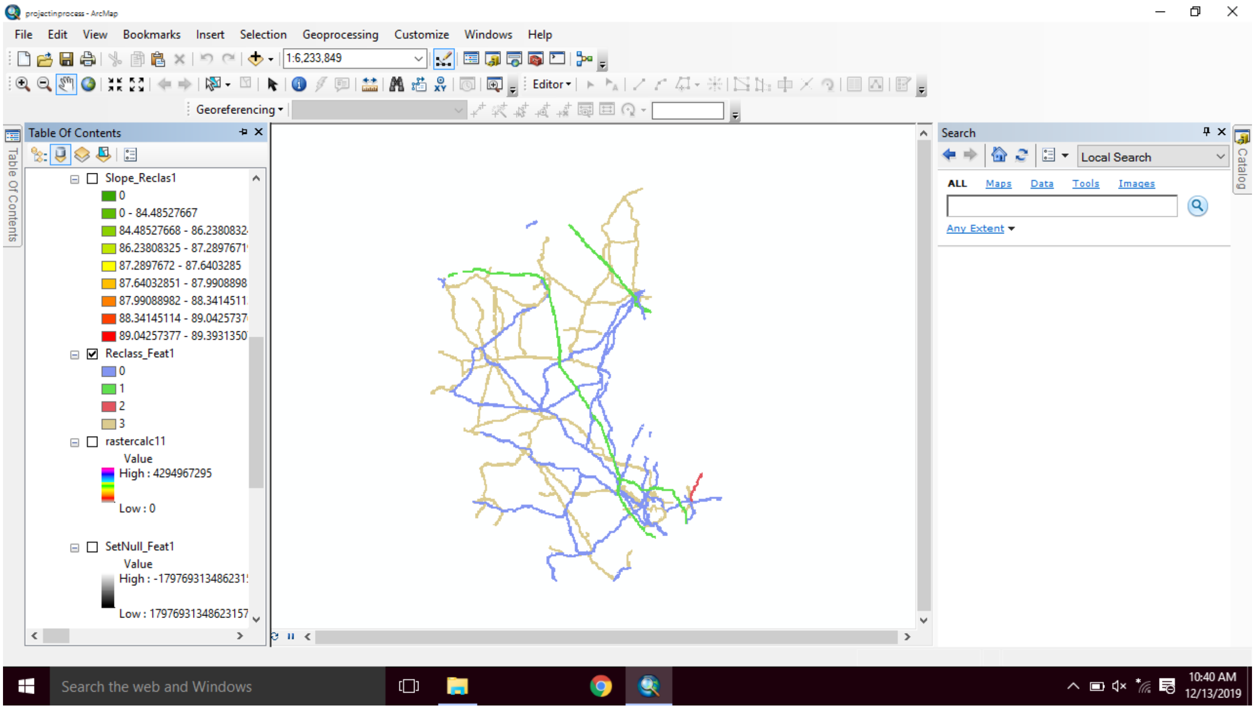
9.

Buffer zones around the transmission lines



10.

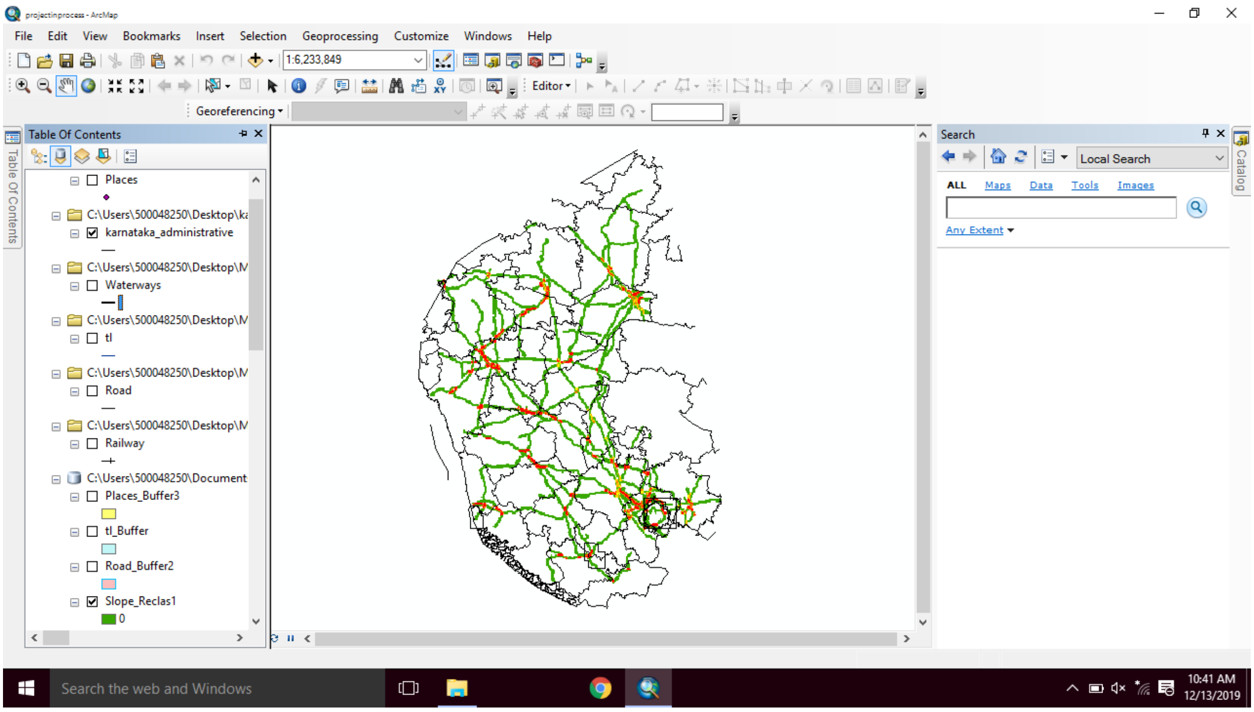
Buffer zones around roadways

11. 

Reclassifying of features

5. Results and Discussions

A final suitability map for whole Karnataka state was created with five different colors pink being most suitable blue being least suitable and black indicates area where there is no possibility of building of new wind farm.



Final Result from Raster calculation from the slope identification

6. Conclusion

After observing the result obtained by using various tools of GIS, It is observed that there are many areas which have high potential for new Wind farms so further investment can be done in these areas for construction of more and more turbine so that a long lasting source of energy can be created.