International Journal of Advance and Applied Research
www.ijaar.co.in
ISSN – 2347-7075 Impact Factor – 7.328
Peer Reviewed Bi-Monthly
Vol.2 No.22 July – Aug 2022

GIS-BASED SUITABILITY ANALYSIS FOR SITING SOLAR POWER PLANTS IN SALEM DISTRICT, TAMIL NADU, INDIA

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Abstract

Solar energy is one of the sustainable and cleanest ways to produce power, and humans can harness it to generate power for day-to-day activities without producing harmful pollutants. Green electricity can become the cheapest form of energy by 2050, and in the long-term supply up to three-quarters of all demand. The installation of a solar power plant will help to satisfy the power demands of the consumers at a cheaper cost. Hence, this study will evidently show the precise location to gather the utmost solar radiation in Salem district, Tamil Nadu. The methodology involves the usage of OSM (Open Series Map) SOI (Survey of India) toposheets to create buffer analysis from roads and streams; Landsat 8 satellite data was used to create a land use/land cover map of the study area. Solar radiation and NDVI maps were created using MODIS data and the Global horizontal irradiance data were obtained from Global Solar Atlas. The final Site Suitability map was made by organizing all the criteria based on the AHP (Analytic Hierarchy Process) of the MCDM (Multi-Criteria Decision-Making) method. The GIS and statistical techniques aid in finding the ideal suitable site for installing a solar power plant in the study area.

Keyword:- *Solar Radiation, Sustainable, Site Suitability, Solar Power Plants, GIS.*

Introduction

Renewable energy sources represent a viable alternative to meet the increasing demand for energy in the future (Colak, Ebru, Memisoglu, Tugba, Gercek, Yasin. 2020). Renewable energy accounted for 26.2% of global electricity generation in 2018, which is expected to grow to 45% by 2040, making renewable energy the fastest-growing source of electricity (Global Energy Institute 2021). When compared to other sources, solar energy is among the most inexpensive, reliable, and available energies (Ahmet Koc, Seda Turk, Gokhan Şahin, 2019). Green electricity can become the cheapest form of energy by 2050, and in the long-term supply up to three-quarters of all demand (Economic Times 2022).

The GIS has great potential in planning and implementing solar PV systems, due to its capabilities in terms of capturing, handling, modeling, analyzing, and visualizing spatial data (Resch., Bernd., Sagl., Günther., Törnros., Tobias., Bachmaier., Andreas., Eggers., JanBleicke., Herkel., Sebastian., Narmsara., Sattaya., Gündra., Hartmut. 2014). Integration of GIS and MCDA is best suited for solving complex site selection problems and the combination of these two tools provides a more reliable decision for the most suitable site selection (Al Garni, H.Z., Awasthi, A. 2018). A study on Solar Energy Potential for Bumthang valley in central Bhutan has used geographic information systems (GIS) and Analytic Hierarchy Process

(AHP) (Tempa, U., Jai Govind Singh, Change, C., Thani,P. 2020). To manage multi-layered geographic data, regulate benchmark weight, and present the resulting product in an appropriate format, the combined use of GIS and MCDM techniques has provided significant benefits. (Marina. Giamalaki & Theocharis Tsoutsos 2019). Another study presents a GIS-based method for locating suitable sites for utility-scale wind and solar farms in Thailand's Songkhla Province (Shahid. Ali., Juntakean Taweekun., Kuaanan Techato., Waewsak, J., Gyawali, S. 2019). To determine the best suitable areas for solar power plants, AHP combined with a GIS tool is applied in the Ayranci region in Karaman, Turkey (Uyan, M. 2017).

The multi-criteria weight methodology has been used to rank land suitability evaluation for crop production in Morocco (Ennaji, W., Barakat, A., Baghdadi, M. 2018). A combination of GIS and the AHP has been used to identify the most suitable sites for PV system installations in southern England (Watson, Joss J.W., Hudson, Malcolm D., 2015), Tanzania (Aly, A., Jensen, S.S., Pedersen, A.B. 2017), Turkey (Tercan, E., Eymen, A., Urfalı, T., Saracoglu, B.O. 2021), West Africa (Yushchenko, A., de Bono, A., Chatenoux, B., Patel, M.K., Ray, N. 2018), and Morocco (Merrouni, A.A., Elalaoui, F.E., Mezrhab, A., Mezrhab, A., Ghennioui, A. 2018). A case study was performed for the Desert of Chihuahua, Mexico, a region with the potential to provide a significant portion of the country's energy demand, using the AHP method (Prieto-Amparán, J. A., Pinedo-Alvarez, A., Morales-Nieto, C. R., Valles-Aragón, M. C., Álvarez-Holguín, A., Villarreal-Guerrero, F. 2021). A study on the most suitable areas for solar-wind energy with case studies in four counties of Igdir: Tuzluca, Igdir Central, Karakoyunlu, and Aralik included the analysis of both qualitative and quantitative factors and the problems were solved by using a mapping technique and AHP method (Ahmet Koc, Seda Turk, Gokhan Şahin, 2019). Ruiz et al. (2020) applied reliable site-suitability assessment tools for solar power plants to account for protecting cultural, natural, and ecological conservation areas (Ruiz, H.S., Sunarso, A., Ibrahim-Bathis, K., Murti, S.A., Budiarto,I. 2020). Hence, in the present study, an attempt is made to analyze the suitable sites for the installation of solar power plants using GIS technologies, to acquire most of the solar energy to satisfy the electricity need to the maximum extent, in the Mayiladuthurai District.

Objectives

The aim of the study is to identify a suitable site for installing a solar power plant using GIS techniques in Salem, Tamil Nadu.

Study Area

Salem District is situated between 11 14' and 12 53' in North Latitude between 77 44' and 78 50' in East longitude and bounded on North by Dharmapuri District, South by Trichy and Namakkal District, East by Villupuram and Perambalur Districts and West by Erode District and Karnataka State. Salem district is divided into 4 Revenue Divisions (Attur, Mettur, Salem and Sankari) and 9 Taluks. The district comprises of one Municipal Corporation, 4 Municipalities, 33 Town Panchayats, and 30 Census towns. There are 585 Revenue Villages in the Salem district. The total area of Salem Districts is 5217.74 Sq.km. The estimated population of the study area was 34, 82 lakhs people as per the 2011 census. Salem district forms part of the upland plateau region of Tamil Nadu with many hill ranges, hillocks and undulating terrain with a gentle slope towards east. Salem district has an average elevation of 278 m (912 ft). The climate of the Salem District is generally warm. The hottest period of the year is generally from the months of March to May. The highest temperature goes up to 39.8 C in the month of May (Salem District profile, 2018). The climate becomes cool from December to February when it touches a minimum of 16.7 C in the month of December. On average, the District receives an annual rainfall of 979.9 mm. The district is a part of Cauvery and Ponnaiar river basins and Sarabanga, Tirumanimuttar, Vasista and Suveda are the important watersheds/sub basins.

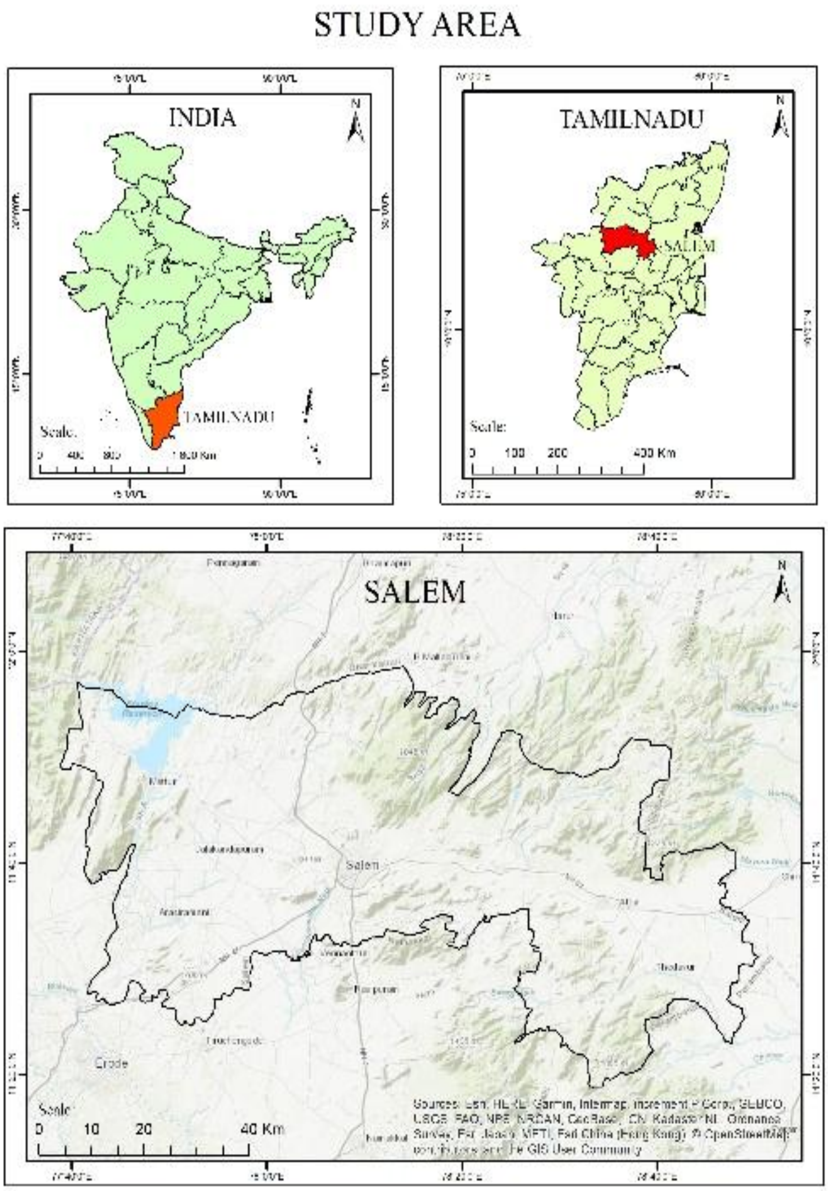

Fig. 1: Study Area

Data, Methodology, and Criteria

The secondary data sources used in this research work are- Landsat 8 satellite imagery, SRTM DEM data, WorldClim temperature data, MODIS data, Solargis GHI data, and GIS vector data in shape files, which include Proximity to roads, Proximity to settlements, Proximity to power transmission lines and Proximity to streams. The methodology is shown in Fig 2.

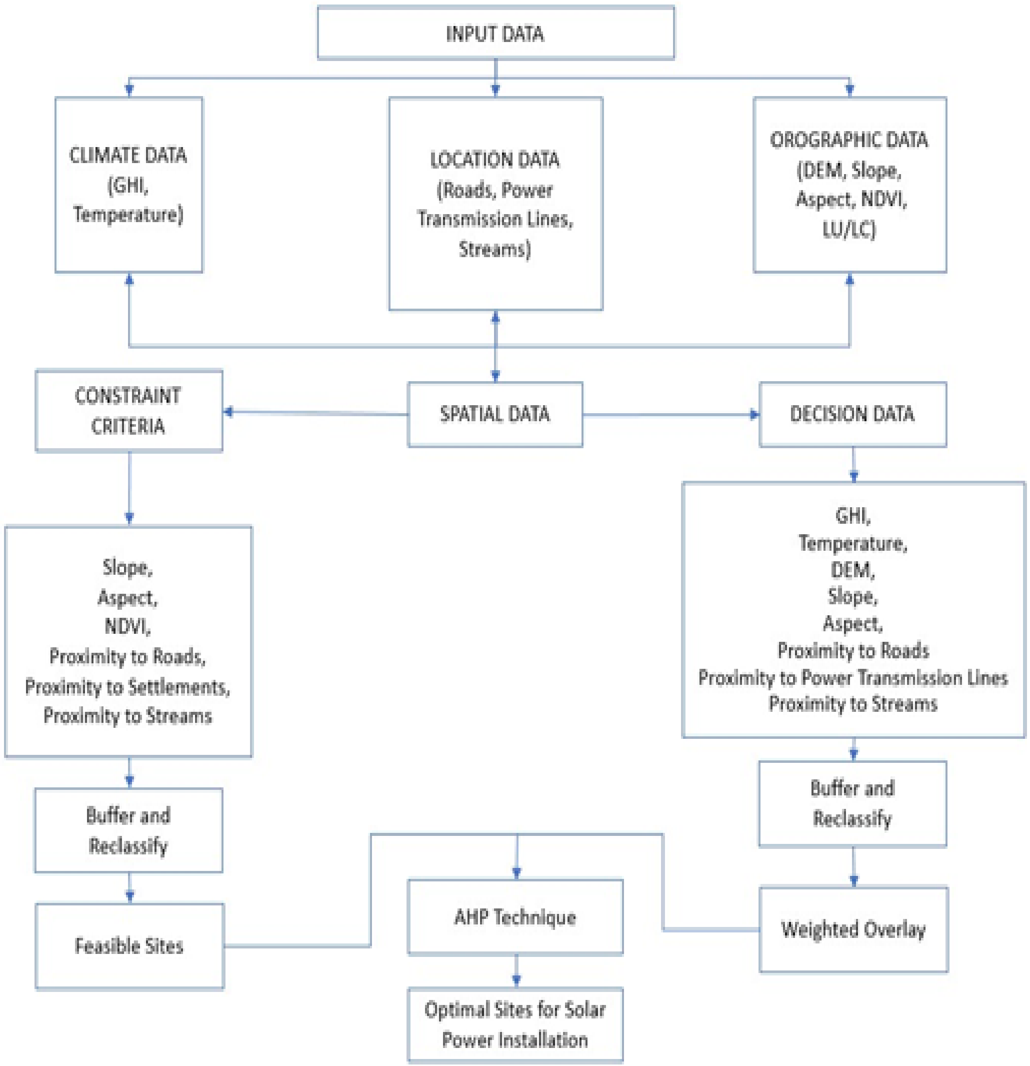

Fig. 2: Methodology

Parameters:

Digital Elevation Model (DEM)

Doljak and Stanojevic (Doljak, D., & Stanojevic, G. 2017) interpolated data about the annual average duration of sunshine, relative humidity, and air temperature data collected from 56 stations in Serbia for the period 1961-2010 by using Regression Kriging in SAGA GIS software with EU-DEM, geographic latitude, and longitude as predictors. For the present, SRTM DEM data was used to create the slope and aspect maps and is shown in Fig.3a. The average elevation of the study area is 278 m and the DEM classes (in m) identified are >1500, 1000 - 1500, 500 - 1000, 100 – 500 and <100.

Slope

The slope influences the solar radiation distribution on Earth's surface and determines the potential for electric energy production (Cioban, Alina, Criveanu, Horia, Matei, Florica, Pop, Ioana, Rotaru, Ancuta, 2013). The local shadowing effects of the terrain due to land slope play a crucial role in modifying the distribution of solar irradiation (Pietras-Szewczyk, Małgorzata, 2017). Slope was a highly important factor, as some rows of panels situated on higher slopes would block or shadow others at lower elevations, thereby affecting system efficiency (Sánchez-Lozano, J.M., Teruel-Solano, J., Soto-Elvira, P.L., García-Cascales, M.S. 2013; McKinney, M. 2014; Guo, M., Zang, H., Gao, S., Chen, T., Xiao, J., Cheng, L., Sun, G. 2017). Only slopes under 5% were considered inclusive, whereas some studies did not exclude areas of steep slopes, only categorizing them (Sheikh, N., & Kocaoglu, D. 2011; Carrion, J., Estrella, A., Dols, F., Toro, M., Rodrıguez, M., & Ridao, A. 2008). South-facing slopes are considered the best for siting solar panels, as sun rays are better captured at this orientation, with minimal shading or shadowing (Miller, A., & Lumby, B. 2012).

In the present study, the slope classes (in%) identified are <5, 5 - 10, 10 - 20, 20 - 30, and >30 and as shown in (Fig.3b). As the lower slope angle helps in maximum harvest of the solar power plant, the area that falls under the slope of less than 5%, is highly suitable for the installation of solar panels in the study area

Aspect:

Aspect made up an important criterion as it determines the amount of solar energy received by the solar panels (Hassaan, M. A., Hassan, A., Al-Dashti, H. 2020). The aspect orientations facing South, Southwest, and Southeast are considered best for solar panels to be situated anywhere in the northern hemisphere (Hassaan, M. A., Hassan, A., Al-Dashti, H. 2020). In the present study, the aspect data that is derived from the DEM data is shown in Fig.3c. From the map, it could be observed that a suitable aspect orientation, required to capture a higher amount of solar radiation, is noticed.

Temperature

The available site is assessed using a unique and cohesive approach, including temperature as a parameter, to select the most appropriate locations for solar farm development in the Valencian Community, a Spanish region in the east of Spain (Inmaculada Guaita-Pradas., Inmaculada Marques-Perez., Aurea Gallego., Baldomero Segura 2019). The average temperature of the study area ranges from 26˚C to 30˚C and the month with the most sunshine is May (Average sunshine: 11.5h). The month with the least sunshine is November (Average sunshine: 5.7h). Approximately 1469.58 hours of sunshine are recorded in the study area throughout the year, on an average of 122.46 hours per month (en.climate-data.org, 2020). The distribution of temperature in the study area is shown in Fig.3d.

Global Horizontal Irradiance (GHI)

Solar energy is usually expressed in Global Horizontal Irradiance (GHI) referring to the total amount of shortwave radiation received from above by a surface horizontal to the ground (Vaisala, 2020). GHI includes both Direct Normal Irradiance (DNI) and Diffuse Horizontal Irradiance (DHF) (Vaisala, 2020).

The study area has an average solar irradiance of 5.58 kWh/m^2 (Vaisala, 2020). The GHI map (Fig.3e) shows the areas receiving solar irradiance, under the classes- Very low, low, moderate, high, and very high, in the study area.

Normalized Difference Vegetation Index (NDVI): The site suitability analysis for the identification of potential sites for solar power plants is calculated using NDVI (Jesal Zala. 2021). The NDVI of the study area is derived with classes- Very high, high, moderate, low and very low- shown in the Fig.3f. NDVI will help delineate the regions with high vegetation as constraints to the situation of solar power plant in the study area.

Landuse: The site suitability analysis for identification of potential sites for solar power plants in Gujarat is calculated using landuse (Jesal Zala. 2021). The landuse map of the study area is used to demarcate the built-up area, that are used as a constraint criteria in locating the suitable sites for the installation of solar power plant. The landuse classes- Builtup, waterbodies, Fallow land and Vegetation are shown in Fig.3g.

Proximity to Roads:

The locational site of the solar plant should not be installed in the proximity of roads within <50 m (Al Garni, H.Z. & Awasthi, A. 2017; Uyan, M. 2013; Georgiou, A., & Skarlatos, D. 2016). But the sites had to be close enough to roads in order to adhere to economic realities involved in implementing large-scale projects (Tisza, K. 2014). Though roads are one of the standard restriction factors (Table1), accessibility of the sites is also equally important. The road map (Fig.3h) shows that the study area possess good road connectivity throughout the district.

Proximity to Settlements :

The locational site of the solar plant should not be installed in the proximity of settlements within <500 m (Al Garni, H.Z. & Awasthi, A. 2017; Uyan, M. 2013; Georgiou, A., & Skarlatos, D. 2016). But the sites had to be close enough to human settlements, in order to adhere to economic realities involved in implementing large-scale projects (Tisza, K. 2014). The distribution of settlements are extracted from the landuse map, of the study area.

Proximity to Power Transmission Lines

The power grids and power transmission lines play a major role in installing solar power plants. The solar power park has to be connected to a high voltage power grid (Gerbo, Abayneh., Suryabhagavan, Karuturi Venkata., Kumar Raghuvanshi, Tarun. 2020; Brewer, J., Ames, D. P., Solan, D., Lee, R., Carlisle, J. 2015; Yousefi, Hossein., Hafeznia, Hamed., Yousefi-Sahzabi, Amin. 2018). The proximity to power transmission lines are shown in fig.3i. From the figure, it could be observed that the study area has two major power transmission lines with <=150 kv, >200 and <= 400 kv, and >700 kv capacity.

Proximity to Streams:

The solar power plant locations were affected by streams and water bodies (Abraham Hizkiel Nebey., Biniyam Zemene Taye., Tewodros Gera Workineh. 2020). As per the standard restriction factors (Table1) water body is a parameter that has least mportance while choosing a site for solar power plant. But, considering the need of a cooling system, water bodies are necessary for proper functioning of a solar power plant. The study area is drained by streams of Cauvery, Ponnaiar, Sarabanga, Tirumanimuttar, Vasista and Suveda. The proximity to streams are analysed for the study area and the same is shown in Fig.3j.

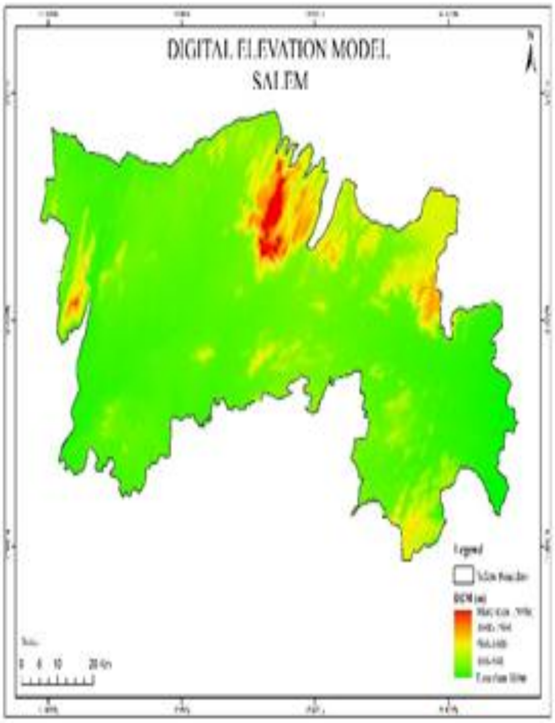

Fig. 3a: DEM

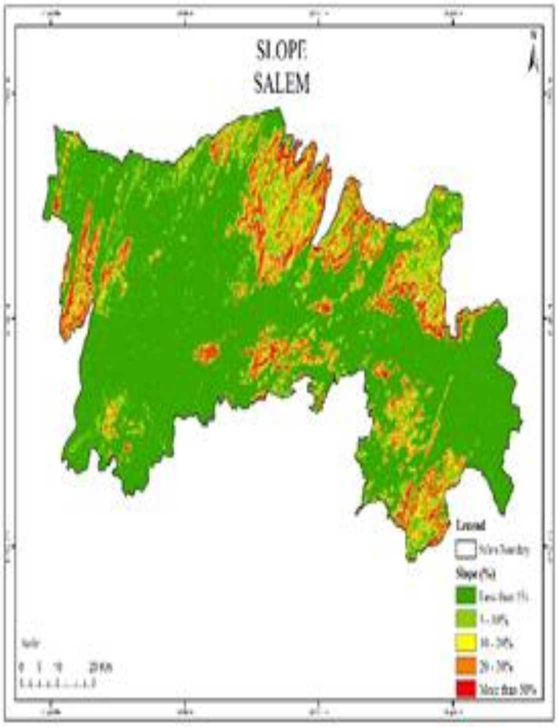

Fig. 3b: Slope

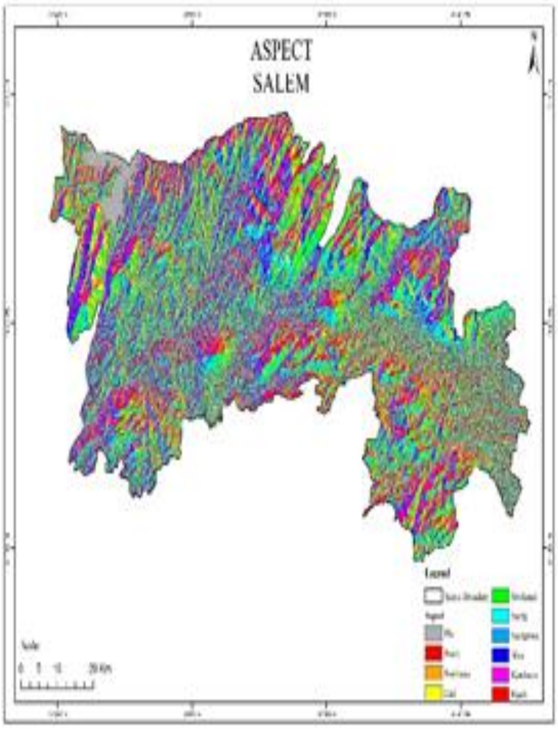

Fig. 3c: Aspect

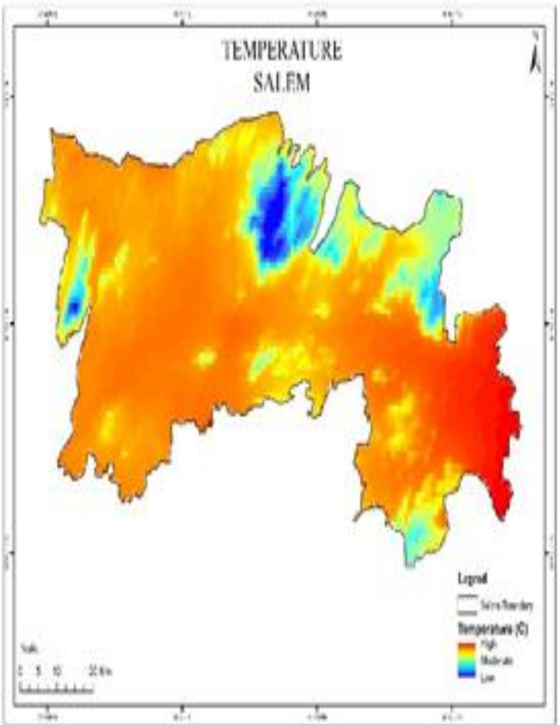

Fig. 3d: Temperature

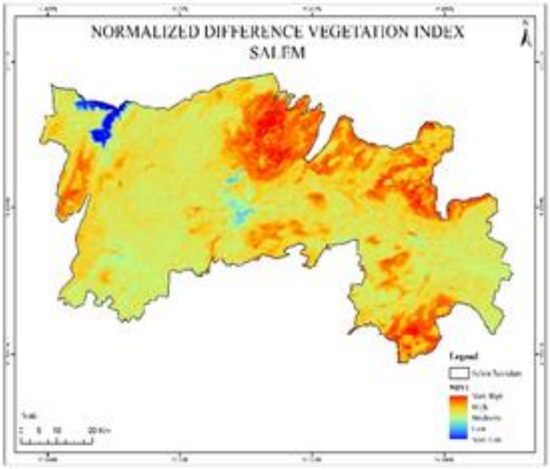

Fig. 3f: NDVI

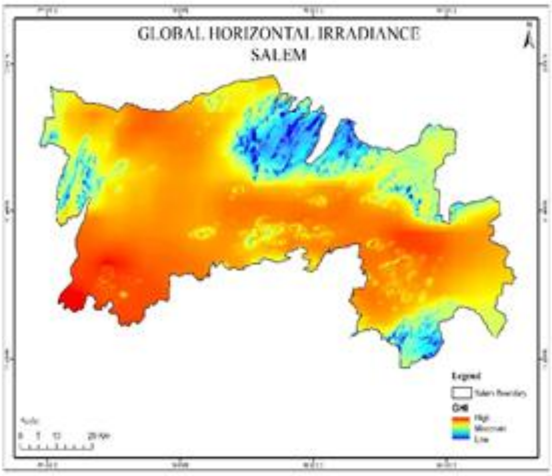

Fig. 3e: GHI

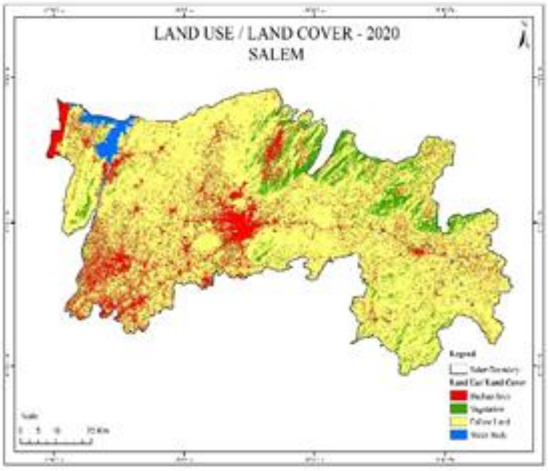

Fig. 3g: LU/LC

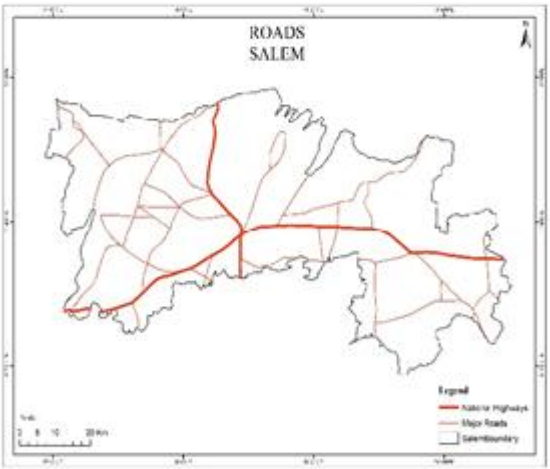

Fig. 3h: Roads

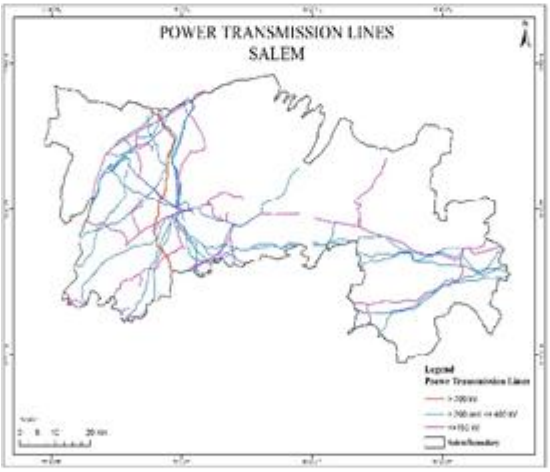

Fig. 3i: Power Transmission Lines

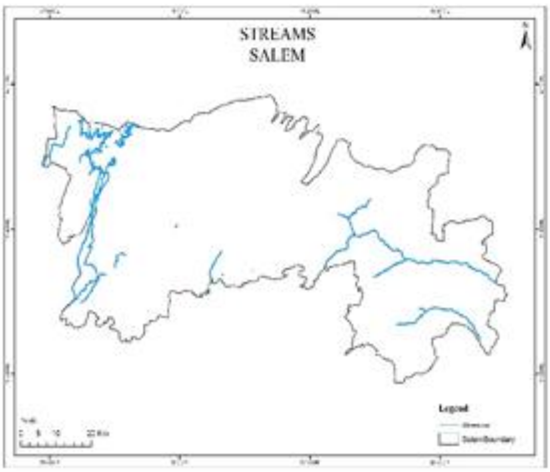

Fig. 3j: Streams

(a).Constraint Criteria

This process helps to delineate the restricted or constraint factors that would aid in visualizing unsuitable areas from optimal areas. The parameters that are used to separate the constraint area are-slope, aspect, NDVI, roads, settlements and streams. The slope and aspect maps created from the DEM data. And the proximity to roads, streams, power transmission lines, vegetation cover, and settlement was also analyzed using MODIS and Landsat data. The reclassified constraint criteria are analysed using raster calculator tool in ArcGIS toolbox, where 0 refers to unsuitable areas and 1 refers to the suitable areas for installing the solar power plants (Olubunmi O. Omoloso., Deborah Alaigba., Olatunji Aboyeji., Ifeoluwa Balogun., Samuel Akande. 2020). Table 1 shows the standard restriction factors to be considered while locating the suitable sites for solar power plants (Georgiou, A., & Skarlatos, D. 2016).

Table 1: Standard Restriction Factors

Restriction	Buffer	Impact Type
Roads	< 50m	Social
Aspect	South, South-east, South-west, East, West	Technical
Human Settlements	<500m	Social
Slope	>5˚	Technical
Land Cover	High Vegetation, Build-up areas, Water bodies	Environmental

a)Decision Criteria

The decision criteria are the factors that are favorable for the installation and efficient functioning of the solar power panels. The parameters considered for decision criteria are; Global Horizontal Irradiance (GHI), temperature, DEM, slope, aspect, roads, power transmission lines and streams. The solar panel efficiently works depending on the surface temperature. The surface temperature the study area is relatively uniform, so the 30 years average temperature of the study area was used as one of the decision criteria in this study. The solar panels have to be placed at a right distance from the roads, power transmission lines and settlements for easy connection and usage of the power source. The lower slope of the study area is a positive factor for installation of the solar panels. The slope directions of south, south west and south east are considered as the best orientations for receiving more energy from the sun (Olubunmi O. Omoloso., Deborah Alaigba., Olatunji Aboyeji., Ifeoluwa Balogun., Samuel Akande. 2020). **Table 2** shows the importance of the scale values assigned for each criterion of the decision criteria map.

Table 2: Ratio Scale Importance

Importance	Scale Values
Minimum Importance	1
Moderate Importance	2
Strong Importance	3
Very Strong Importance	4
Extreme Importance	5

In the present study, weightage was given to the parameters based on its importance in determining the efficiency in receiving more amount of solar energy. The weighted decision criteria is divided into sub-criteria and are given scale values from high to low. **Table 3** (Noorollahi, E., Fadai, D., Shirazi, M.A., Ghodsipour, S.H. 2016) shows the weightage of each parameter, sub-criteria for each parameter and their respective scale values from 1 (Minimum importance) to 5 (Extreme importance) as shown in **Table 2**.

Table 3: Decision Criteria Considered for Site Suitability

Decision criteria	Weight	Sub-criteria	Scale value
Slope (%)	0.106	Less than 5% 5 – 10 % 10 – 20 % 20 – 30 % More than 30 %	5 4 3 2 1
Aspect	0.062	South Southwest & Southeast East & West Flat others	5 4 3 2 1
Proximity to streams (m)	0.102	50 m 100 m 500 m 1000 m 1500 m	5 4 3 2 1
Proximity to roads (m)	0.254	50 m 100 m 500 m 1000 m 1500 m	5 4 3 2 1
Proximity to power lines (m)	0.324	50 m 100 m 500 m 1000 m 1500 m	5 4 3 2 1
Elevation (m)	0.060	More than 20 m 10 – 15 m 5 – 10 m 1 – 5 m Less than 1 m	5 4 3 2 1
Temperature (℃)	0.066	Less than 22℃ 22℃ - 24℃ 24℃ - 28℃ 28℃ - 30℃ More than 30℃	5 4 3 2 1
Global Horizontal Irradiance (GHI)	0.086	1,696.220947 - 1,871.456353 1,871.456354 - 1,912.387251 1,912.387252 - 1,950.759967 1,950.759968 - 1,978.899959 1,978.89996 - 2,022.389038	5 4 3 2 1

Land Suitability Map for Potential Sites

The land suitability map was created using the Analytical Hierarchical Process (AHP) method. Land suitability refers to the degree to which the suitable and unsuitable areas can be differentiated. The decision criteria made using weighted overlay and the constraint criteria map made using raster calculator are used as inputs for AHP technique which shows the optimal and less suitable areas for the installation of the PV plants.

Results And Discussion:-

Constraint Criteria

The constraint criteria maps that were made according to the standard restriction factors (Table 1) are shown below in figures 4a, 4b, 4c, 4d, 4e and 4f. These reclassified constraint criteria maps were joined together using the raster calculator tool the in Arc GIS toolbox to obtain the overall constraint map layer shown in Fig. 4g. About 22.01% of the study area is found to be suitable for the installation of solar panels.

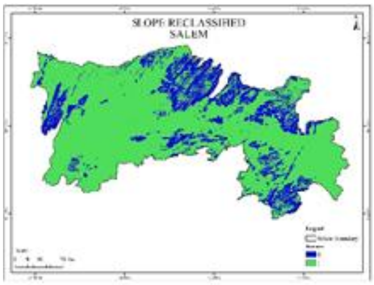

Fig. 4a: Reclassified Slope

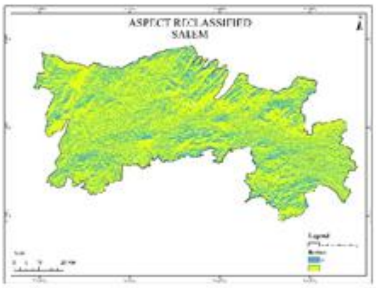

Fig. 4b: Reclassfied Aspect

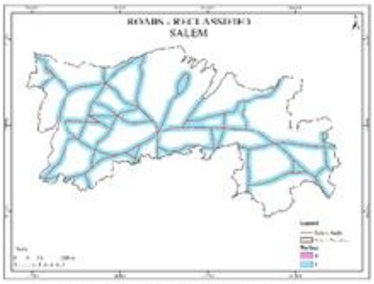

Fig.4d: Reclassified Roads

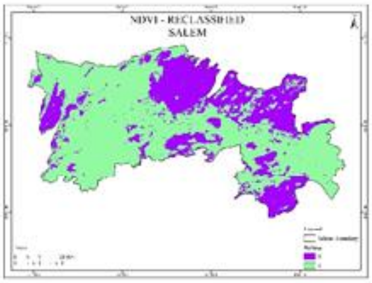

Fig. 4c: Reclassified NDVI

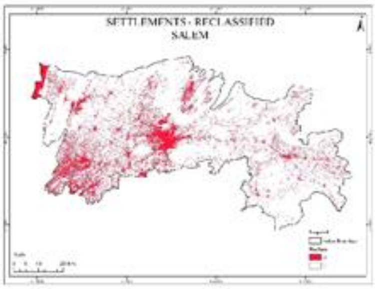

Fig. 4e: Reclassified Settlements

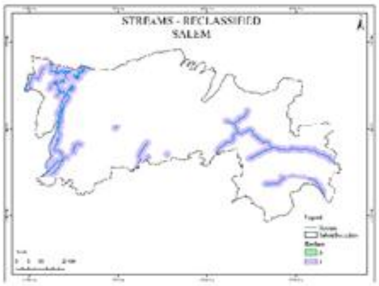

Fig. 4f: Reclassified Streams

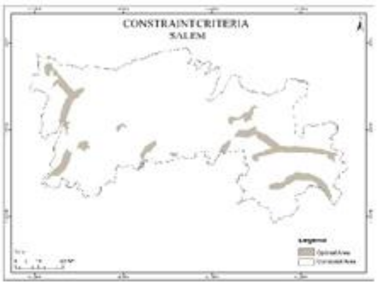

Fig. 4g. Constraint Map

Decision Criteria

The images from 5a, 5b, 5c, 5d, 5e, 5f, 5g and 5h shows the reclassified inputs for the decision criteria shown in Fig.5i, created using Weightage overlay analysis. The weightage for each parameter is shown in **Table 3**.

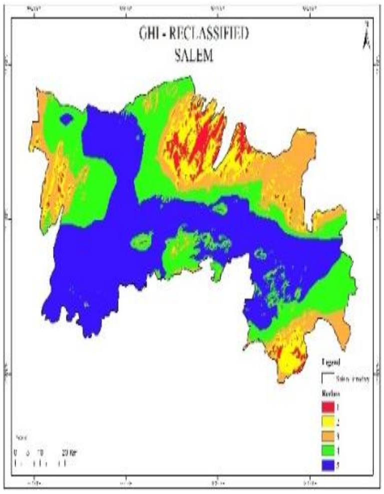

Fig. 5a: Reclassified GHI

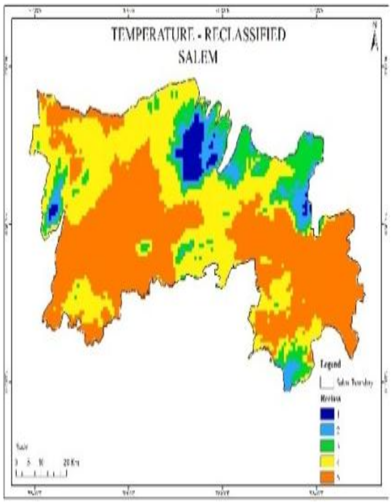

Fig. 5b: Reclassified Temperature

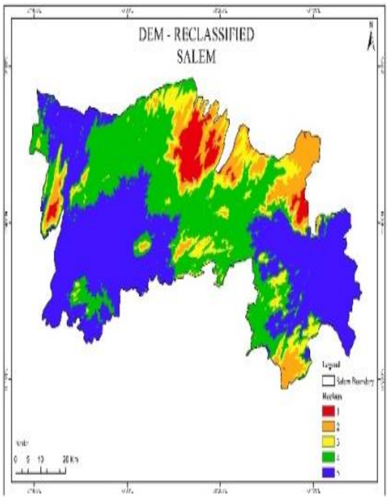

Fig. 5c: Reclassified DEM

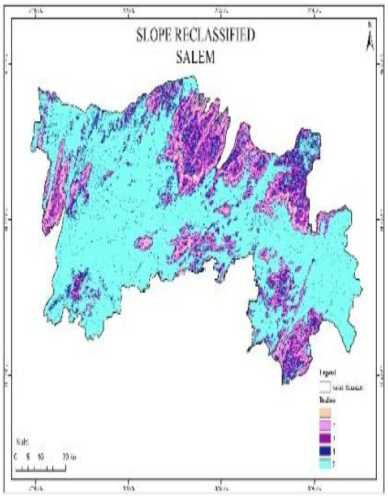

Fig. 5d: Reclassified Slope

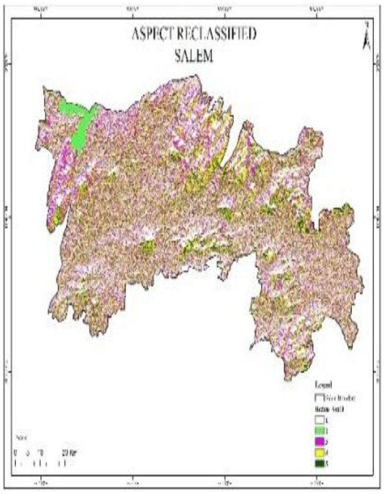

Fig. 5e: Reclassified Aspect

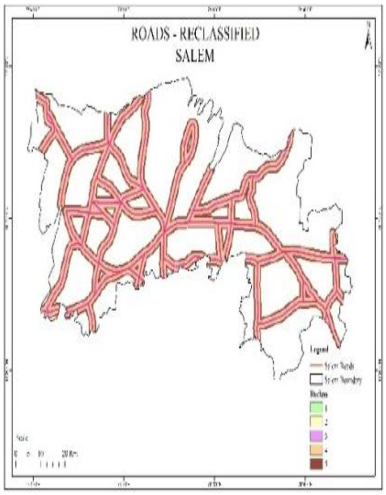

Fig.5f: Reclassified Distance from Roads

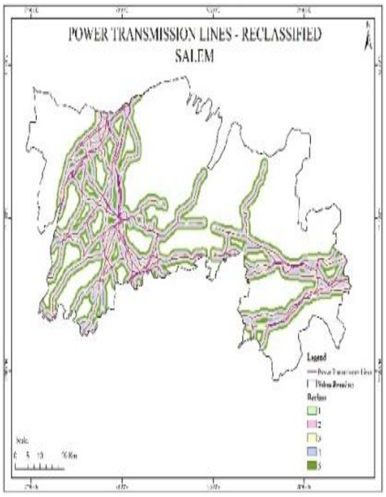

Fig. 5g: Reclassified Distance from Power Transmission Lines

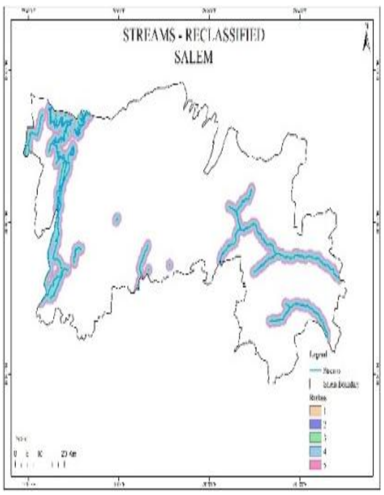

Fig. 5h: Reclassified Distance from Streams

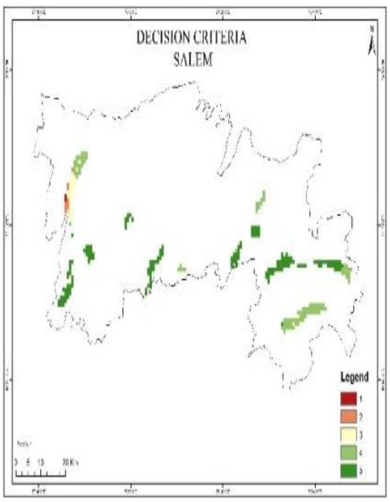

Fig. 5i: Decision Criteria Map

Potential Energy Generation of the Study Area

As per the ratio scale importance **Table 2**, the suitable areas are classified under five classes- Excellent, Good, Fair, Poor and Very Poor, and is shown in **Table 4**.

Table 4: **Solar power produced in the graded area**

Suitability	Area (sq. km)	Power Produced (MW)/Year
Excellent	617.9334	1257.6881
Good	383.7764	781.6373
Fair	112.1554	228.4269
Poor	27.3224	55.6475
Very Poor	7.2324	14.7302
Total	**1148.42**	**2338.13**

The average solar irradiance of the study area is 5.58 kWh/m^2. The suitable area for solar panel installation in the study area is 1148.42 sq. km which is capable of producing 2338.13 MW of electricity if completely used. The Excellent suitability area will yield up to 1257.6881 MW, Good, Fair, Poor and Very Poorly suitable areas could contribute 781.6373 MW, 228.4269 MW, 55.6475 MW and 14.7302 MW respectively.

Site Suitability for solar power plants

The final site suitability map for solar power parks was created using the AHP analysis with the decision criteria map (Fig.5i) and constraint map (Fig.4g.), as inputs, and the same is shown in Fig.6

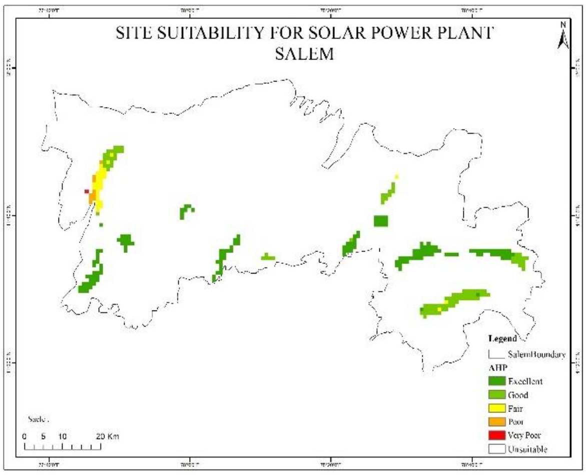

Fig.6: Site Suitability for Solar Power

From the figure, it could be observed that the suitable areas are classified as excellent, good, fair and poor as per the ratio scale importance **Table 2**.

The site suitability for the solar power plants in Salem district is 22% (1148.42 sq.km) and 78% (4069.32 sq.km) are found unsuitable. Out of the 22% , nearly 53.34% (617.9334 sq. km) is categorized as 'Excellent', 33.43% fall under 'Good' (338.7746 sq. km), followed by 'Fairly suitable' for 9.77% (112.1554 sq.km) and 2.83% (27.3224 sq. km) is 'Poorly Suitable'. Only 0.63% (7.2324 sq. km) of the area is 'Very Poorly suitable' for the site suitability of solar power plants in the study area. The final site suitability map shows that the excellently suitable areas are confined to southern region of the study area noted with lower slope and vegetation, higher temperature and GHI that would promote the installation of the solar power panels. The areas with good suitability are seen in the central and eastern part of the district. The fairly suitable and poorly suitable areas are noticed in the western part of the district. The northern part of the study area are found unsuitable for the installation of solar panels due to the presence of hills and water bodies.

Conclusions:-

The findings showed that the southwestern sections of the district, which make up roughly 22% of the research area, are the best places to build solar power facilities. This study makes a valuable methodological contribution to the research community. In the future, societal aspects like population and energy usage can be incorporated for a thorough analysis. As a result, this study helps to sustainably close the energy gap in the study area between supply and demand.

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