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"GIS - BASED SOLAR POTENTIAL ANALYSIS OF GOVERNMENT BUILDINGS: A CASE STUDY OF MUNICIPAL WARD IN UDAIPUR", RAJASTHAN, INDIA

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Abstract: The increasing demand for renewable energy solutions has emphasized the need for efficient rooftop solar photovoltaic (PV) system assessment in urban areas. This study integrates geographic Information System (GIS) and Remote Sensing techniques to evaluate the solar potential of government buildings in a municipal ward pf Udaipur. The methodology includes ward boundary and rooftop boundary digitization using Google Earth Imagery & the height of buildings was measured in Ruler tool, followed by the Extraction of Digital Surface Model (DSM) data from NASA sources. Solar insolation analysis is conducted in SAGA GIS to identify the most suitable rooftop for solar panel installation. Additionally existing solar panel are mapped, and optimal locations for new installations are proposed using Helioscope software, considering factors such as panel tilt, azimuth angle, and energy generation capacity. The study provides a comprehensive framework for urban solar suitability mapping.

Keywords: GIS, Remote Sensing, Digital Surface Model, Rooftop Photovoltaic, Helioscope

I. INTRODUCTION

The rapid growth of urban populations and the rising demand for electricity have created unprecedented pressure on conventional energy systems, which are largely dependent on fuels. These non-renewable resources not only face the challenge of depletion but also contribute significantly to environmental issues such as greenhouse gas emissions, urban air pollution, and climate change. To counter these challenges, renewable energy technologies have gained global attention, with solar photovoltaic (PV) systems emerging as one of the most promising solutions. The global shift towards renewable energy sources has intensified research on solar photovoltaic (PV) as a sustainable alternative to fossil fuels. Urban areas with their extensive built infrastructure, offer a significant opportunity for rooftop solar installations, reducing carbon emission and enhancing energy self-sufficiency. Identifying suitable rooftops for solar panels requires a systematic approach that integrates spatial analysis, building characteristics, and solar radiation data. Geographic Information System and remote sensing techniques provide an effective means to assess rooftop solar potential by leveraging spatial datasets and analytical tools (Sharma & Patel, 2021). Udaipur, known as the "city of Lakes," has substantial solar energy potential due to its high solar insolation levels, averaging 5.5-6.5 kWh/m^2/day (MNRE,2023). Government buildings, in particular, serve as ideal candidates for solar installations due to their large rooftop areas and continuous electricity demand. However, a detailed assessment is required to determine their solar potential based on factors such as rooftop orientation, shading, and available space. This study employs a GIS-based methodology to analyse the rooftop solar potential of government buildings in a municipal ward of Udaipur. The research integrates various geospatial datasets, including Digital Surface Model (DSM) data from NASA, solar insolation mapping using SAGA GIS, and solar simulation using Helioscope software. The objectives of this research are: (1) To map and evaluate the current distribution of existing rooftop solar installation on selected government buildings. (2) To identify suitable and unsuitable rooftops based on annual solar insolation values. (3) To propose optimal solar panel layouts and estimate the energy generation potential using Helioscope simulations. By combining geospatial analysis with solar design simulations, this study provides a comprehensive framework for urban rooftop solar assessment. The finding are expected to support policymakers, urban planners, and government authorities in promoting renewable energy adoption, reducing electricity costs, and advancing sustainable urban energy systems in Udaipur and beyond.

II. STUDY AREA

The study focuses on a selected municipal ward in Udaipur, Rajasthan, covering five government buildings; Maharana Bhopal Hospital, Meera Girls College, District and Session Court, District Collectorate Office and the Post Office. These buildings were chosen due to their substantial rooftop areas, high energy demand, Institutional importance and potential

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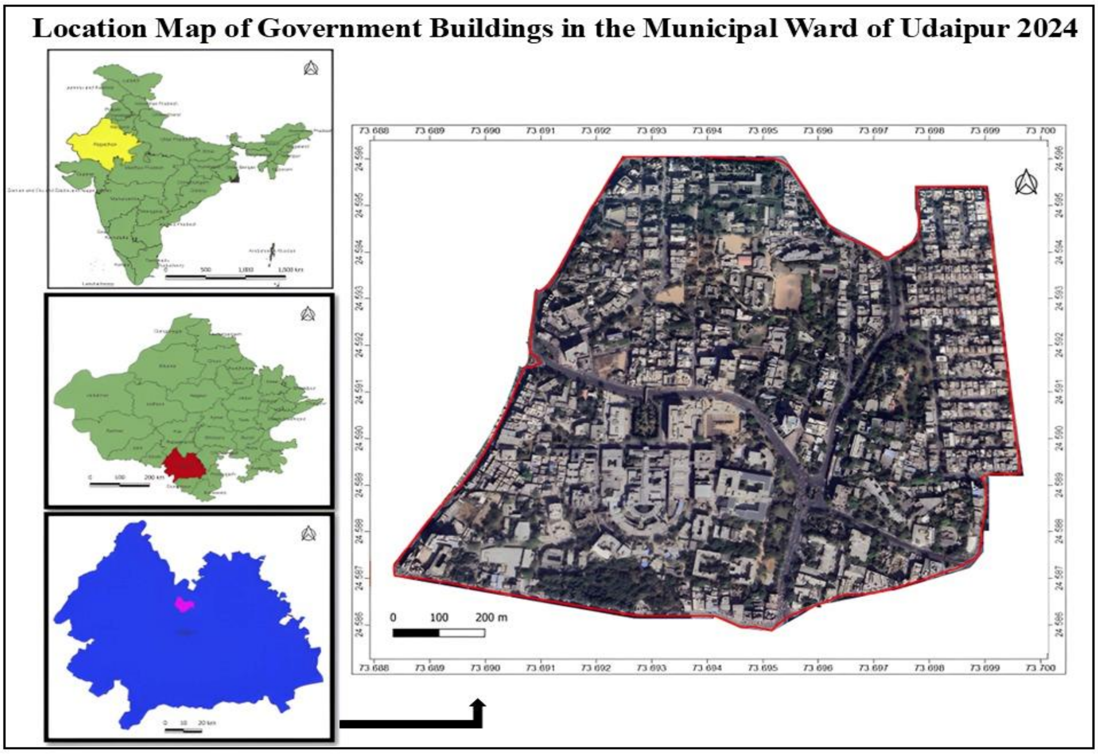
for large-scale solar panel installations. Udaipur is located in the southern part of Rajasthan, between $24^0 34'$ to $24^0 37'$N latitude and $73^0 40'$ to $73^0 44'$E longitude, at an elevation of about 598 meters above mean sea level. The terrain is relatively flat in urban areas, minimizing shading effects from surrounding structures. It is popularly known as the “City of Lakes” due to the presence of major water bodies such as Pichola Lake, Fateh Sagar Lake, and Swaroop Sagar Lake. The urban fabric of Udaipur consists of a dense built-up core surrounded by expanding residential, Institutional, and commercial zones. Climatically, Udaipur experiences a hot and semi-arid climate with abundant solar radiation throughout the year, making it an ideal location for solar energy projects. The city receives an average of 5.5-6.5kWh/m^2/day of solar insolation (MNRE,2023), ensuring optimal conditions for photovoltaic (PV) power generations. The selected ward was digitized using Google Earth Pro, and building footprints were extracted for spatial analysis. The study incorporated DSM data to assess elevation variations and rooftop height, providing essential input for solar radiation modelling. The combination of GIS-based analysis and solar simulation software allowed for precise identifications of the most suitable rooftops for solar panel installations.



III. METHODOLOGY

A multi-step GIS-based methodology was adopted to analyse the rooftop solar potential of government buildings in Udaipur. The workflow consisted of data collection, preprocessing, solar radiation analysis, and solar panel suitability assessment, where the municipal ward boundary was digitized using Google Earth Pro. High-resolution satellite imagery served as the basemap, over which the rooftops of selected government buildings were delineated in QGIS. To account for building height, the ruler tool in Google Earth was used, and additional elevation inputs were derived from the NASA Digital Surface Model (DSM). These datasets provided the fundamental spatial framework for rooftop solar analysis.

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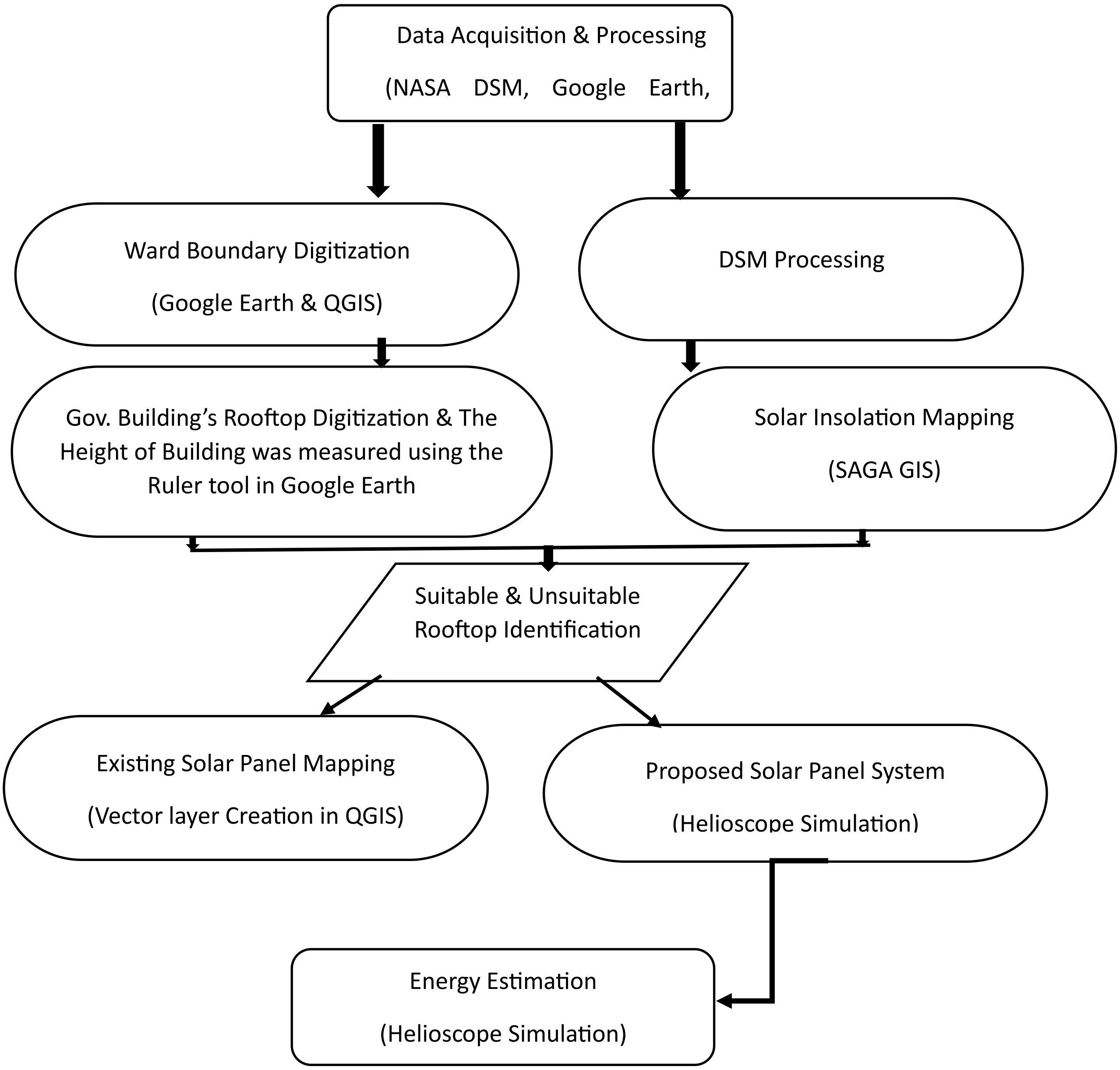
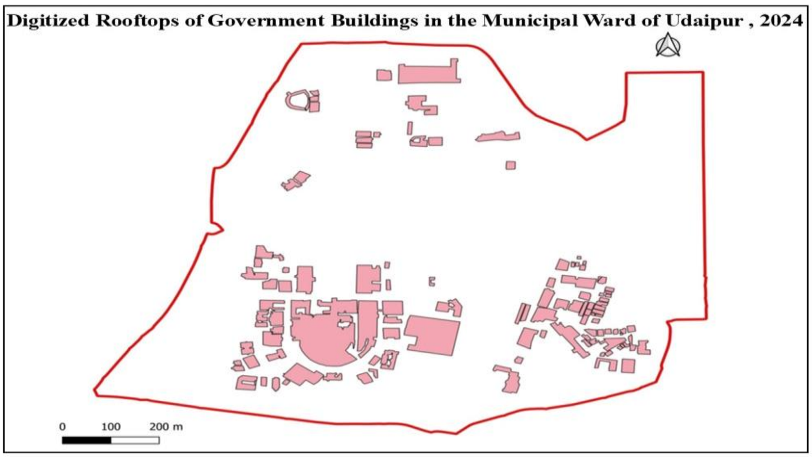


Flow Chart of Methodology



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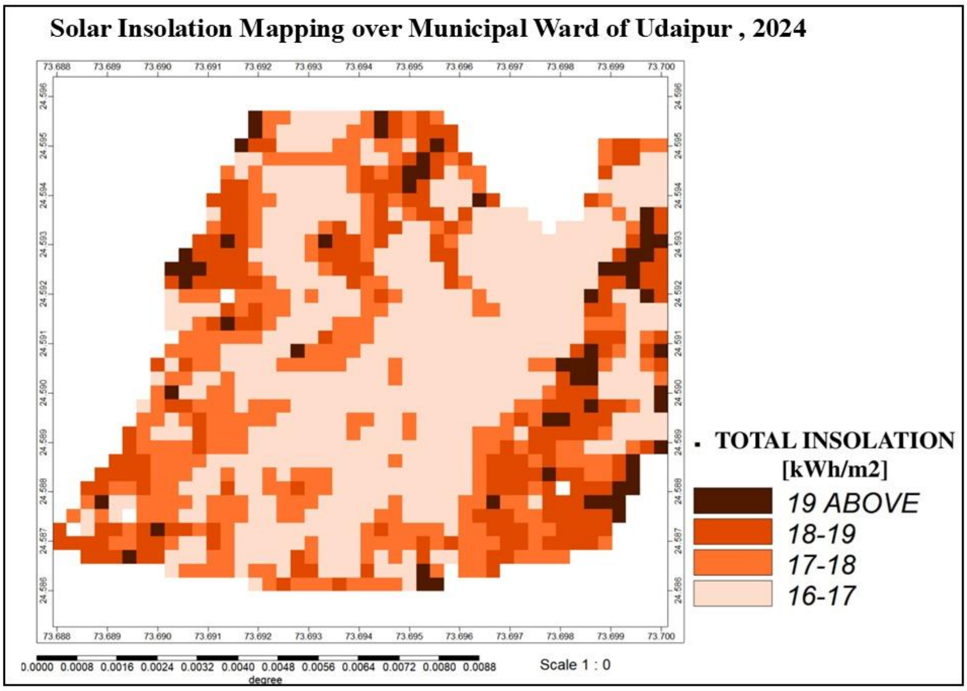
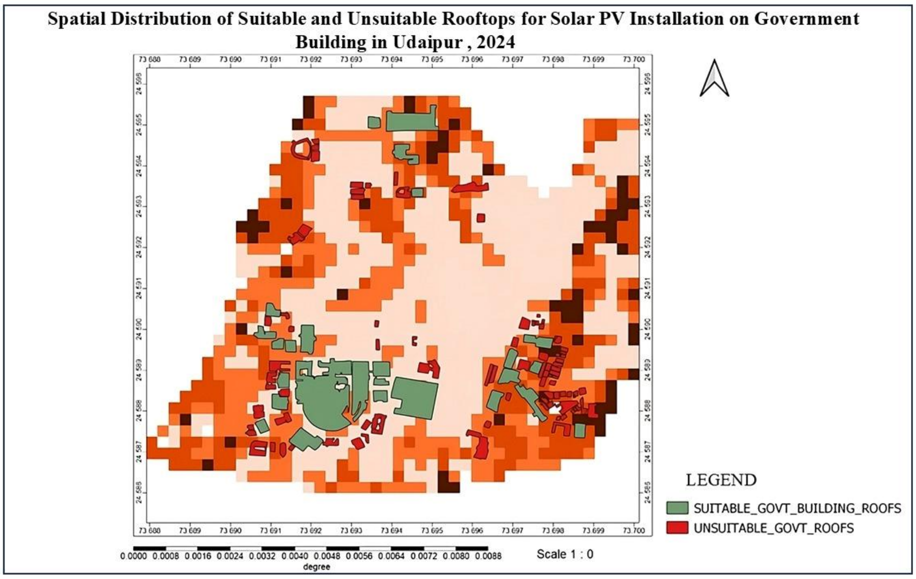
The municipal ward boundary was digitized using Google Earth Pro (Google,2023). High- resolution satellite imagery was used as a basemap for rooftop digitization in QGIS.

SAGA GIS was used to generate a solar radiation map based on terrain elevation. SAGA GIS is an open-source geographic information system designed primarily for advanced geoscientific analysis, including terrain analysis, hydrology, remote sensing, and other raster-based tasks. First, a Digital Elevation Model (DEM) of the area is loaded into SAGA GIS. Next, run the Potential Incoming Solar Radiation tool, which uses the DEM along with atmospheric and time-based factors to calculate how much solar energy a given area receives. The tool then generates a new grid that stores the calculated solar radiation values for every pixel. Finally, this grid is displayed as a coloured represent varying levels of solar radiation. This makes it easy to visualize which parts pf the landscape receives the most solar energy.



The DSM was processed to generate solar radiation maps, which were then overlaid on the digitized rooftop polygons. This allowed the classification of rooftop surfaces into suitable and unsuitable categories depending on their annual solar exposure. Rooftops receiving consistently high radiation were identified as suitable for photovoltaic installation, while areas influenced by shading, orientation, or slope were categorized as unsuitable.



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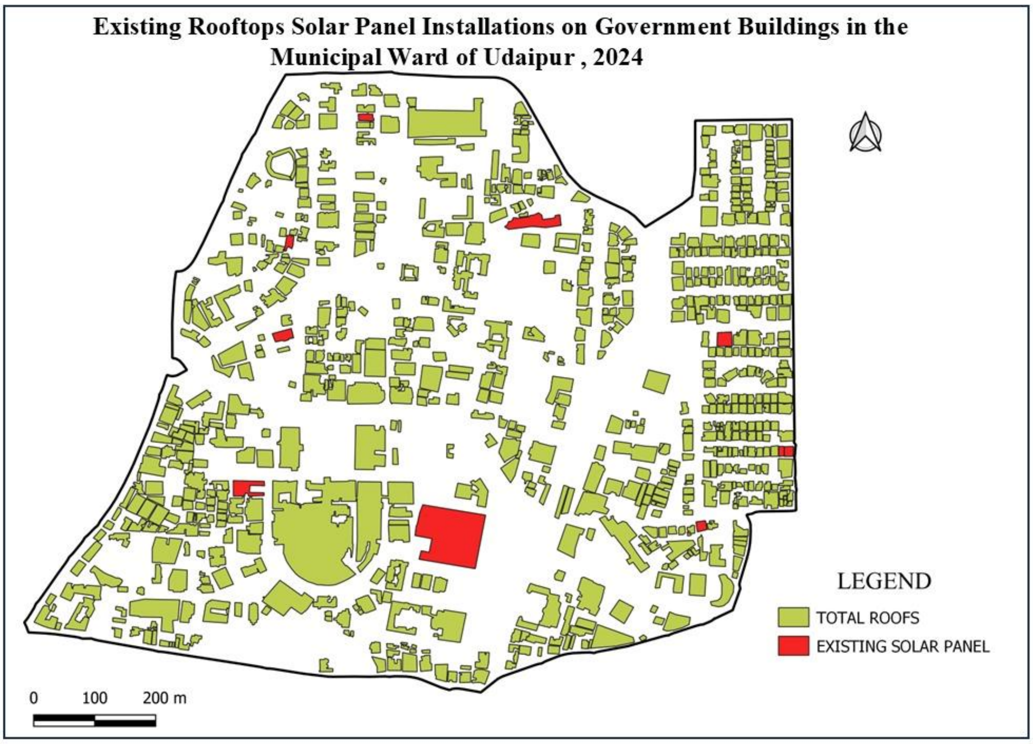
To assess the current state of infrastructure within the study area, an existing solar panel mapping exercise was carried out. High-resolution satellite imagery from Google Earth Pro was used to visually identify and digitize rooftop solar panels in the municipal ward. Existing rooftop solar panels across the ward were digitized by creating a vector layer over satellite imagery using QGIS.

Once suitable rooftops were identified, the study advanced to the stage of solar panel design and simulation using Helioscope software. The rooftops deemed suitable from the insolation analysis were modelled in Helioscope to simulate realistic solar panel layouts. Parameters such as tilt angle, azimuth orientation, system capacity, and shading effects were incorporated to determine the most efficient rooftop configurations. The software further generated estimates pf daily electricity production, which allowed for building-wise comparisons of solar generation potential.
The final stage involved energy estimation and result compilation, where the proposed solar setups were quantifies in terms of both total solar setups were quantified in terms of both total solar capacity (KW) and expected energy output (kWh/day). This comprehensive methodological framework, combining GIS-based analysis with Helioscope simulations, ensured that the solar suitability of government buildings was assessed with precision, while also producing practical outputs that could support decision-making and policy formulation.

IV. RESULTS AND PROPOSED SOLAR SETUPS

Existing rooftop Solar panel installation across the municipal ward were mapped by digitizing visible solar panels from satellite imagery using QGIS. A vector layer was created to mark solar panels present on building rooftops. The spatial analysis revealed that while some rooftops already had solar panels, a large percentage of suitable rooftop area remains underutilized.



To determine the optimal solar panel configuration for selected government buildings, Helioscope an advanced solar design and simulation software, was utilized. The suitable rooftops identified from the solar insolation map were further analyze to simulate the proposed solar panel setups. Based on total solar insolation values exceeding 5.5 kWh/m^2/day, five government buildings were shortlisted for simulation. The rooftops were categorized based on their solar exposure, area, and tilt availability.

Map generated as final output includes, detailed insets view for the selected rooftops, each labelled with estimated system capacity, panel orientation and expected per day energy output.

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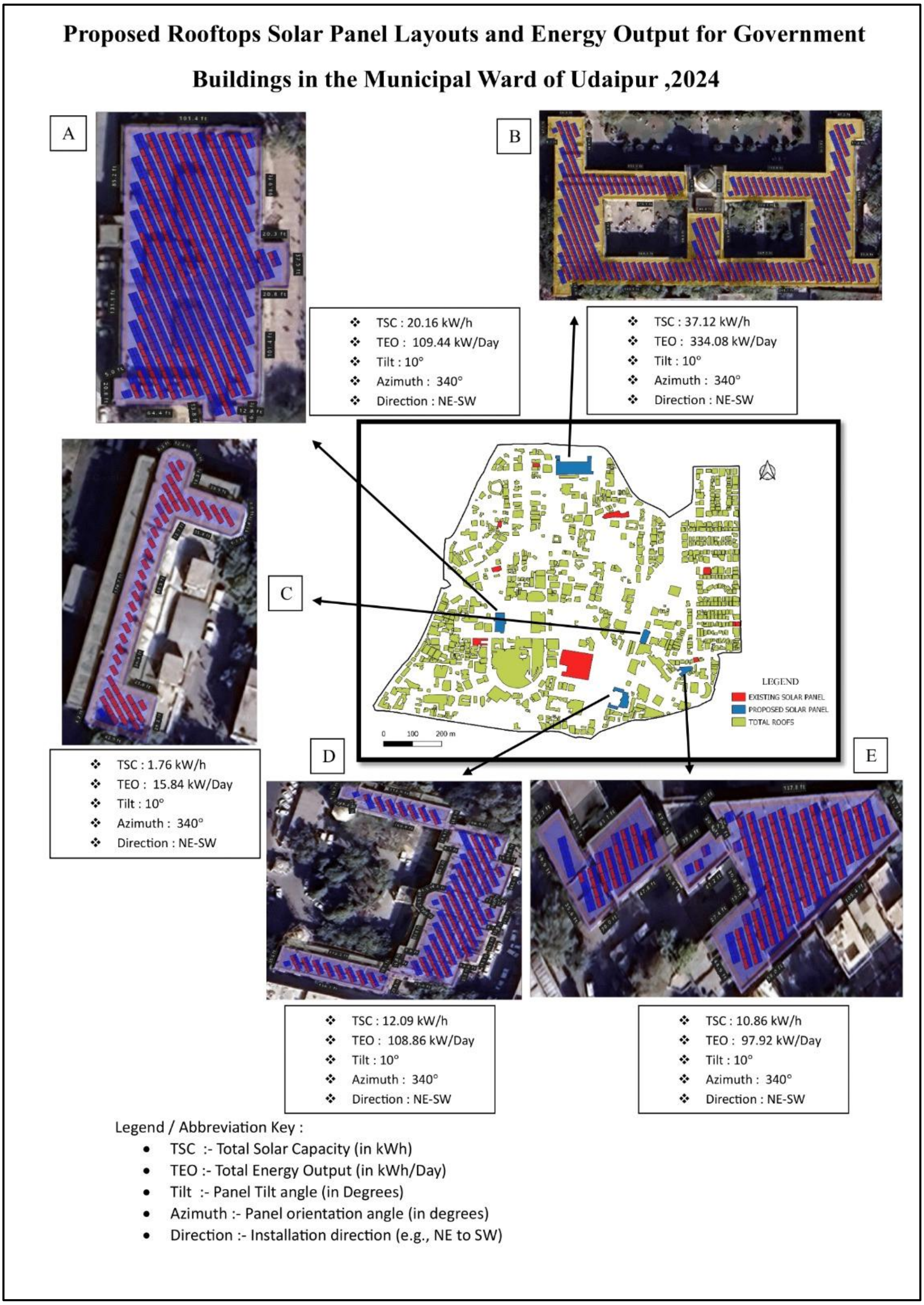

* (A) Maharana Bhopal Hospital, (B) Meera Girls College, (C) District & Session Court, (D) District Collectorate office, (E) Post office Udaipur.

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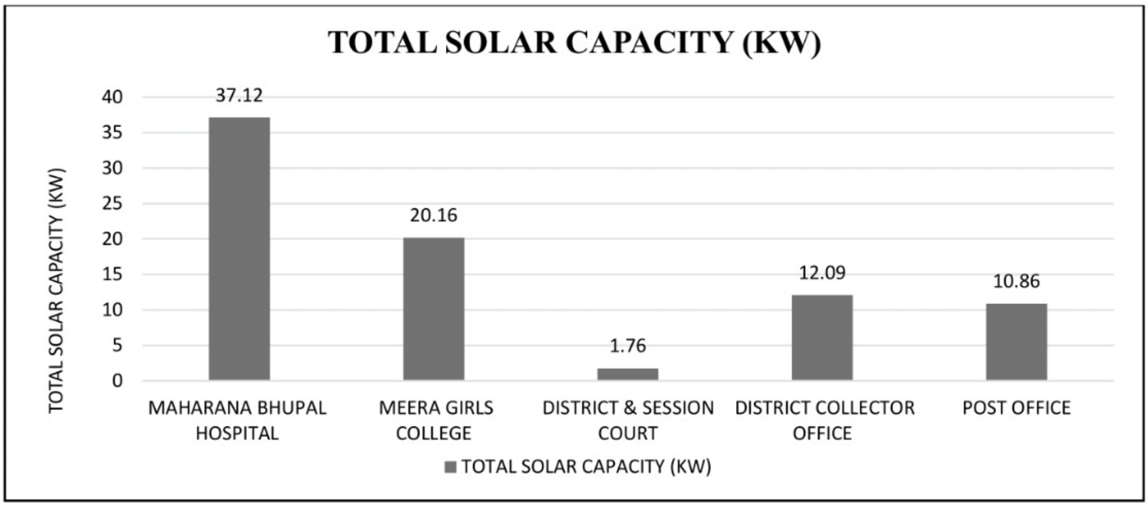
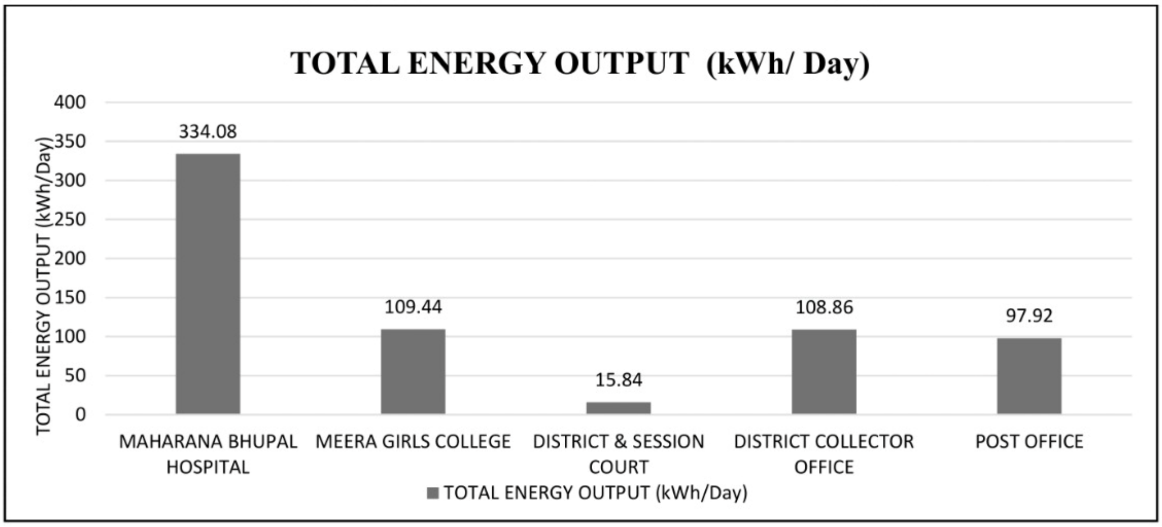


Sr.No.	Building Name	Total Solar Capacity (KW)
1	Maharana Bhupal Hospital	37.12
2	Meera girls college	20.16
3	District & session court	1.76
4	District Collector office	12.09
5	Post office	10.86
6	Total Production	81.99



Sr.No.	Building Name	Total Energy Output (kWh/Day)
1	Maharana Bhupal Hospital	334.08
2	Meera girls college	109.44
3	District & session court	15.84
4	District Collector office	108.86
5	Post office	97.92
6	Total Production	666.14

Based on Helioscope simulation for the selected buildings, detailed energy estimation was performed to evaluate the expected solar energy generation potential. The key parameters considered for energy simulation include panel tilt, azimuth orientation, panel size, solar insolation data for the proposed solar setups across the five government buildings:

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The panel tilt was optimized at 10^0, the azimuth orientation was set at 340^0(Northwest-facing) to maximize solar capture and Direction was aligned from Northeast to Southwest (NE-SW) for best exposure.

The simulation resulted in a Total Solar Capacity (TSC) of 81.99 kW/h across all rooftops. The estimated the estimated Total Energy Output (TEO) from the proposed system is approximately 666.14 kWh/day, assuming average irradiance levels and operational efficiency. These values represent a considerable improvement in renewable energy utilization and demonstrated the potential of leveraging ideal gov. building rooftop for clean energy generation.

V. CONCLUSION

The results indicate the selected rooftops together could generate approximately 666 kWh/day, which if implemented could substantially reduce the dependence of these government institutions on conventional electricity sources. Among the analysed buildings, Maharana Bhupal Hospital and Meera Girl's College emerged as the most promising sites due to their large, unshaded rooftops and high energy requirements. On the other hand, smaller institutions such as the District and Sessions Court offered limited potential, yet even these contribute meaningfully when viewed as part of the collective capacity. Beyond the numerical results, this study emphasizes the role of government buildings as ideal candidates for rooftop solar adoption. Their continuous electricity demand, large rooftop surfaces, and public significance make them demonstration sites that can set an example for residential, commercial and institutional stakeholders in the city. Successful implementation of rooftop solar system in these buildings would not only reduce electricity costs but also create visible models of sustainable energy use, thereby encouraging widespread adoption across Udaipur. Another important contribution of this study lies in the methodology itself. The integration of DSM-based insolation mapping, rooftop suitability classification, and Helioscope simulation provides a replicable framework that can be applied to other wards of Udaipur and similar urban centres in India. This approach ensures that rooftop potential is not just estimated theoretically but is supported by realistic simulation of panel layouts, orientation, and daily energy output. However, the study also recognizes its limitations. The analysis was based on satellite-derived DSM data and did not account for temporary or seasonal shading variations, which may slightly alter solar potential. Moreover, economic feasibility, payback period, and grid integration challenges were beyond the scope of this research but remain crucial factors for implementation. Addressing these aspects in future studies would provide a more comprehensive understanding of the practicality of rooftop solar deployment. In conclusion, this study reaffirms that rooftop solar adoption in Udaipur is not only technically feasible but also highly desirable for advancing sustainable urban development.

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