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Site Suitability Analysis of Solar Farm using AHP Technique

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Abstract — *This paper incorporates Geoinformatics techniques to determine site suitability analysis for establishment of solar farms based on photovoltaic (PV) solar cell technology in the district of Pune, state of Maharashtra, India. By analyzing the data on various factors affecting the PV solar farm site suitability, one can map these factors according to different weightage linked to each factor and using Analytical Hierarchy Process (AHP) techniques. Remote sensing (RS) based satellite data processing of LANDSAT 8 datasets were used to derive Land Use Land Cover (LULC) map. Later, along with Cartosat-1 Digital Elevation Model (CartoDEM) which is a National DEM developed by the Indian Space Research Organization (ISRO) was used to model the slope and aspect map for the study area. Also, Global Horizontal Irradiation (GHI) data from GLOBAL SOLAR ATLAS was utilized to derive solar irradiation map along with, boundaries and others vector datasets from NREL and DIVA-GIS.*
Paper aims to produce an site suitability map which indicates the highly suitable and productive area to establish a solar farm.
Result shows that Pune district can be considered as very good location to establish solar farm for photovoltaic based systems, the extremely suitable area to establish solar farm represent 27% (4217 km^2) and 44% (6815 km^2) is strongly suitable area from total area of 15,642 km².

Keywords- *PV; GIS; RS; AHP; MCDA; Site Suitability; Pune District.*

I. INTRODUCTION

In India more than 70% of its energy is produced by fossil fuels. Energy is not just linked to climate but also linked to our Gross Domestic Product (GDP). As a developing country a enormous supply of energy is required to continue a GDP growth. Even if nuclear energy is a cleaner energy source than fossil fuels, but it also has a negative impact. One of the safest and clean energy production method is solar energy. Because India is located in the equatorial region of earth, it has good solar energy potential. It can generate revenue form a barren land as well as installing solar panels on water bodies or water areas. As solar power is a fast developing industry in India because 10000.00 MW capacity was initially targeted solar power for financial year-2018-19 but the government of India is achieved 23858.13 MW as on 31.12.2018, which is 41.9% greater than target. For pune district existing scenario of solar power capacity is 55MW.

One of the main issues to make a solar farm is that it requires a high initial capital. So we want our solar farms to be as efficient as possible. The efficiency of solar farm is influenced by a number of factors, that factors includes solar radiation, land use land cover, slope, aspect, proximity to transmission line/grid, proximity to road, proximity to rail, proximity to water bodies/ water areas. This leads us to my study "Site suitability analysis of solar farm using Geoinformatics", Our main goal is to find most appropriate location for a solar farm in the district of Pune, that can be best location currently and for next 30 years. The most enchanting thing about this study is that, this is a scalable study which then can be used to find best location all over India. The Multi-Criteria Decision Making (MCDM) approach, high spatial resolution maps along with geographic information system (GIS) tools provide crucial framework for site selection of solar farm.

Table 1. Maharashtra state installed solar power capacity progress in MW (https://mnre.gov.in/physical-progress-achievements)

31st March 2015	*31st March 2016*	*31st March 2017*	*31st December 2017*	*31st December 2018*
360.75	385.76	452.37	763.08	1447.3

II. METHODOLOGY

2.1 Study Area

Pune is a district in the state of Maharashtra, India. Pune City Central is the District Headquarters. Temperatures are moderate and rainfall is unpredictable, in tune with the Indian monsoon. Summers, from early March to July, are dry and hot.

2.2 Remote Sensing or Geoinformatics

Technology & science consist with various elements like production, presentation, storage, acquisition, processing and dissemination of geoinformation. Geoinformation evaluated and analized with geocomputations and geovisualization. These geospital analysis and modeling is useful for development of various systems viz. geospital database, human-computer ineration and networking technologies .

2.3 Data Source

Data have collected from different sources like NREL, DIV-AGIS, ISRO, Global Solar Atlas and Earth Explorer USGS which is in the form of Line, Polygon and TIFF formats.

Table 2. Study Area Details

Sr. No.	***Geographical Variable***	***Instance***
1	Northwest Side	Thane district
2	West Side	Raigad district
3	South Side	Satara district
4	Southeast	Solapur district
5	North and Northeast	Ahmednagar district
6	Altitude	559 metres (1,863 feet)
7	North Latitude	17.5° and 19.2°
8	East Longitude	73.2° and 75.1°
9	Area	15,642 km².
10	Temperatures Range	20 to 38 °C (68 to 100 °F) and may reach 40 °C (104 °F)

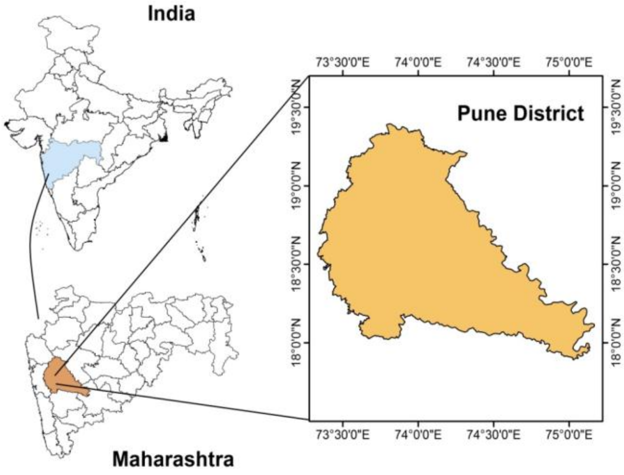


Figure 1 Study Area

Table 3. Existing scenario of solar power plants in pune district

Name of Solar plant	***Latitude***	***Longitude***	***Address***	***Cap. MW***	***Establis-hment Year***
Clover Solar Pvt. Ltd.	18.191051	74.220446	Supa, Tal. Baramati	**2**	2011
Tata Power Ltd	18.301934	73.311421	Mulshi.	**3**	2011
MAHA GENC O Ltd	18.18582	74.340264	Village Shirsuphal, Tal. Baramati	**36**	2014
MAHA GENC O Ltd	18.223499	74.280098	Village Shirsuphal, Tal. Baramati	**14**	2015

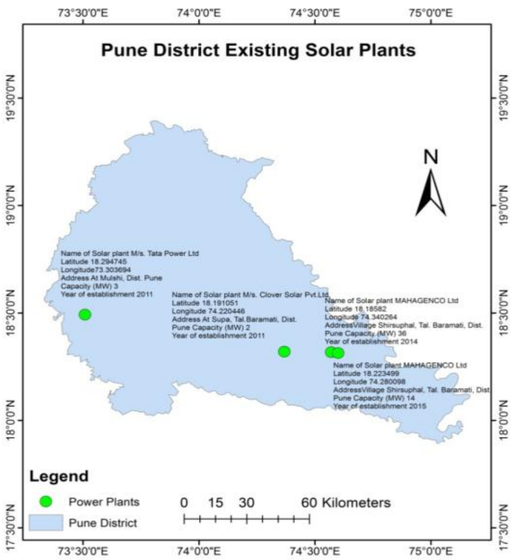


Figure 2 Existing scenario of solar power plants in pune district

III. ANALYTICAL HIERARCHY PROCESS (AHP) METHOD

The site suitability for solar power plant has verity of parameters and complex issues, a trade of must be made among available alternatives in order to optimize and find best suitable site.

Usually, to solve this type of problem, researchers and decision makers use the Multi-Criteria Decision Making (MCDM) methods. Analytical Hierarchy Process is a mathematical approach that is mostly recommended by Researchers to handle complex decisions for different criteria. It was developed by Satty in 1977. It decreases complex decisions to a series of pairwise comparison.

Moreover, it is a valuable method to check the consistency of the decision, thus reducing the bias in the decision-making progression [3]. At the beginning of each AHP process we defined a goal and selected the alternatives and criteria [3]. Afterwards, a pairwise comparison matrix (A) is generated [3].

Let us assume that n is the number of criteria, then the matrix (A) will be a matrix where each entry aij of the matrix describes the importance of the ith criterion to the jth criterion.

Table 4. Data Sources

Sr. No.	Data	Source	Original Data	Original Data Spatial Resolution	Time Period	Final Data	Final Data Spatial Resolutio
1	Country Boundary, State Boundary, District Boundary, Water Bodies	NERL (https://maps.nrel.gov) DIVA-GIS (http://www.diva-gis.org)	Polygon	--	NERL-2018 DIVA-GIS- NA	Raster	30 m
2	Road Network, Rails Network, Transmission Lines, Water lines,	NERL (https://maps.nrel.gov) DIVA-GIS (http://www.diva-gis.org)	Line	--	NERL-2018 DIVA-GIS- NA	Raster	30 m
3	Digital Elevation Model (DEM)	CartoDEM - ISRO (https://bhuvan.nrsc.gov.in/bhuvan_links.php)	TIFF	0.00027777778 m	2005-2014	Raster	30 m
4	Solar Radiation	Global Solar Atlas (https://globalsolaratlas.info/downloads/india)	TIFF	0.0083333333 m	2017	Raster	30 m
5	Landsat-8 Imaginary	Earth Explorer USGS (https://earthexplorer.usgs.gov)	TIFF	Bands 1, 2, 3, 4, 5, 6, 7 & 9 - 30 m, Band 8 - 15 m, Band 10 & 11 – 100m	2018	Raster	30 m

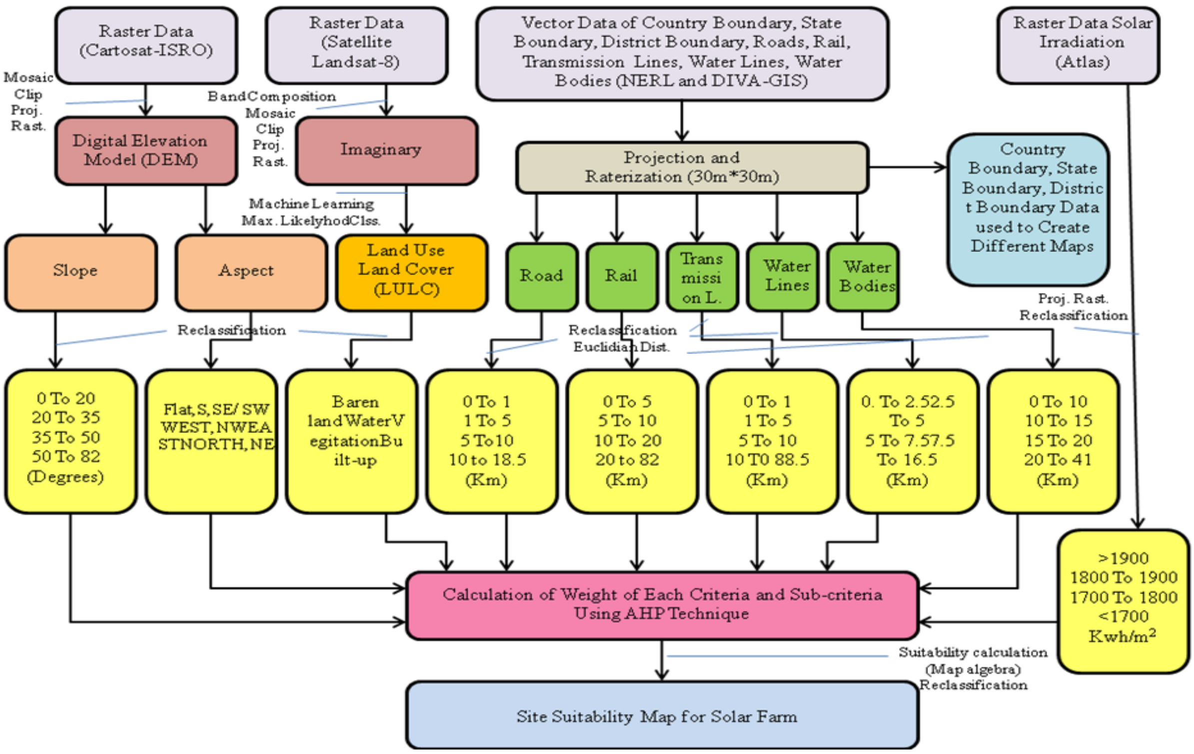


Figure 3 Conceptual Model

Figure 4 Saaty's 9-points rating scale [7]

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very	strongly	moderately	equally	moderately	strongly	very	extremely

less important ⟶ more important

The relative importance of the two criteria is measured according to a numerical scale from 1 to 9.

3.1 Pairwise Matrix

$$A = \begin{pmatrix} a_{11} & a_{12} & \dots & a_{1j} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2j} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & a_{ij} & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mj} & \dots & a_{mn} \end{pmatrix} \quad (1)$$

where *aij* is the element of matrix *A* in the *i*-th row and the *j*-th column.

a. Multiply the matrix *A*. Value of the matrix element A^2 is obtained by the formula

$$a_{ij}^{\ 2} = \sum_{k=1}^{n} a_{ik} . a_{kj} \quad (2)$$

where *aik*is the element of matrix *A* in the *i*-th row and the *k*-th column and *akj*is the element of matrix *A* in the *k*-th row and the *j*-th column.

b. Sum the elements of each row of the matrix A^2 in order to obtain a matrix *B* with the formula

$$b_i = \sum_{j=1}^{n} a_{ij} = a_{i1} + a_{i2} + \dots + a_{ij} + \dots + a_{nj} \quad (3)$$

with *bi* is the *i*-th elements of matrix *B*. Matrix B can be expressed as follows:

$$B = \begin{pmatrix} b_1 \\ b_2 \\ \dots \\ b_j \\ \dots \\ b_m \end{pmatrix} \quad (4)$$

Add up all elements of the matrix *B* using the formula

$$\sum_{i=1}^{n} b_i = b_1 + b_2 + \dots + b_n \quad (5)$$

c. Based on the above results, further normalization of the matrix *B* to obtain the eigenvector of the matrix *B*. Eigenvector matrix *B* is described in the form of a matrix *C* in below Equation 4. (The matrix A is normalised for calculation of relative criteria weights. It is achieved by equations shown below (eq no.6))

$$C = \begin{pmatrix} b_1 / \sum_{i=1}^{n} b_i \\ b_2 / \sum_{i=1}^{n} b_i \\ \dots \\ b_j / \sum_{i=1}^{n} b_i \\ \dots \\ b_m / \sum_{i=1}^{n} b_i \end{pmatrix} \quad (6)$$

where *ci* is the *i*-th element of matrix elements *C*.

3.2 Measurement of Consistency

Consistency is an important characteristic of AHP. Assessment criteria between elements with one another is not entirely consistent. AHP allows the assessment inconsistencies but should not exceed 10 %. This measurement is done by aggregating the entire eigenvector obtained from various levels of hierarchy, such that the obtained composite weighted vector which generates a sequence of decision making. Measurement consistency of a matrix based on an eigenvector maximum (λmax). The closer λmax obtained with *n*, the more consistent results.

a. Calculate λmax of each matrix of order n by summing the multiplication of the number of weights all criteria in each column of the matrix with the principal eigenvector of the matrix.

b. Calculating the value of the consistency index for each matrix of order *n* using the formula :

$$CI = (\lambda max - n) / (n - 1) \quad (7)$$

where *CI* = consistency index, *λmax*= largest eigenvector of a matrix of order *n*, *n* = order of the matrix.

c . Consistency ratio is calculated by the formula :

$$CR = CI / RI \qquad (8)$$

where CR = ratio of consistency (consistency ratio), RI = random index (random index) for a matrix of order n.

Maximum eigenvalue of a matrix will not be less than the value of n such that there can be no consistency index (CI) were negative. Comparison between CI and random index (RI) for a matrix is defined as the Consistency Ratio (CR) expressed in Equation 6. Where RI is the average index value generated randomly obtained through experiments using samples with large quantities. Random value index (RI) for the matrix of the order of 1 to 15 as shown in Table 2. Comparison matrix is acceptable if the value of the consistency ratio (CR) < 0.1. Limitation received whether consistency of a matrix is actually no standard . According to some experimentation and experience, the level of inconsistency is 10 % below the level of inconsistency that is still acceptable. More than that there should be a revision of the assessment because the level of inconsistency that is too large can lead to errors.

Table 5. Random Index

N	1,2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

Table 6. Calculated weights of criteria and sub-criteria using AHP Technique

Criteria	**Criteria Weight**	**Sub Criteria**	**Sub Criteria Weight**	**Criteria**	**Criteria Weight**	**Sub Criteria**	**Sub Criteria Weight**
Solar Radiation (Kwh/m^2)	0.3864	>1500	0.524	Distance from Rail (Km)	0.0412	0 To 5	0.7104
		1400-1500	0.2836			5 To 10	0.1329
		1300-1400	0.1511			10 To 20	0.094
		< 1300	0.0413			20 to 82	0.0628
LULC (Land Use Land Cover)	0.1217	Baren land	0.7328	Distance from Road (Km)	0.0354	0 To 1	0.7104
		Water	0.1193			1 To 5	0.1329
		Vegitation	0.0879			5 To10	0.094
		Built-up	0.0601			10 to 18.5	0.0628
Slope/Tilt (Degrees)	0.1698	0 To 20	0.6624	Distance from Water Lines (Km)	0.0279	0. To 2.5	0.7001
		20 To 35	0.213			2.5 To 5	0.1499
		35 To 50	0.0764			5 To 7.5	0.0878
		50 To 82	0.0482			7.5 To 16.5	0.0622
Aspect/Direction	0.073	Flat,S,SE or SW	0.7001	Distance from Water Bodies (Km)	0.023	0 To 10	0.7001
		WEST,NW	0.1499			10 To 15	0.1499
		EAST	0.0878			15 To 20	0.0878
		NORTH,NE	0.0622			20 To 41	0.0622
Distance from Transmission Line (Km)	0.1216	0 To 1	0.7001				
		1 To 5	0.1499				
		5 To 10	0.0878				
		10 T0 88.5	0.0622				

IV. CRITERIAS

4.1 Solar Radiation/Solar irradiance

Earth receives energy radiations in the form of sun light. The factor called solar irradiance measures output of solar energy at earth surface. The quantum of solar radiance varies based on seasonal variations, elevation, altitude and geographical location. For implementation of PV systems, optimal availability of solar irradiance need to be ensured. To have economical viability 1300 KWh / m^2 solar radiation is required for most part of day. For optimal efficiency of PV systems the ambient temperature must be at a lower value and there is a decrease in efficiency when solar radiation exceeds 2000KWh/ m^2.

4.2 Land Use Land Cover

One concern regarding establishment of solar farms is land use as an important environmental factor for site selection. Land use was evaluated for four level as barren, water, vegetation and built-up areas. Barren areas were considered as the best areas and built-up areas have the lowest priority for exploitation solar farms.

4.3 Slope (Tilt)

Slope is one of the highly important factors in site selection of PV farms, Slope refers to the measures of the rate of change of elevation of surface while a value of 90 degrees indicates a surface that is completely vertical. Here a slope map was created through the interpretation of DEM that covers the study area. In this study the lower degree of slope is highly suitable than the higher degree of slope.

4.4 Aspect (Azimuth)

Aspect refers to the direction in which the slope faces. It is measured in degrees, moving clockwise from 0 degree to 360 degree. It begins with 0 degree at the north, and then in a clockwise direction ends at 360 degree again at the north. Aspect is often classified into four major directions namely; north, east, south, and west. A value of 0 degree is north, 90 degree is east, 180 degree is south and 270 degree is west. Aspect map produced from DEM. The prepared aspect map describes the direction in azimuth for land slope angles for the study area.

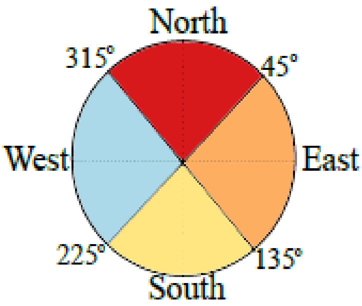


Figure 5 Aspect values: 1(Flat): 0 degrees, 2(North): 315-45 degrees, 3(East): 45-135 degrees, 4(South):135-225 degrees, 5(West): 225-315 degrees.

4.5 Distance from Power Transmission Lines

Considering the high costs associated with construction of power transmission lines, one of the important criteria in listing of solar farms is distance from transmission lines. Overall, electric power transmission lines influence the positioning of solar farms in terms of safety, network security, and quick accessibility for installing equipment and potential repairs. Studies have demonstrated that the best distance from power networks for the safety of solar farms and the network. In other words, the proximity of the location of solar farm construction to electric energy transmission lines is an important economical advantage.

4.6 Distance from Major Roads/Proximity to Roads

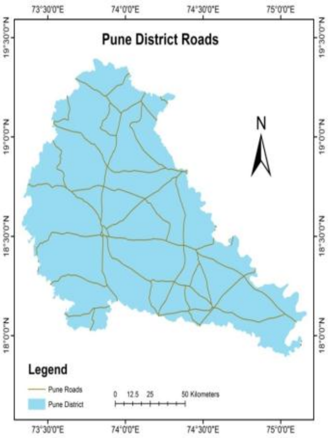
Road connectivity is important factor for overall solar farm Capital investment requirements. When the site is detached from road connectivity, very high expenditure need to be incurred for transportation of man and machineries. There by increasing overall investments in terms of time and money.

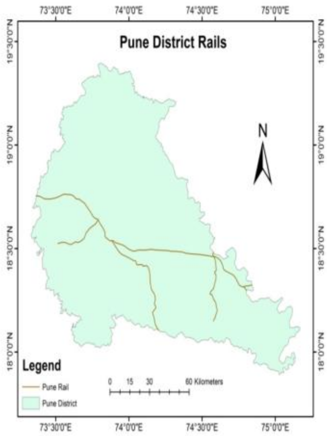
4.7 Water Resources

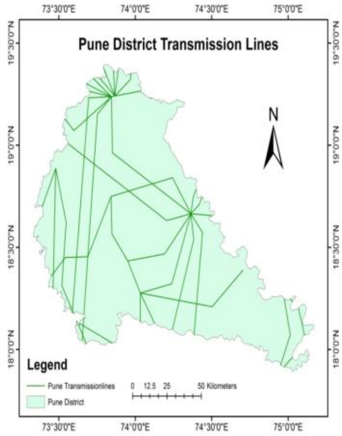
Even if the water availability is crucial for solar power plants, especially in arid regions, very few studies on the literature deal with this factor.

V. RESULT AND DISCUSSION

Figure 6 Roads Map *Figure 7 Rails Map* *Figure 8 Transmission Lines Map* *Figure 9 Water Map Bodies*







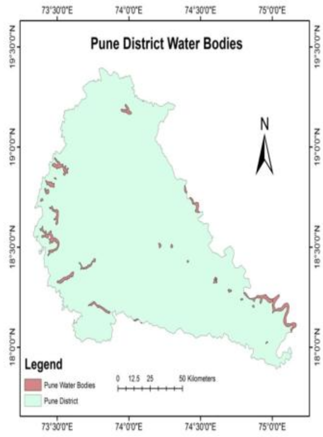
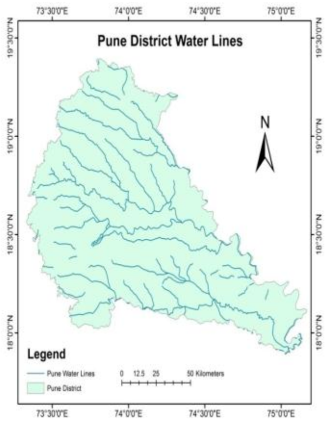
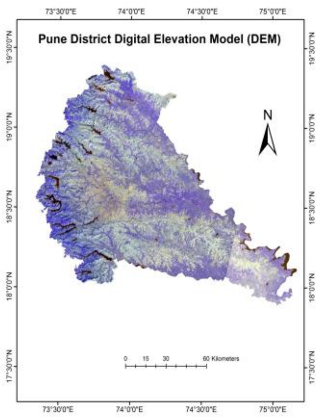
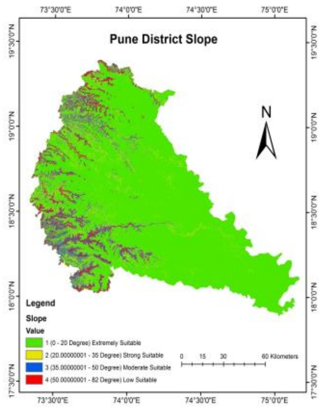


Figure 10 Water Lines Map *Figure 11 Digital Elevation Map Model (DEM) Map* *Figure 12 Slope Map* *Figure 13 Aspect Map*







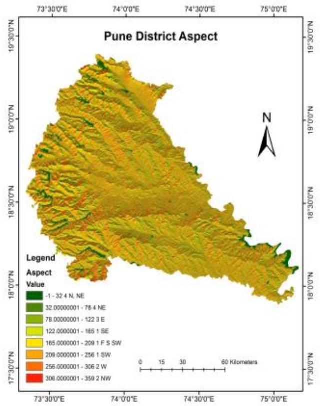
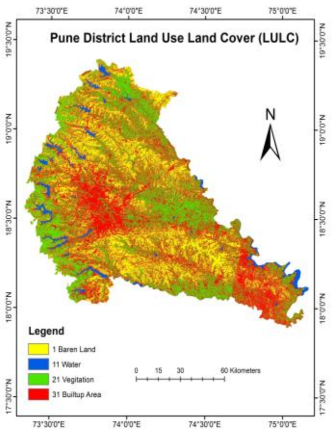


Table 6 Result of land Use Land Cover Map



Particulars	*PixelCount*	*Percentage (%)*	*Area km^2*
Barenland	558759	27	502.88310
Water	2628764	3	2365.88760
Vegetation	5068079	30	4561.27110
Builtup	9070032	40	8163.02880
Total	**17325634**	**100**	**15593.07060**

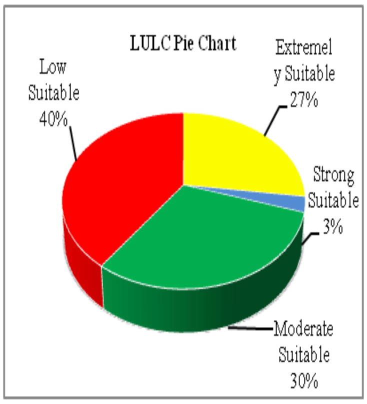


Figure 13 Land Use Map Land Cover (LULC)

Figure 14 LULC Pie Chart

Figure 15 Solar Radiation (GHI) Map

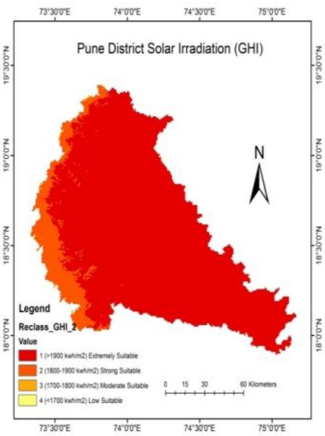


Figure 16 Roads Euclidian Distance Map

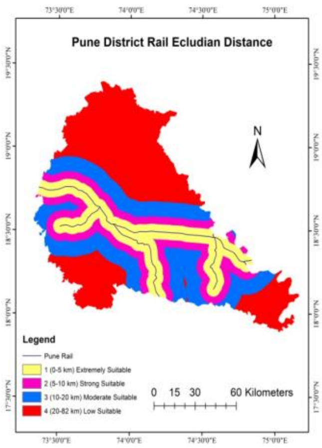


Figure 17 Rail Euclidian Distance Map

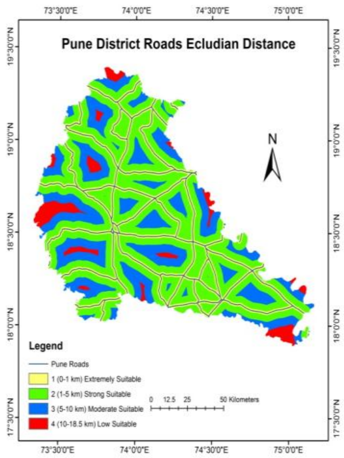


Figure18 Transmission Line Euclidian Distance Map

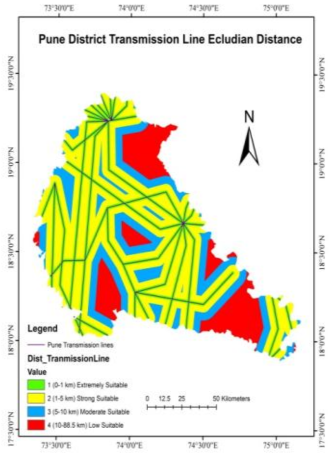


Figure 19 Water Lines Map Euclidian Distance Map

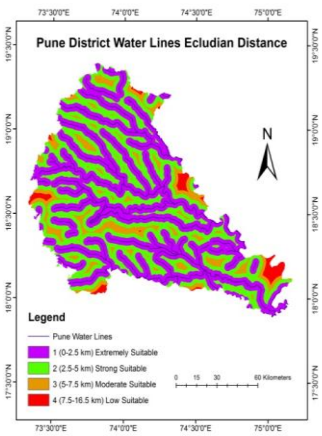


Figure 20 Water Bodies Euclidian Distance Map

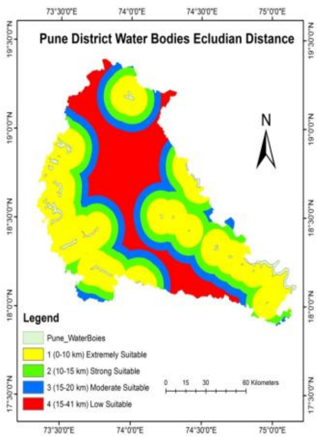


Figure 21 Pune District Solar Farm Suitability

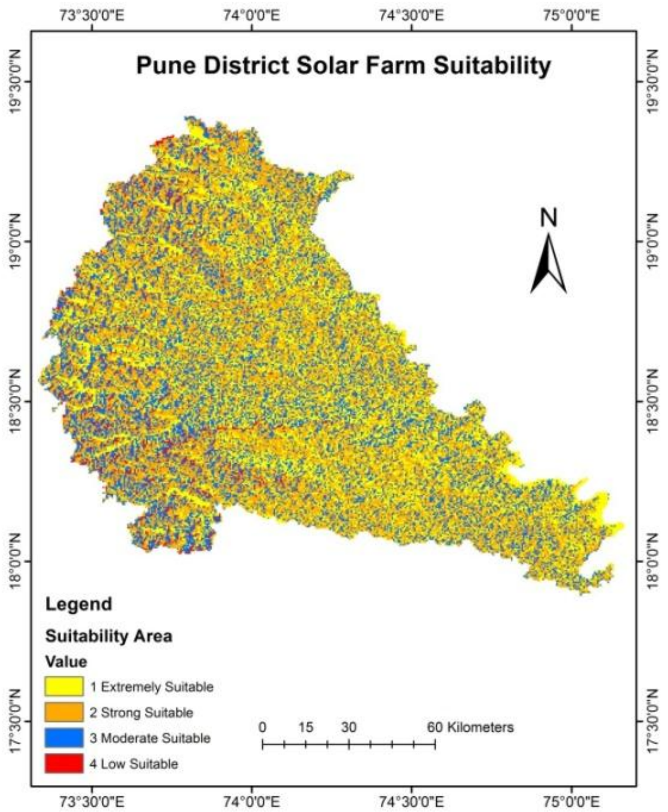


Figure 22 Solar Farm Suitability Pie Chart

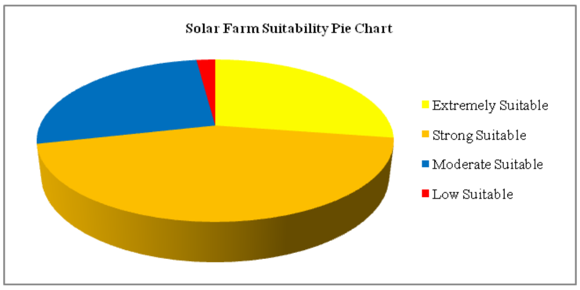


Table 7 Result of Suitability Map

Sr. No.	***Particulars***	***Pixel Count***	***Percentage (%)***	***Area km²***
1	Extremely Suitable	16988	27	4247.00000
2	Strong Suitable	27263	44	6815.75000
3	Moderate Suitable	16461	27	4115.25000
4	Low Suitable	1261	2	315.25000
	Total Count	61973	100	**15493.25000**

LULC map classification has shown that 27% area is barren land, 3% area is water, 30% area is vegetation and 40% area is built-up

It has been found that total of 4247Km^2 extremely suitable area, 6815.75 Km^{2}strong suitable area, 4115.25Km2moderate suitable area, 315.25Km^2 low suitable area on the basis of suitability map.

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