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Optimal Solar Farm Site Selection using GIS and Analytic Hierarchy Process

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Abstract

Solar energy has become an important source of clean energy due to the increasing global demand for electricity. The selection of sites for solar power plants is necessary for large-scale projects, as it depends on key factors such as quality of terrain, solar irradiance, proximity to transmission lines, land use, slope and distance from roads and residential areas. The paper gives a solution to identify optimal locations for solar farms by using GIS and AHP within the selected study area. The Analytic Hierarchy Process (AHP) is a widely used multi-criteria decision-making (MCDM) method to calculate the weights for identified environmental and economic factors. It is used to assign weights to the criteria and calculate a land suitability index (LSI) for evaluating potential sites. The LSI model categorizes sites into four groups: “low suitable”, “moderately suitable”, “Suitable” and “best suitable”. The result shows the study area is classified as low suitability by ‘red’, while ‘orange’ indicates moderate suitability. Additionally, blue’ indicates a suitable area, and ‘green’ shows the best-suited area for solar farms.

Keywords: Solar energy, Site selection, Multiple criteria analysis, Analytical hierarchy process(AHP), Geographic information system(GIS), Land Suitability Index (LSI).

1. INTRODUCTION

Over recent years the increasing worldwide energy requirements combined with environmental problems and limited availability of fossil fuels have set off an increase in interest in renewable power alternatives. Solar power stands as the primary renewable source because it offers good availability alongside environmental sustainability along with decreasing implementation costs. The effective utilization of solar power requires both strategic planning together with optimal site selection for maximizing efficiency.

The selection sites for solar power plants are important for large-scale projects, as it depends on key factors such as quality of terrain, solar irradiance, proximity to transmission lines, land use, slope and distance from road and residential areas. The project satisfies this need by developing a web-based tool to identify optimal locations for solar farms by utilizing Geographic information system (GIS) and Analytic Hierarchy Process (AHP) within the selected area. The project exists to locate optimal solar farm sites through a system that supports immediate energy planning needs.

2. LITERATURE SURVEY

2.1 GIS-based solar farms site selection using analytic hierarchy process (AHP) in Karapinar region, Konya/Turkey

Mevlut Uyan's research deals with the process of finding proper locations in Turkey's Karapinar region for solar farm development. The site selection process is performed using both Geographic Information Systems (GIS) and Analytic Hierarchy Process (AHP). The research implements five fundamental criteria which consider environmental and economic factors to determine proper sites for solar energy projects. The land evaluation process divides the area into four suitability zones where the low suitable category occupies 15.38% while moderate suitable takes up 14.38%, suitable amounts to 15.98% and best suitable makes up 13.92%. The study region contains 40.34% of areas that solar farm development should not take place. AHP demonstrates its ability for multi-criteria decision-making through its implementation within GIS to evaluate the chosen criteria systematically. The strong methodology enables both quick assessment procedures while handling multiple influencing elements. The study findings provide essential information that helps leaders make decisions for better land management along with sustainable solar power development in this region.

2.2 Applying a Combination of AHP, ANP, and PROMETHEE Methods to Find the Optimal Location for Solar Power Plant

Nima Mirzaei and Raheleh Nowzari conducted research through "Applying a Combination of AHP, ANP, and PROMETHEE Methods to Find the Optimal Location for Solar Power Plant" to determine suitable locations for solar power facilities in Antalya, Isparta, Konya, Mersin, and Niğde Turkish cities. The authors evaluate six essential criteria such as solar radiation and average temperature together with land cost and earthquake risk through the combination of Analytical Hierarchy Process (AHP) and Analytical Network Process (ANP) with PROMETHEE. The researchers use data obtained from trusted sources to process their analysis through SuperDecisions and VisualPROMETHEE software platforms. The study determined Mersin to be the most suitable site for solar energy development followed by Antalya and then Niğde took the lowest position. The research results demonstrate how decision frameworks create essential tools for renewable energy site selection and demonstrate Mersin's capability to harness solar power effectively within Turkey's renewable energy sector.

2.3 Towards advanced sustainable criteria for choosing the best site for collecting solar energy in cities using multi-criteria GIS

Research by Shery William Salama examines how Geographic Information Systems (GIS) with multi-criteria decision-making methods can identify suitable locations for solar energy farms in New Aswan City. The study examines important factors which consist of solar radiation with topography alongside accessibility and land use together with power infrastructure proximity. The data was obtained from the Urban Planning Authority which researchers analyzed through ArcGIS 10.3 to generate complex spatial models. A weighted suitability model was developed by giving significance to each criterion which positioned solar farm locations from unsuitable to highly suitable. The research shows that the New Aswan City has different suitable areas which identified particular zones as good locations for solar power plant development. The research demonstrates how GIS applications support renewable energy planning by providing important information for officials who want to increase solar energy networks in cities.

2.4 Integrating GIS and AHP for Photovoltaic Farm Site Selection: A Case Study of Ikorodu, Nigeria

The method used combines Geographic Information System technology with Analytic Hierarchy Process procedures to determine suitable locations for solar photovoltaic (PV) farm installation. The study uses environmental, technical and economic along with social factors to determine optimal locations for solar PV farm development. AHP obtains criterion weights through pairwise assessments while GIS performs spatial analysis to break down the land domains in Ikorodu. The assessment revealed that 68.77% of the study area displays unsuitability for PV development whereas 17.78% was classified as highly suitable. Stakeholders can use this research framework because it demonstrates the need to utilize multiple assessment criteria for making decisions about renewable energy planning. This study demonstrates support for solar energy expansion as per Nigeria's renewable energy plans while addressing limitations that urban land utilization faces.

3. PROPOSED SYSTEM

The solar site selection tool is designed for professionals, and policy makers to identify ideal locations for solar site installation. The system uses real-world solar data with geospatial data and multi-criteria decision-making methods to provide site recommendations.

Core Components and Their Interactions

1.Site Selection Interface: The system provides an interactive map where users can select areas of interest by drawing rectangles. This allows for analysis of locations ranging from small urban neighbourhoods to large rural regions.

2.Parameter Weighting System: Users can customize the decision model through sliders that assign relative importance to five key factors: solar irradiance, elevation, land suitability, distance to infrastructure, and terrain slope.

3.Data Integration Layer: The system uses NASA's POWER API to retrieve accurate solar irradiance data while at the same time generating simulated values for other parameters.

4.Analytical Processing: when the data is collected, the system applies AHP method to calculate normalized scores and ranks the selected sites according to the specific requirements and priorities.

5.Multi-format Visualization Suite: Results are presented through multiple complementary visualizations including colour-coded maps, parameter-specific heat maps, data tables, and downloadable reports.

4. METHODOLOGY

4.1 User Interface and Area Selection

The interface uses Folium's mapping integrated with Streamlit to create a responsive drawing experience. The system has Folium's Draw plugin to enable rectangle drawing functionality with clear visual feedback. When a user outlines an area, the application captures this area and extracts the minimum and maximum latitude and longitude values to define the boundary for site evaluation.

To maintain a good user experience, the application uses Streamlit's session state to maintain the drawn area while the other components of the system update. This approach prevents users from having to redraw their area multiple times during the process, greatly improving the system for complex site selection process that may require changes to parameters and weights.

4.2 Site Generation and Data Collection

Once the area is defined, the system uses random point generation within the user-defined region to create a set of 200 sites, ensuring large coverage of the area of interest. For each candidate location, the application makes parameterized HTTP requests to NASA's POWER API, specifying coordinates, the "ALLSKY_SFC_SW_DWN" parameter (solar irradiance), community type (RE for Renewable Energy), and the timeframe (2020). From these results, the system calculates the annual average of daily solar irradiance values, providing a scientifically valid baseline for solar potential.

To optimize performance, the application implements concurrent API requests using Python's concurrent futures module. This parallel processing approach significantly reduces the total time required to collect data for all candidate sites—an essential optimization when analysing large areas with many potential locations. The system also includes timeout parameters and exception handling to ensure robustness when dealing with external API calls, gracefully excluding problematic sites from the analysis rather than failing completely.

For the remaining parameters—elevation, land suitability, distance to infrastructure, and slope—the current implementation generates random values between 0 and 1.

4.3 Analytic Hierarchy Process (AHP)

Analytic Hierarchy Process is the foundation of the site selection process. It is a method of structuring a complicated decision-making process with the help of mathematics and psychology. It starts with a 5×5 pairwise comparison matrix in which every element is the relative importance of one criteria with respect to another. Diagonal elements are always 1 (equal importance of a criteria to itself), and if importance level X is assigned to criteria A with respect to criteria B, then criteria B is immediately assigned importance 1/X with respect to A to maintain the mathematics intact throughout the matrix.

After it makes the pairwise matrix from user input, the system then moves to a normalization step where the sum of each column is calculated and then the value in each cell divided by the column sum to build a normalized matrix. This conversion makes all of the values relative to each other for comparison on various criteria. The ultimate weights on the criteria are then calculated by averaging out each row of the normalized matrix to build values equal to the relative value of each factor in the ultimate decision and equal to 1, and thus ready to use as direct multiplier factors in the scoring formula.

4.4 Site Ranking

Site ranking starts off by normalizing the data using scikit-learn's MinMaxScaler so that all of the parameter values are on a common 0-1 scale. This is because parameters are in different units and ranges (e.g., solar irradiance in kWh/m²/day and height in meters). Parameters with large numerial ranges would otherwise have an over-weighting effect on the outcome, regardless of how significant they are in reality to the decision. Normalization enables equal comparison and prevents any one factor from being able to swamp all the others simply because it is being measured in a specific unit.

After normalization, the system computes the overall score of every site with the aid of the weighted sum model whereby Score is the sum of every normalized value of the parameter multiplied by its weight as obtained from the AHP process. This sum and multiplication are what are used to sum up all the factors into one overall score that considers the overall suitability of the site as reflected in the degree of importance input by the user. These scores form the basis of ranking whereby sites are ranked in descending order to generate a ranked list whereby the best sites are the top sites for the installation of solar.

This ranking process offers a quantitative basis to what otherwise would be an incoherent and subjective decision-making process. By breaking down the multi-dimensional site selection problem into discrete elements, standardizing their values, and applying systematically derived weights, the system assists users in making more objective and justifiable site selection decisions without precluding them from injecting their expert judgment via the weighting process.

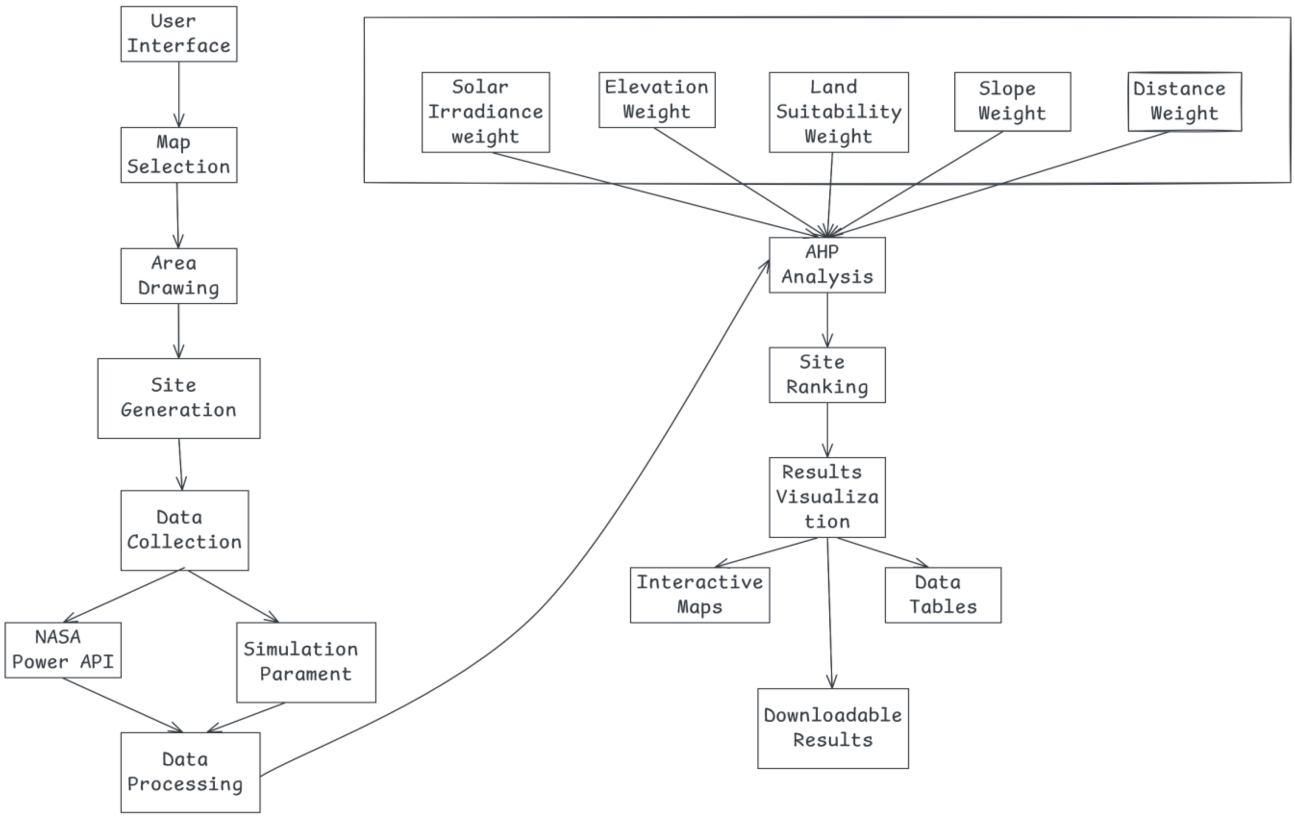
4.5 Visualization and Results

The system offers a multi-layered approach to result visualization, beginning with a colour-coded primary map that implements a four-tier colour scheme (green, blue, orange, red) corresponding to score quartiles (>0.75, 0.5-0.75, 0.25-0.5, ≤ 0.25). Each site is represented by a circular marker whose colour instantly communicates its relative quality to the user, with interactive tooltips providing exact score information when hovering over markers. This visual approach allows users to quickly identify spatial patterns and high-potential regions without needing to analyze numeric data.

For deeper analysis, the system generates individual parameter maps for each criterion, each using distinct colour gradients: viridis for solar, plasma for elevation, inferno for land suitability, viridis again for distance, and magma for slope. Each map includes a legend showing the colour scale relative to the parameter's minimum and maximum values. This decomposed visualization approach enables users to understand how individual factors contribute to the final rankings and identify areas where specific parameters might be particularly favorable or problematic.

Complementing these visual representations, the system provides a verification report with statistical summaries of the solar irradiance data including average, minimum, and maximum values. This verification step helps users validate the quality of the data and understand the solar potential range within their selected region. All site data is additionally presented in an interactive, sortable data table showing coordinates and individual parameter values, enabling detailed comparison between sites and identification of specific strengths and weaknesses. To facilitate integration with external workflows and further analysis, the system offers one-click CSV export with properly formatted values. This export functionality allows users to incorporate the results into broader energy planning processes, combine them with additional datasets, or perform customized analyses beyond the capabilities of the web application. Together, these visualization and export features transform complex multi-criteria analysis into accessible insights that can directly inform decision-making.

Figure 1: System architecture



5. TECHNOLOGIES USED

Programming Stack

- Python: Core language for logic, data manipulation, and API integration.
- Streamlit: Web interface toolkit for quick interactive application prototyping.
- Folium + Streamlit-Folium: Interactive map visualizations and user inputs.

Data Analysis & Management

- NumPy: High-performance matrix calculations, ideal for AHP computation.
- Pandas: Organized tabular data handling and CSV output.
- scikit-learn: MinMaxScaler for feature normalization.

API and Networking

- Requests: For issuing and handling HTTP requests to external APIs.
- Concurrent.futures: For concurrent data retrieval and enhancing performance.

Visualization

- Branca & Folium Plugins: Highly capable mapping plugins for color scaling and user interaction.

External Data Source

- NASA POWER API: Provides solar irradiance data globally, using satellite imagery and atmospheric reanalysis models.

6. RESULTS

Figure 2: Area selection

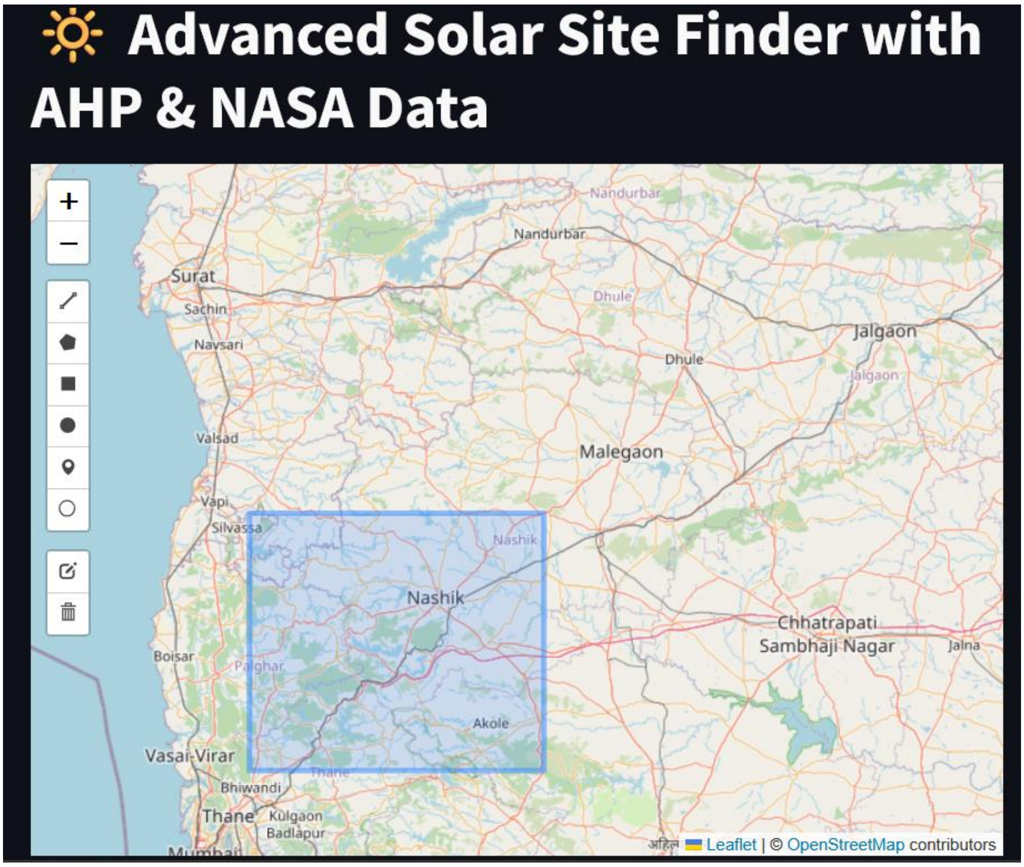


Figure 3: Solar Site prediction

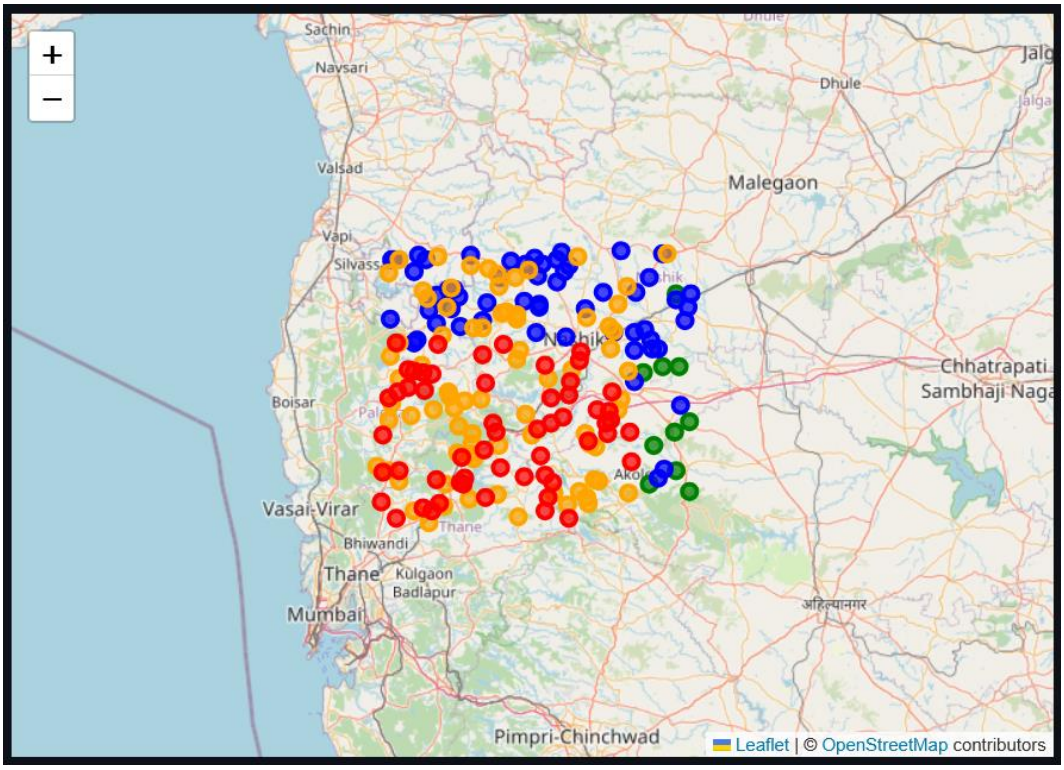


Figure 4: Solar Irradiance Map

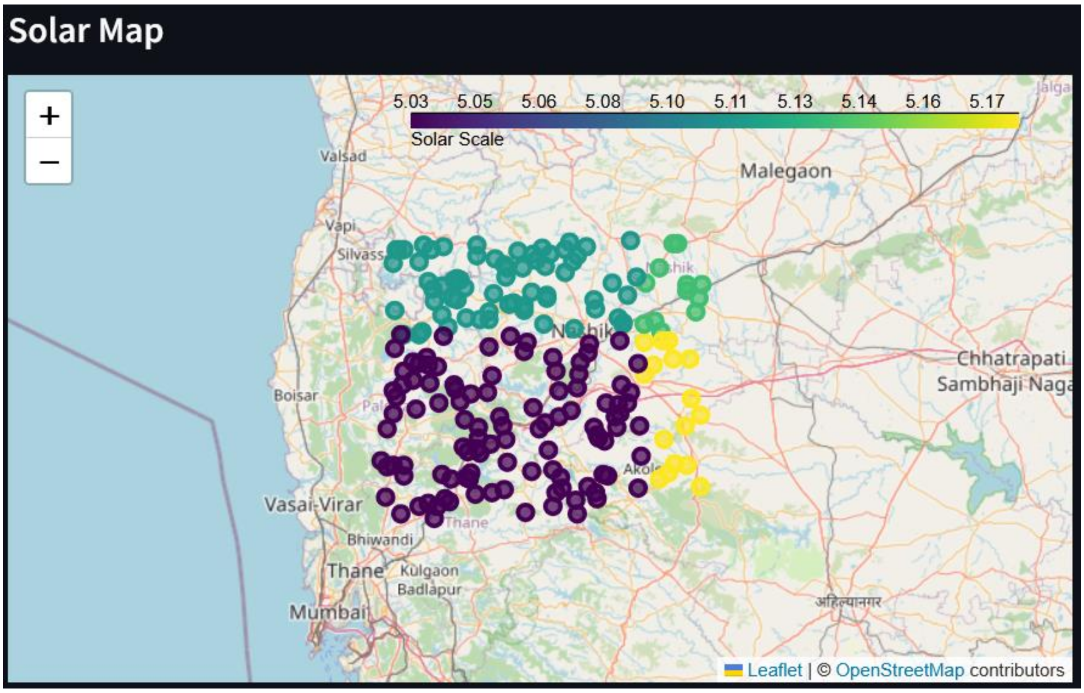


Figure 5: Elevation data Map

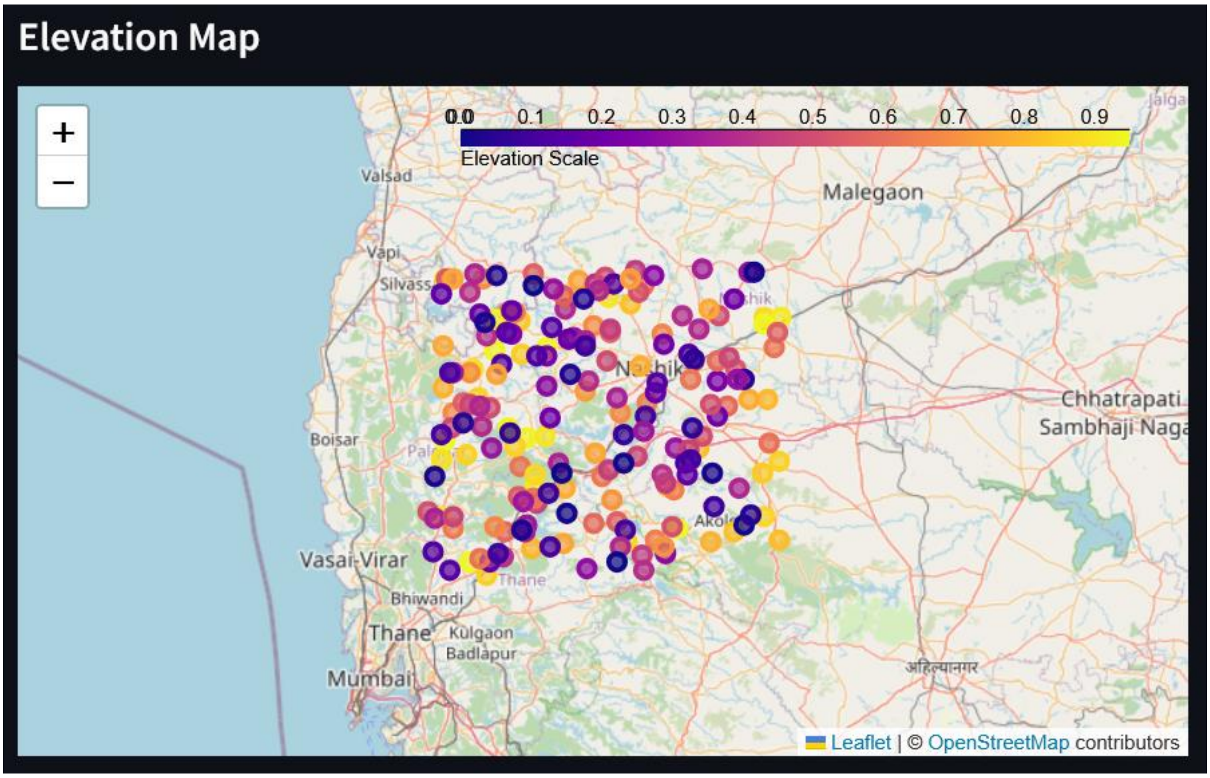


Figure 6: Land use data Map

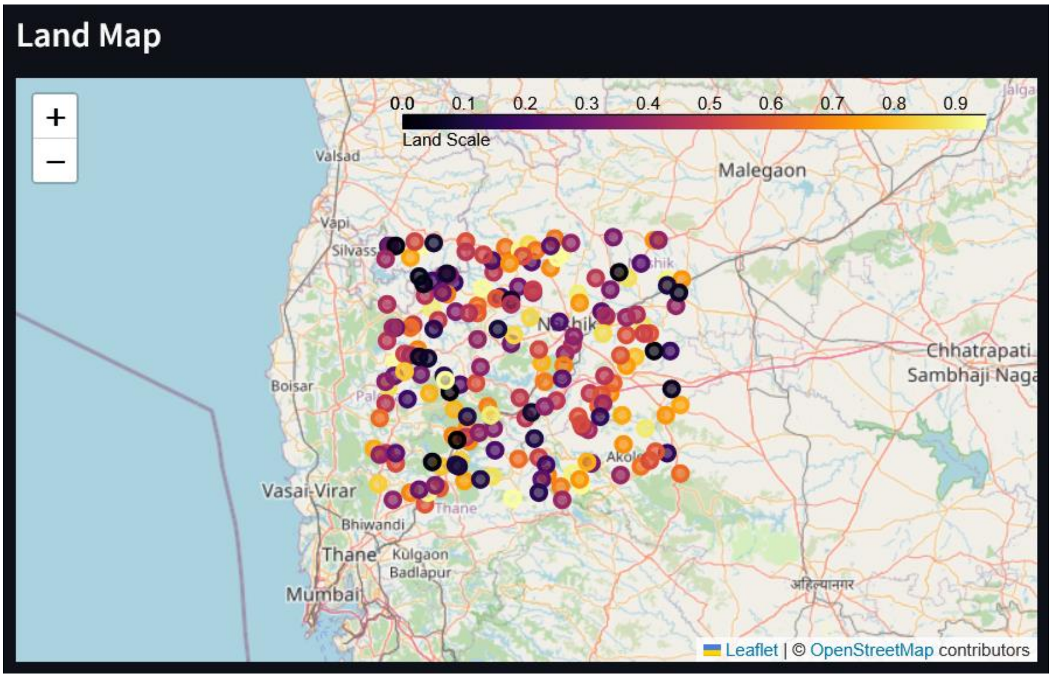


Figure 7: Distance from the road data map

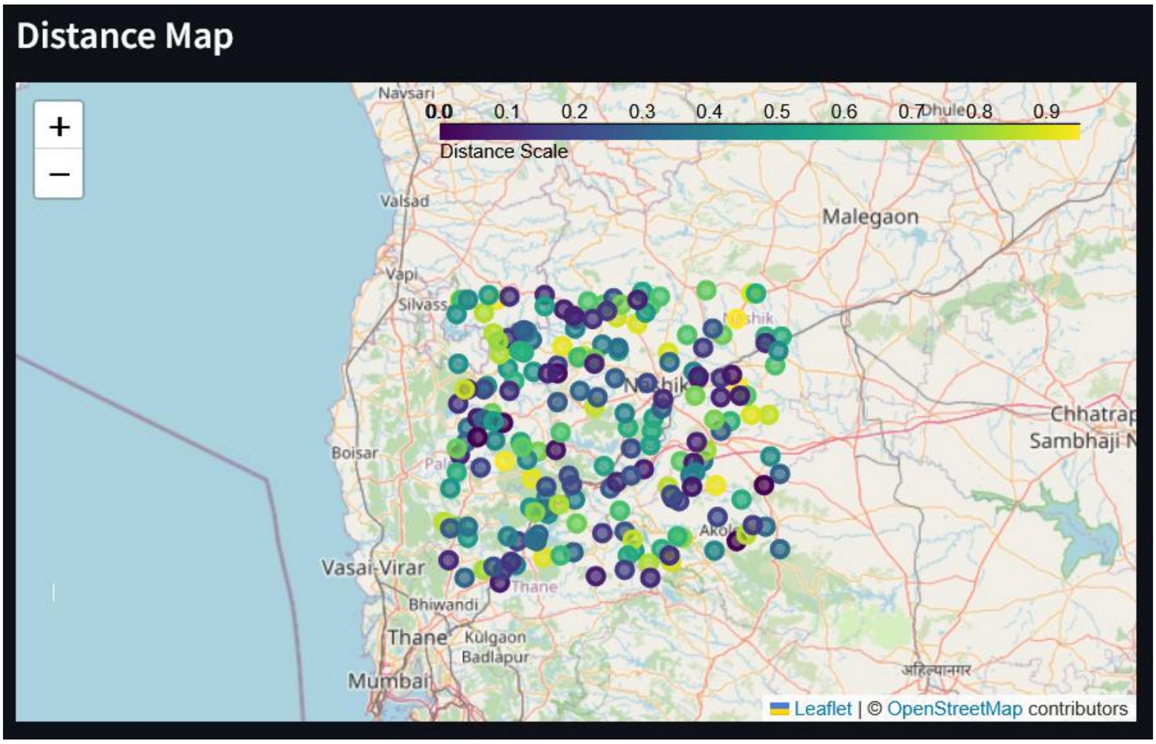


Figure 8: Slope data map

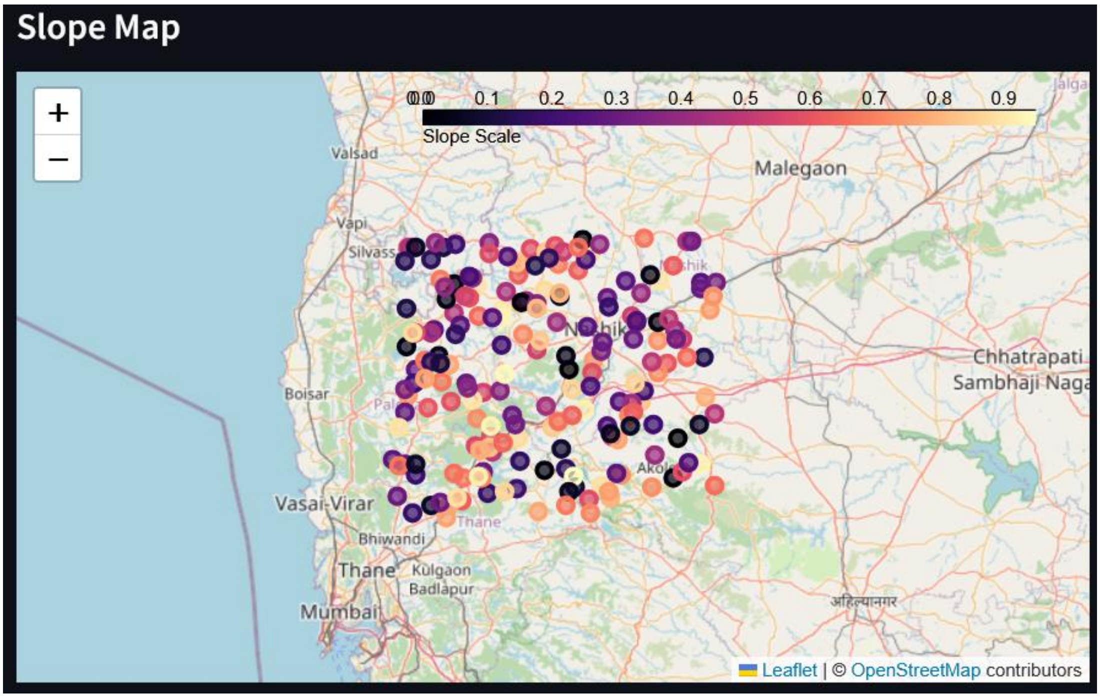


Figure 9: Site data and analysis score

	Latitude	Longitude	Solar	Elevation	Land	Distance	Slope	Score
0	19.724325	74.212363	5.179918	0.905662	0.802115	0.313821	0.510304	0.86
1	19.893565	74.041592	5.179918	0.623146	0.855454	0.653128	0.640394	0.85
2	19.481984	74.210174	5.179918	0.855256	0.666191	0.353818	0.695443	0.84
3	19.687613	74.155953	5.179918	0.886451	0.770882	0.005249	0.085693	0.80
4	19.914786	74.175955	5.179918	0.844856	0.187273	0.906714	0.146093	0.80
5	19.917352	74.114215	5.179918	0.810595	0.027184	0.943973	0.692065	0.80
6	19.554737	74.165845	5.179918	0.919012	0.158264	0.366311	0.974790	0.79
7	19.644891	74.078175	5.179918	0.394708	0.942806	0.618616	0.006338	0.79
8	19.506182	74.065482	5.179918	0.865046	0.691784	0.008043	0.028310	0.78
9	20.167155	74.164637	5.135519	0.923766	0.968068	0.641511	0.269496	0.76

7. CONCLUSION

Renewable sources of energy are sources of energy that are extracted from natural resources and don't diminish over a period of time. Solar energy is one of the most prolific sources of energy that can be found. Solar energy is used for the generation of electricity, heating and cooling, water heating and different industrial uses. It offers a clean and sustainable alternative to fossil fuels. The paper presents an application of integrating the Analytic Hierarchy Process (AHP) with Geographic Information Systems (GIS) for the optimal site selection for solar farms in the selected area. Five key criteria were analyzed to calculate the Land Suitability Index (LSI), which was used to generate a final suitability map. The results show the most suitable locations for solar farm development and also identify areas unsuitable for development. This paper provides a structured methodology and a valuable decision-support tool for stakeholders, researchers, and solar energy developers to make informed decisions in the planning and expansion of solar energy infrastructure.

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