ASSESSING POTENTIAL SOLAR SITE SUITABILITY IN PALAKKAD DISTRICT USING GIS AND AHP METHODS

DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD MASTER OF SCIENCE IN GEOGRAPHY

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PALAKKAD

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CERTIFICATE

This is to certify that dissertation "**Assessing Solar Site potential Suitability in Palakkad District Using GIS and AHP Methods**" is a bonafied work prepared by NITHIN ANDREWS X under the guidance of Dr. INDU T K, Assistant Professor, Department of Geography, Yuvakshetra Institute of Management Studies and submitted to Calicut University as a partial fulfilment of the Masters of Science in Geography during the year 2022-2024 and no part of this work has been submitted for any other degree or certificates earlier.

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DECLARATION

I, hereby declare that the project entitled "**Assessing Solar Site potential Suitability in Palakkad District Using GIS and AHP Methods**" which is submitted to the Department of Geography, Yuvakshetra Institute of Management Studies, under University of Calicut. This bonafied record of project work carried out by me, under the supervision and guidance of Dr. INDU T K, Assistant Professor, Department of Geography, Yuvakshetra Institute of Management Studies, is for the partial fulfilment of requirement for the Masters of Science in Geography, and it has not previously formed the basis for the award of any degree, diploma, fellowship or any other similar title as recognition.

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CHAPTER 1

INTRODUCTION

Identifying suitable sites is a crucial component of developing distributed energy resources such as solar. The site suitability refers to the degree to which site is suitable or appropriate for a particular use or purpose. While considering site suitability for a solar power plant installation, it involves evaluating factors such as solar resources, the availability of land, Climatic conditions, topography, access to transmission lines and so on. The analysis of site suitability typically involves a systematic evaluation of these factors to identify potential sites that are most suitable for the desired use. For instance, solar radiation data can be utilized to assess the solar resource potential of a location, while topographic data can help evaluate the land's slope and flatness. Considering all these factors ensures that the installation is as cost-effective, efficient, and environmentally sustainable as possible.

1.1 RENEWABLE ENERGY

Renewable energy is becoming increasingly essential in today's world due to its numerous advantages over non-renewable energy sources. Non-renewable sources, such as fossil fuels, coal, and natural gas, are limited in supply and their extraction and use have caused significant environmental damage. The extraction and combustion of these fossil fuels have contributed to global warming, air pollution, and water contamination. Conversely, renewable energy sources are sustainable, non-polluting, and abundantly available in nature. These include solar, wind, geothermal, hydroelectric, and biomass energy.

Renewable energy is generated through natural processes that are continually replenished, making it a highly sustainable long-term solution to the world's energy needs. The use of renewable energy can provide numerous benefits to the economy, society, and the environment. Economically, it can create a multitude of jobs in various sectors, from manufacturing and installation to maintenance and research. It can also reduce energy costs over time, as renewable technologies become more efficient and widespread.

Renewable energy technologies have seen significant advancements in recent years, making them more efficient, cost-effective, and reliable. Solar energy, for instance, is plentiful and can be harnessed using photovoltaic panels or solar thermal technology. Wind energy is generated through wind turbines, which are becoming increasingly efficient and cheaper to produce. Geothermal energy, sourced from the Earth's core heat, can be utilized for electricity generation or building heating. Hydroelectric power is derived from the energy of moving water, such as through dams and turbines. Biomass energy is produced from organic materials like wood chips, crop waste, or animal waste.

Renewable energy offers an excellent alternative to non-renewable sources and can significantly reduce global dependence on fossil fuels. It is crucial for a sustainable future, and countries worldwide are investing in renewable energy technologies to meet their energy demands. By embracing renewable energy, we can lower our carbon footprint, mitigate the adverse effects of climate change, and preserve the environment for future generations.

1.1.1 BENEFITS OF RENEWABLE ENERGY

Renewable energy has several benefits, including improving the reliability, security, and resilience of the national power grid. It also helps reduce carbon emissions and air pollution resulting from energy production and creates economic development opportunities and jobs in the manufacturing and installation sectors. Moreover, renewable energy is considered the most eco-friendly source of energy as it does not emit carbon dioxide, which is a primary contributor to global warming, unlike fossil fuels.

Renewable energy sources produce little to no greenhouse gases or pollutants, helping to reduce air and water pollution and combat climate change. Investment in renewable energy creates jobs in manufacturing, installation, and maintenance, stimulating local economies. Technological advancements have significantly reduced the costs of renewable energy, making it more competitive with traditional energy sources. Long-term, renewables can lead to lower energy bills for consumers. Utilizing local renewable energy resources reduces dependence on imported fuels, enhancing national energy security.

1.1.2 TYPES OF RENEWABLE ENERGY

There are several types of renewable energy sources available today, each with unique methods of harnessing natural processes to generate power. Solar energy is produced by the sun and can be converted into electricity using photovoltaic panels or concentrated solar power systems. Concentrated Solar Power (CSP) systems use mirrors or lenses to focus sunlight onto a small area to produce heat, which is then used to generate electricity through a steam turbine. Wind Energy generated by capturing the kinetic energy of wind using wind turbines. These turbines convert wind movement into mechanical power, which is then converted into electricity. Wind farms can be located onshore or offshore.

Hydroelectric Energy Produced by the energy of moving water. This is typically achieved by building dams to create reservoirs. Water released from the reservoir flows through turbines, generating electricity. There are also run-of-the-river systems that divert a portion of river flow through turbines without the need for large dams. Geothermal Energy Obtained from the Earth's internal heat. Geothermal power plants drill wells into geothermal reservoirs to access steam or hot water, which is then used to drive turbines and generate electricity. Geothermal energy can also be used directly for heating buildings and other applications. Biomass Energy Generated from organic materials such as wood, agricultural residues, or waste. Biomass can be converted into biofuels like biogas or biodiesel, or it can be burned directly to produce heat and electricity. Biomass energy helps in managing waste and reducing greenhouse gas emissions. Ocean Energy Derived from the movement of ocean waves, tides, and currents. Technologies to harness ocean energy include: Tidal Turbine Similar to underwater wind turbines, they capture energy from tidal currents. Wave Energy Converters Devices that capture the energy of ocean waves. Ocean Thermal Energy Conversion (OTEC) Uses the temperature difference between warmer surface water and colder deep water to generate electricity. Each of these renewable energy sources contributes to a sustainable energy mix, reducing dependence on fossil fuels, lowering greenhouse gas emissions, and providing clean, reliable power for the future.

1.1.3 IMPORTANCE OF RENEWABLE ENERGY

The global crisis on conventional sources of energy has enforced each nation to deliberate on alternative energy resources. In recent years, energy demands for nations like India have amplified many folds due to speedy urbanization and industrial growth. India is one of the highest populated country in the world. The country needs vast energy resources in the coming decades for electricity generation. Power sector plays a important role in the growth of Indian economy. Renewable energy sector in India emerged as an integral part of solutions to meet the nation’s energy needs and essential player for energy access. To cater to the rising energy demands India has set up an independent ministry for alternative energy resources. The ministry of new and renewable energy (MNRE) has taken several steps for clean energy. The largest renewable capacity expansion programme in the world being taken up by India.

1.1.4 SOLAR ENERGY

Solar energy is an abundant and clean renewable resource that is increasingly replacing non-renewable energy sources. It is one of the most environmentally friendly energy options available, with minimal negative impact on the environment. The growing energy demand necessitates the development of solar power plants, complementing the diverse mix of current energy supplies. Solar power generation has become one of the fastest-growing sectors within renewable energy. It is affordable, has low operating costs, and boasts low construction expenses and efficient power distribution networks. Solar transmitters are strategically located near road networks, power lines, areas with high solar potential, and human settlements.

Being a tropical country, lying north of the equator, solar energy is one of the readily available renewable energy resource options to meet this need. most agreeable ways to strike a balance between energy service delivery and a clean environment is by utilization of renewable energy (RE) sources. Besides the fact that they are sustainable, being replenished freely by nature, their greater advantage is that they produce little or no by-products like the carbon emission. For the sustainable development the nation wants to improve its energy potential due to being fastest-growing economies in the world. There are several alternative energy sources like solar.Therefore, it is required to identify the suitable locations for establishing the photovoltaic (PV) energy resources with respect to techno economic and environmental feasibility

1.2 REMOTE SENSING AND GIS IN RENEWABLE ENERGY

Remote sensing (RS) and the geographic information system (GIS) were widely applied for the site-selection purposes and the identification of new possible locations for solar power facilities using processing, modeling, analyzing, and visualizing spatial data sources.By identifying areas with high solar irradiance and suitable land characteristics, solar energy potential assessments can guide the selection of ideal sites for solar power plant development. Maximizing energy production by understanding the solar resource potential of a particular location, developers can design solar energy systems that are optimized for maximum energy output. Through this Informing investment decisions, Accurate solar energy potential assessments can provide valuable insights for investors, enabling them to make informed decisions regarding the feasibility and potential return on investment for solar energy projects. Developing effective solar energy policies: By understanding the spatial distribution of solar energy resources, policymakers can formulate targeted policies and incentives to promote solar energy adoption in regions with high solar potential. Many researchers have used the GIS based and MCDA methods to delineate the site selection of solar power plants. Site suitability analysis means finding potential locations for a solar PV installation. ArcGIS is a decision support tool for proposing suitable sites to government. Finding suitable locations for a solar PV installation enables increasing the efficiency of a solar PV power system. The analytical hierarchy process (AHP) was applied to categorize the site suitability process in the earth’s crust. This includes pair-wise comparison procedures and multi-criteria decision analysis (MCDA) to demarcate the biophysical, socio-economic, and physical principles. he weighted overlay method (WOM) through the AHP approach delivers exact, strong results for suitable site selection of an area. This technique was used for suitable site selection, established with numerous criteria through quantitative valuation. The AHP, MCDA, and WOA approaches were widely used for different purposes, like hospital site selection, potential groundwater-zone selection, landslide-susceptibility analysis, potential plantation areas, potential sites for building contracts, paddy production, and many other environment-related investigation. These methods were used to identify potential sites based on the particular criteria. Not only AHP, but many other methods, like the fuzzy analytical hierarchy process (FAHP), logistic regression, random forest, support vector machine, and artificial neural network (ANN), were also used. satellite-derived data, such as solar radiation data, to estimate the amount of solar energy available in a specific location. By integrating this data with Geographic Information Systems (GIS), researchers and policymakers can create comprehensive solar energy potential maps that can guide informed decision-making regarding solar energy project development and planning. The growing demand for clean energy has propelled solar energy to the forefront of renewable energy solutions.A suitable site for solar installation depends not only on the amount of solar radiation received, but also on other technical, economical, environmental, and social factors such as local topography, the need to conserve protected areas, environmental impact, water availability, and urban development. Therefore, site selection is not simple. All of these factors as well as the scope for expansion, proximity to urban areas and roads, and ac cess to power grids need to be consider.

1.3 STATEMENT OF THE PROBLEM

Kerala’s present electricity demand Need increases. Kerala is currently facing a challenge in meeting its rising electricity needs. Electricity generation capacity struggles to keep pace with the rising demand. The state has witnessed a significant surge in power consumption, particularly during the summer Increased economic activity and a growing population have led to a rise in electricity consumption. This is attributed to factors like increased use of air conditioners and overall economic growth. In the year 2018-19 the energy consumption is 21750.25 MU. In the year 2023-24 the energy consumption is 27696.06 MU. In the 5 year gap the energy consumption highly increase around 5945.81 MU that is 27.33% increase in the energy consumption .Recent data shows daily consumption exceeding 5700 MW, pushing the grid's limits. New records have been set for daily consumption and peak demand, pushing the limits of Kerala's power grid .Kerala has crossed 5000 MW in the middle of the April in the year 2023.The power

Year	Consumption (MU)
2018-19	21750.25
2023-24	28696.06

Table 1.1 Kerala electricity consumption rate

(Source : Kerala Electricity Board)

demand has exceeded the state's expectations of 4700MW and 4600MW for April and May respective. Kerala has witnessed a 12% hike in power demand from 2022 and consumption has also increased by 8% compared to 2022.The power minister has urged the consumer to restrict power consumption during peak hours (6 pm-11 pm). We have Limited Resources for electricity generation. While Kerala depends heavily on hydropower plants, which are susceptible to fluctuations in rainfall. In Kerala the total no of Hydroelectric Plants are 42, there are 9 in working progress and Projects commissioned ,Work awarded during 2023-24 is respectively 1 and 2 . The total capacity of Hydroelectric Plants is 2096.36. Pallivasal Extension scheme and Thottiyar HEP are the main project in these. Insufficient rainfall patterns can significantly reduce hydropower generation .It does not meet the energy needs and Kerala purchases power from the national grid to meet the gap between demand and generation. It relies heavily on imported power to meet the gap. To meet the demand-supply gap, Kerala imports a large amount of power from other states. This dependence exposes the state to price fluctuations and potential supply disruptions. Kerala State Electricity Board (KSEB) faces financial difficulties, impacting investments in infrastructure upgrades and expansion of power generation capacity. So we need to focus on other sources like renewable energy sources like solar, tides and wind. There are so many initiative taken by the state and central government to push the renewable energy sources .

The amount of solar energy reaching the earth's surface is 6000 times the present global consumption of energy .and most of it remains unused for human well-being. Solar energy has an imperative role in ensuring energy security while addressing environmental concerns.Solar energy has an immense potential in a tropical country like India .So it is essential to analyze the solar energy potential for future development

1.4 AIM AND OBJECTIVES OF THE STUDY

- To identify the solar radiation in Palakkad district
- To identify the slope of the Palakkad district
- To identify the road and grid network system available in the Palakkad district
- To identify the protected forest areas that can’t support solar without the destruction of natural habitat
- To Assessing Potential Solar Site Suitability in Palakkad District

1.5 SIGNIFICANCE OF THE STUDY

- Combating Climate Change: By reducing reliance on fossil fuels, solar power significantly reduces greenhouse gas emissions like carbon dioxide, a major contributor to climate change. This helps mitigate rising global temperatures, extreme weather events, and ocean acidification.
- Preserving Ecosystems: Fossil fuel extraction and transportation can harm delicate ecosystems. Solar power eliminates these risks, protecting the biodiversity of Palakkad's unique flora and fauna.
- Land Use: Large-scale solar farms require land, but compared to traditional energy sources, they have a much smaller footprint. Additionally, solar panels can be installed on rooftops, minimizing land use impact.
- Reduced Dependence on Imported Fuels: India relies on imported fossil fuels, making it vulnerable to price fluctuations. Solar power generation lowers this dependence, stabilizing energy costs over the long term.
- Boosting Local Economies: The installation and maintenance of solar panels creates new jobs in Palakkad, stimulating the local economy and providing opportunities for skilled workers.
- Increased Property Values: Homes and businesses with solar panels can see an increase in property value due to lower energy costs and environmental benefits.
- Empowering Communities: Remote villages in Palakkad can benefit from solar power by gaining access to reliable electricity for lighting, appliances, and communication. This improves living standards and empowers communities.
- Educational Opportunities: Investment in solar technology can create educational opportunities in Palakkad, fostering a skilled workforce for the future of renewable energy.
- Improved Public Health: Reduced air pollution from solar power directly translates to improved public health. Respiratory illnesses and heart disease can decrease, leading to a healthier population.

- Grid Modernization: Integration of solar power into the grid necessitates advancements in grid management systems. This can lead to a more resilient and efficient power grid for Palakkad.
- Battery Storage Solutions: Research and development efforts are focused on improving battery storage technologies to capture and store excess solar energy. This will allow for a more reliable and constant supply of renewable energy.
- Innovation in Solar Technology: As solar power becomes more prevalent, continuous improvements in solar panel efficiency and affordability are expected. This will further incentivize adoption and contribute to a cleaner future.

1.6 LIMITATION

- Intermittency: Solar power generation is dependent on sunlight, which can be intermittent due to weather conditions, seasonal variations, and day-night cycles. This intermittency can pose challenges for consistent power supply.
- Land Use: Large-scale solar power installations require significant amounts of land, which could potentially lead to conflicts with agriculture, wildlife habitats, or other land uses.
- High Initial Costs: The initial investment for solar power systems, including the cost of solar panels, inverters, and installation, can be high. This can be a barrier for widespread adoption, particularly for individuals and small businesses.
- Maintenance Costs: While solar panels have relatively low maintenance costs, the need for periodic cleaning, repairs, and component replacements (e.g., inverters) adds to the overall cost over time.
- Energy Storage: To address the issue of intermittency, energy storage solutions such as batteries are necessary. However, current battery technology can be expensive and may have limited capacity and lifespan.

- Grid Integration: Integrating solar power into the existing electrical grid can be challenging. The grid must be capable of handling variable energy inputs and may require upgrades to accommodate distributed generation.
- Inconsistent Policies: Inconsistent or unclear government policies and incentives for solar power can create uncertainty for investors and hinder the growth of the solar industry.
- Permitting and Approval Processes: Lengthy and complex permitting and approval processes for solar projects can delay implementation and increase costs.
- Awareness and Acceptance: Lack of awareness and understanding of solar power technology among the general public and local communities can slow down adoption rates. There might also be resistance to change from traditional energy sources.
- Skill Gaps: There may be a shortage of skilled labor for the installation, operation, and maintenance of solar power systems, necessitating training programs and capacity-building initiatives.
- Manufacturing Impact: The production of solar panels involves the use of hazardous materials and energy-intensive processes, which can have environmental impacts if not managed properly.
- Waste Management: The disposal of solar panels at the end of their lifespan poses a waste management challenge, as they contain materials that need to be recycled or disposed of safely
- Microclimatic Variations: Specific microclimatic conditions in certain parts of Palakkad, such as heavy monsoons or prolonged cloudy periods, can reduce the efficiency and reliability of solar power generation.
- Topographical Challenges: Hilly or uneven terrain can complicate the installation of solar panels and infrastructure, requiring additional costs and engineering solutions
- Access to Financing: Securing financing for solar projects can be difficult, especially for small-scale or community-led initiatives. High-interest rates and lack of financial incentives can also be barriers.

1.7 METHODOLOGY

Site suitability analysis is crucial for the successful installation of solar panels. The analysis helps to identify suitable locations for solar panel installations, ensuring optimal performance and maximum energy output. By conducting site suitability analysis, potential issues that can negatively affect solar panel installations can be identified and addressed early on. This helps to reduce project costs and minimize the risk of system failure or underperformance. Ultimately, site suitability analysis is essential for maximizing the return on investment in solar energy systems and promoting the widespread adoption of renewable energy technologies. The method used is AHP (Analytical Hierarchy Process) for the factors structured decision-making tool that can be used to evaluate the importance of different factors involved in site suitability analysis for solar panel installation. AHP breaks down complex decisions into smaller, manageable parts and allows for transparent, consistent, and objective decision-making. In the study area, we aim to apply the AHP method to evaluate the site suitability of an area using different factors such as solar-radiation, slope, ,proximity to grid and proximity to road.

1.8 ANALYTICAL HIERARCHICAL PROCESS

The Analytic Hierarchy Process (AHP) is a decision-making method that allows for the prioritization and evaluation of various factors based on their relative importance. It was developed by Thomas Saaty in the 1970s and is widely used in fields such as engineering, business, and environmental management. The AHP breaks down complex decision problems into smaller, more manageable parts and allows decision- makers to compare the importance of criteria and alternatives in a structured and quantitative manner. The method uses a pairwise comparison process to determine the relative importance of criteria and alternatives, which are then weighted and aggregated to produce an overall ranking. The AHP has been applied in various fields, including landslide susceptibility assessment, where it has been used to identify and weight factors that contribute to the occurrence of landslides.

The Analytical Hierarchy Process (AHP) offers advantages over other methods that rely on assigning weights or scores to different factors. With the AHP, decision-makers are able to assign Saaty ratio scale priorities, which provides a more systematic and consistent way to determine the relative importance of each factor. This approach helps to overcome the problem of arbitrary weighting, and can lead to more accurate and reliable results in decision-making processes (Yalcin, 2008). AHP application for landslide study can be found in many scientific research studies (Chung and Leclerc, 1994; Barredo et al., 2000; Ayalew et al., 2004; Komac, 2005; Akgun and Bulut, 2007; Yalcin, 2008). The landslide susceptibility index is totally based on the AHP approach. It is also calculated on the husis of the weighted linear combination given by Voogd (1983) as equation 1, but, the Wj and Xij values are quantitatively determined by pairwise comparisons and eigenvector methods (Saaty, 1977), Saaty's proposal (2000) AHP method is used in this research to analytically assign preferences based on when comparing two attributes (layer classes, parameters in a layer, etc), the following numerical relational scale is used Table 3.8 Pairwise comparison matrix with scores.

Scales	Degree of preferences	Explanations
1	Equally	Two activities contribute equally to the objective.
3	Moderately	Experience and judgment slightly to moderately favor slightly on activity over another.
5	Strongly	Experience and judgment strongly or essentially favor strongly or essentially favor one activity over another
7	Very strongly	An activity is strongly favored over another and its dominance is showed in practice
9	Extremely	the evidence of favoring one activity over another is of the highest degree possible of an affirmation
2,4,6,8	Intermediate values	Used to represent compromises between the references in weights 1,2,3,7 and 9
Reciprocals	Opposites	used for inverse comparison

Table 1.2 Scale between Two Parameters In AHP (Saaty,2000)

The AHP method has the advantage of being able to evaluate pairwise rating inconsistency, which is an important feature. By using the eigenvalue technique, it is possible to calculate a consistency measure that provides an approximate mathematical indication of any inconsistencies or intransitivity in a set of pairwise ratings. According to Saaty (2000), whies a reciprocal matrix is consistent, the largest eigenvalue (Mas) is equal to the number of comparisons made (n), or Max. To quantify the level of consistency a consistency index (CI) is defined.

Cl-Amax-nn-1

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1145	1.49

Table 1.3 Random Consistency Index (Saaty,2000)

CR-CIRI

In the AHP method, after obtaining the pairwise comparison matrix, it is necessary to check the consistency of the matrix. One way to do this is by calculating the consistency ratio (CR). CR is calculated by dividing the consistency index (CI) by the random index (RI). RI is calculated based on the size of the matrix. If the value of CR is 10%, the inconsistency is considered acceptable. However, if the value of CR is 10%, it indicates that the matrix is too inconsistent and the pairwise comparison needs to be revised (Santy, 1977). Checking the consistency of the matrix is important to ensure the validity and reliability of the results obtained from the AHP method.

1.9 SOFTWARE USED

ArcGIS is a renowned software in the field of geographic information system (GIS) that has been developed by ESRI (Environmental Systems Research Institute). It is extensively utilized in various fields, including geography, natural resource management, urban planning, and environmental science, to comprehend spatial patterns and relationships, tackle intricate problems, and make knowledgeable decisions

EXCEL: Excel is a spreadsheet software developed by Microsoft Corporation. It is used for organizing, manipulating, and analyzing data using a grid of cells arranged in rows and columns. Excel provides a wide range of tools and functions for performing calculations, creating charts and graphs, and performing data analysis. Excel is also commonly used for creating budgets, financial statements, data visualizations, and project plans

1.10 DATA USED

Solar radiation data, essential for evaluating the solar energy potential, was obtained from the Global Solar Atlas. This dataset offers high-resolution, accurate information on solar energy availability in Palakkad, facilitating a detailed assessment of the region's suitability for solar power generation.

Drainage and slope data were sourced from Earth Explorer. These datasets provide detailed topographical and hydrological information, crucial for determining the feasibility and optimal locations for solar power installations, ensuring the project's comprehensiveness and precision.

Grid network data was collected from the KSEB grid map. This information is vital for identifying proximity to the electrical grid, enabling efficient integration of solar power systems and minimizing transmission losses.

Road network data was obtained from the Geological Survey of India. This dataset provides essential information on transportation accessibility, which is critical for the logistics and maintenance of solar power infrastructure, ensuring efficient site selection and operational efficiency.

Geology and geomorphology data were sourced from Bhukosh. These datasets offer insights into the geological and geomorphological characteristics of the region, which are important for assessing the stability and suitability of sites for solar power installations, enhancing the project's reliability and safety.

Land Use and Land Cover (LULC) data were acquired from ESRI Sentinel data. This dataset provides comprehensive information on the current land use patterns and vegetation cover in Palakkad, essential for evaluating the environmental impact and planning the most suitable locations for solar power installations.

Forest area data offer insights into the region's ecological characteristics, including the extent and type of forest cover. This information is crucial for evaluating the environmental impact of solar power installations, ensuring minimal ecological disruption, and supporting biodiversity conservation.

Criteria	Data Source	Website
Solar Radiation	Global Solar Atlas	https://globalsolaratlas.info/
Drainage / Slope	DEM	https://earthexplorer.usgs.gov/
Palakkad Grid Network	KSEB Grid Map	https://pse.kseb.in/PSEHome/
Road	Geological Survey of India	https://www.surveyofindia.gov.in/pages/soi-brochure
Forest cover	Forest survey of India	https://fsi.nic.in/

Table 1.4 Data Sources

1.11 ORGANIZATION OF THE CHAPTER

The dissertation has been organized into 5 chapters. The first year gives general information about solar site suitability, importance of the solar energy in Palakkad district. This chapter discusses the problems, aims and objectives of this study. The second chapter focuses on the literature review. And the third chapter focus on the study area .It provides historical background information, location of Palakkad district, administration,, geology, geomorphology, drainage and land use land cover. Forth chapter sets context for the research and help the readers to to understand the characteristics and criteria of the study area that identify the solar site suitability. It deals with the data analysis and discusses the results of the research.The fifth chapter provides the summary of the study's major findings, conclusion and recommendation

CHAPTER 2

2.0 LITERATURE REVIEW

Richa Mahtta, P.K. Joshi, and Alok Kumar Jindal (2014) studied "Solar Power Potential Mapping in India Using Remote Sensing Inputs and Environmental Parameters." They assessed the potential for solar power in Indian districts using NASA's solar irradiance data and GIS analysis. The study identified suitable sites for concentrating solar power (CSP) and centralized solar photovoltaic (SPV) by excluding unsuitable areas based on land-use and topography. They considered factors like land cover, sunshine hours, and conversion efficiencies to estimate solar power potential, highlighting specific locations suitable for CSP and large-scale SPV installations.

Bijay Halder , Papiya Banik , Hussein Almohamad , Ahmed Abdullah Al Dughairi,Motrih Al-Mutiry,Haya Falah Al Shahrani and Hazem Ghassan Abdo (2021). conducted "Land Suitability Investigation for Solar Power Plant Using GIS,AHP and Multi-Criteria Decision Approach: A Case of Megacity Kolkata, West Bengal, India". This study investigated potential locations for solar power plants near Kolkata, India. Researchers used remote sensing and geographic information systems (GIS) to analyze factors like solar radiation, land use, elevation, and distance to roads. They then employed a technique called multi-criteria decision analysis (MCDA) to weigh these factors and identify the most suitable areas for solar power plants. This could significantly reduce Kolkata's reliance on fossil fuels.

Hassan Z. Al Garni and Anjali Awasthi (2017) conducted a study on "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia".Researchers used GIS to find the best places for large-scale solar power plants, analyzing factors like weather, infrastructure proximity, and environmental rules. They applied multi-criteria decision-making (MCDM) to balance economic and technical aspects, categorizing sites into five suitability classes using a Land Suitability Index (LSI) created with Analytical Hierarchy Process (AHP). In Saudi Arabia, 16% of the land was suitable, mainly in the north and northwest, aligning with roads, power lines, and cities, with good sunlight. This approach combines GIS and MCDM to select prime solar plant locations based on diverse geographic and economic factors.

M. A. Baseera, S. Rehmanb, J.P. Meyerc, Md. M. Alamd proposed " GIS-based site suitability analysis for wind farm development in Saudi Arabia"(2017) .This paper analyzes wind farm site suitability using GIS and MCDM. It considers criteria like wind resources, road access, grid proximity, and distance from settlements and airports. AHP assigns weights to these criteria based on their importance. In Saudi Arabia, the most suitable sites include Ras Tanura on the eastern coast, Turaif in Al-Jawf region, and Al-Wajh on the western coast. Central and southeastern regions are less suitable due to low wind resources and connectivity.

Yan-wei Sun a, Angela Hof b, Run Wang a,n, Jian Liu a, Yan-jie Lin a, De-wei Yang a analyze" GIS-based approach for potential analysis of solar PV generation at the regional scale: A case study of Fujian Province"(2013). The paper discusses using high-resolution solar radiation maps and various constraints to assess the potential for solar PV generation at a regional scale. It includes calculating PV generation costs based on geographical potential, using a geospatial supply curve to show available PV potential at different costs, and evaluating economic feasibility under different feed-in-tariff scenarios. The study also calculates CO2 reduction potential and emphasizes the importance of feed-in tariffs in promoting solar PV energy. Overall, it aims to enhance regional renewable energy strategies and supply/demand assessments.

Muhammad Ali Raza, Muhammad Yousif ,Muhammad Hassan, Muhammad Numan and Syed Ali Abbas Kazmi studied "Site suitability for solar and wind energy in developing countries using combination of GIS- AHP; a case study of Pakistan" (2021).The paper focuses on addressing energy scarcity and climate change in developing countries by planning for renewable energy projects, particularly solar PV and wind energy. It uses a comprehensive method involving Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS) to determine the best locations for these projects. The study incorporates eight critical criteria analyzed using the Analytical Hierarchy Process (AHP) to rank their importance. Applied to Pakistan, the results indicate that 25.28% of the area is suitable for large-scale solar PV farms, 5.93% for large-scale wind farms, and 40.02% for small-scale solar PV installations in remote areas.

Ulfat , F. Javed , F. A. Abbasi , F. Kanwal , A. Usman , M. Jahangir & F. Ahmed conducted study on "Estimation of solar energy potential for Islamabad, Pakistan" (2020).To design an efficient solar energy system, having long-term solar radiation data (20-25 years) is essential. In developing countries like Pakistan, reliable solar radiation data is often scarce, making empirical models necessary to assess solar energy feasibility. This paper presents models for Islamabad to estimate global and diffuse solar radiation. It finds that, except during the monsoon, solar energy can be used efficiently year-round. These models can be applied to other north-eastern areas of Pakistan with similar climate and solar radiation conditions but lacking solar radiation data.

Mahmoud A. Hassaan , Ahmed Hassan And Hassan Al-Dashti investigated "GIS-based suitability analysis for siting solar power plants in Kuwait" (2022). Renewable energy is preferable to fossil fuels because it's free, widely available, and has limited environmental impacts. For Kuwait and other Gulf states, clean energy is crucial for diversifying their energy sources, promoting green economies, and achieving sustainable development. This study introduces a GIS-based model for multi-criteria suitability analysis to identify the best locations for photovoltaic power plants in Kuwait. The model integrates various relevant criteria to determine suitable sites, and it also evaluates the potential electric power that can be generated from these sites.

H.S. Ruiz a,, A. Sunarso , K. Ibrahim-Bathis, S.A. Murti and I. Budiarto studied "GIS-AHP Multi Criteria Decision Analysis for the optimal location ofsolar energy plants in Indonesia"(2023). This study proposes a reliable tool for assessing suitable sites for solar power plants while protecting cultural, natural, and ecological areas. The tool uses an Analytic Hierarchy Process (AHP) based Multi-Criteria Decision Analysis (MCDA) within a Geographic Information System (GIS), incorporating satellite data and local information on land use, topography, settlements, roads, and electrical networks. Focused on West Kalimantan Province (WKP), the study faces challenges due to diverse protected areas. By using GIS spatial analysis and considering infrastructure proximity, it found that while WKP has high solar potential, only 34% of the area is suitable for solar plants when protected areas are considered. Further analysis narrows the optimal locations to just 0.07% to 0.03% of WKP, equating to 46.60 to 108.58 km², with an estimated generation capacity of 2,034 to 4,785 MW. This research provides a decision support model for large-scale solar plant development in tropical countries, balancing renewable energy goals with forest and biodiversity protection.

Roghayeh Ghasempoura, Mohammad Alhuyi Nazaria, Morteza Ebrahimia, Mohammad Hossein Ahmadib, and H. Hadiyantoc conducted a study titled "Multi-Criteria Decision Making (MCDM) Approach for Selecting Solar Plants Site and Technology (2022): A Review." The paper reviews various MCDM methods for selecting solar plant sites and technologies. It notes that no single research covers all necessary criteria, which vary by region, economy, accessibility, power network, and costs. The study emphasizes the importance of these criteria for effective solar power generation and thoroughly investigates them for site selection.

Morice R. O. Odhiambo, Adnan Abbas, Xiaochan Wang, and Gladys Mutinda conducted a study titled "Solar Energy Potential in the Yangtze River Delta Region—A GIS-Based Assessment" (2023). The research evaluates the solar energy potential in the Yangtze River Delta region (YRDR) of China using GIS analysis and high-resolution solar radiation data. The study finds that the YRDR has abundant solar energy, with suitable areas receiving 1446 to 1658 kWh/m², and an estimated maximum solar capacity potential of 4140.5 GW. Jiangsu and Anhui provinces are identified as optimal for solar PV installations. The study highlights the need for local meteorological data to align actual generated power with technical potential, aiding policymakers and investors in developing solar power in the region.

CHAPTER 3

GEOGRAPHICAL PROFILE STUDY AREA

3. INTRODUCTION

This chapter focuses on assessing the solar potential and site suitability for Palakkad, Kerala . The chosen area is located in southwestern India. and receives an average annual solar radiation of 4.92 kWh/day, making it a promising region for solar energy development. The growing demand for clean energy and government policies promoting renewable energy sources motivated the selection of this particular study area. The study area is dominated by Agriculture**.** A significant portion of Palakkad falls under arable land, including both irrigated and unirrigated fields. This makes agriculture a major activity in the district. The Western Ghats bordering the north and south of Palakkad harbor tropical evergreen forests. However, some forested areas have been converted to plantations for crops like tea, pepper, rubber, and eucalyptus. A comprehensive analysis of various factors will be employed to identify the most suitable locations for solar energy systems within this area.

3.1 GEOGRAPHICAL LOCATION

Palakkad, also known as Palghat situated within the latitudes stretching from 10° 21' to 11° 14' north and longitudes stretching from 76° 02' to 76° 45' east.It has a total area of about 4490 sq.km.It is located in the southeastern part of the state, bordering Tamil Nadu. Palakkad is often referred to as the gateway to Kerala due to the presence of the Palakkad Gap, a natural mountain pass in the Western Ghats that connects Kerala to Tamil Nadu. Palakkad district bounded on the north by malappuram district, on the east by Coimbatore District and Tiruppur District of Tamil Nadu , on the south by by Thrissur District and west by lakshadweep sea.

3.2 HISTORICAL BACKGROUND

The ancient history of Palakkad is shrouded in mystery.the Pallava dynasty of Kanchi might have invaded Malabar in the second or third century AD. One of their headquarters was a place called ‘Palakada’ which could be the present-day Palakkad.Malabar was ruled by many ancient South Indian rulers. For centuries, it was governed by the Perumals, who had powerful local leaders called 'Utayavars' overseeing different areas. After the Perumal rule ended, the region was divided among these chieftains. The main rulers after the Perumals were the Valluvakonathiri (ruler of Valluvanad), the rulers of Vengunad (Kollengodu Rajas), and Sekharivarma Rajas of Palakkad.The Zamorins of Calicut invaded Palakkad in 1757, but were repelled with the help of Hyder Ali of Mysore.Hyder Ali and his son Tipu Sultan conquered Palakkad, bringing it under Mysore rule.ThenThe British East India Company (18th-20th Centuries) defeated Tipu Sultan, acquiring Malabar including Palakkad. Palakkad became part of the Madras Presidency. Following India's independence, Kerala state was formed in 1956.The present-day Palakkad district was created in 1957 by merging various taluks. There have been some boundary adjustments since then, with the formation of Malappuram district in 1969.

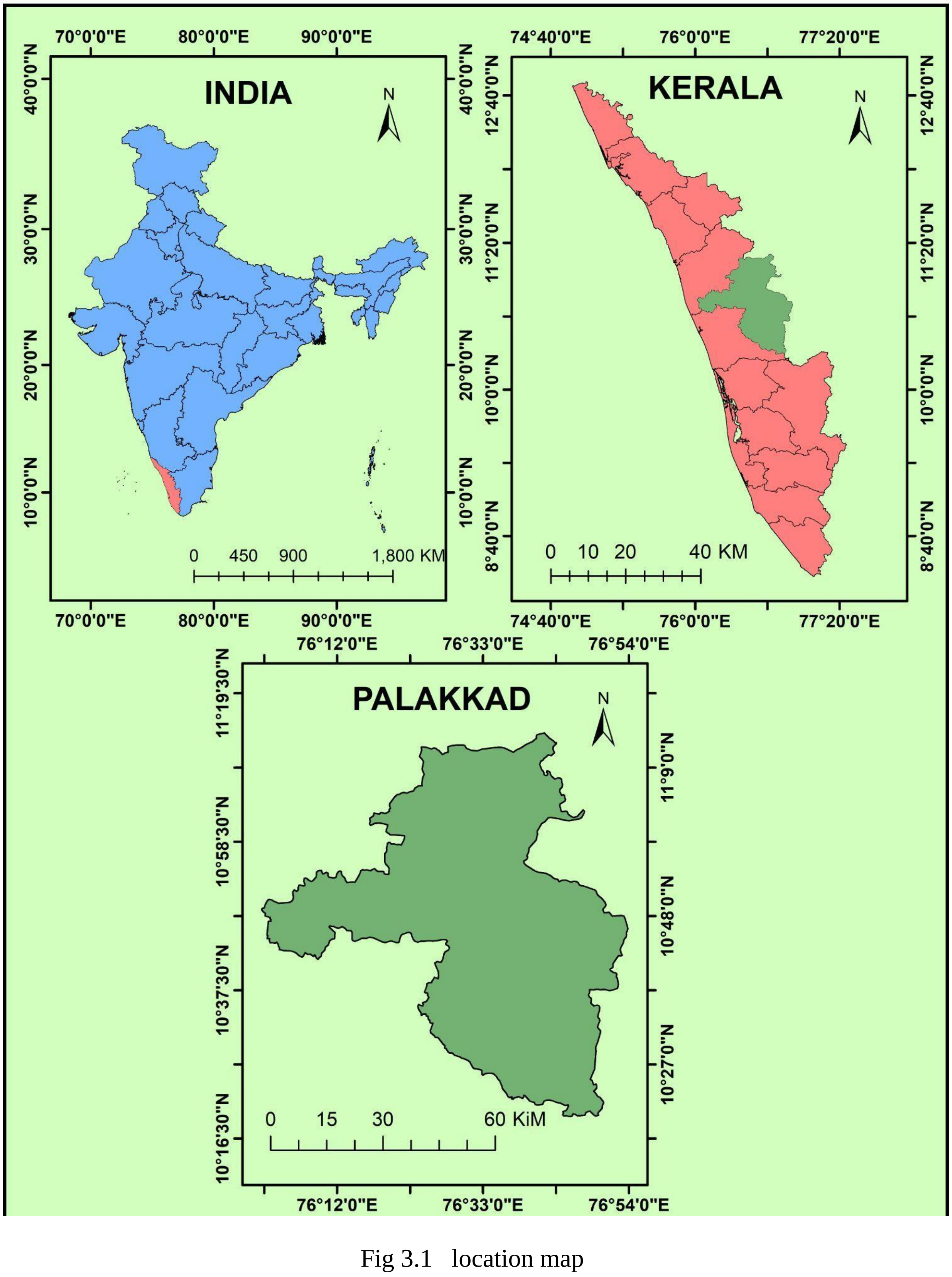

Fig 3.1 location map

(Source : Survey of India)

3.3 ADMINISTRATION

Palakkad district is divided into 6 taluks,13 development blocks and 91 gram panchayats for administrative purposes. In Palakkad district, the urban administrative units include one corporation ,Palakkad Corporation and three Municipalities namely Chittur-Thathamangalam Municipality, Ottappalam Municipality,Shoranur Municipality. Out of the 4490 sq.km approximately 140 square kilometers.area under urban administration and remaining 4,350 square kilometers covers rural area.As per the 2011 Census of India, Palakkad district has a population of approximately 2,810,892..Urban Population Approximately 854,000 and Rural Population Approximately 1,956,892. district has a population density of approximately 627 inhabitants per square kilometer.As in case of many district in kerala sex ratio of about 1069 females for every 1000 males, indicating that there are more females than males in Palakkad district.the decadal population growth rate for Palakkad district between 2001 and 2011 was approximately 7.39%..the literacy rate for Palakkad district Approximately 88.49%.

Sl no	Name of taluk	Population	Taluk headquarters
1	Alathur	342,947	Alathur
2	Chittur	343,442	Chittur
3	Mannarkkad	393,238	Mannarkkad
4	Ottappalam	502,079	Ottappalam
5	Palakkad	716,184	Palakkad
6	Pattambi	414,002	Pattambi

Table 2.1 Administrative division

(Source : Census of India 2011)

3.4 PHYSIOGRAPHY

The Palakkad district is located in the central region of Kerala and is bordered by the Malappuram district to the northwest, the Thrissur district to the southwest, the Nilgiris district to the northeast, and the Coimbatore district of Tamil Nadu to the east. The district is known for its diverse topography, including hills, forests, rivers, and waterfalls.Based on physiographic nature Kerala is divided in to three regions namely highland ,midland and lowland .palakkad mainly fall into highland Elevation > 250 m (820 ft) Includes the Nelliyampathy-Parambikulam area in the south and the Attappadi-Malampuzha area in the north.The highest point in Palakkad district is located within the Western Ghats,in the Nelliyampathy Hills. which reaches an elevation of approximately 1,580 meters (5,180 feet) above sea level. And midland Elevation 75-250 m (246-820 ft),Covers most parts of the district.Palakkad district is mostly flat with some undulating terrain.It is known as the "rice bowl of Kerala" due to its fertile plains. primarily consists of flat and gently undulating terrain. The landscape is characterized by extensive plains interspersed with low hills and occasional ridges. These plains are highly fertile, making them ideal for agriculture, especially rice cultivation. The district is often referred to as the "Granary of Kerala" due to its abundant agricultural productivity.To the east of Palakkad district lie the Western Ghats, a mountain range that runs parallel to the western coast of India. These mountains serve as a prominent geographical feature, influencing the district's climate and ecology. the Western Ghats, stretching for hundreds of kilometers. But in Palakkad, this wall takes a dramatic break, creating a 30-kilometer-wide passage called the Palakkad Gap. This natural wonder acts as a gateway between Kerala and Tamil Nadu, allowing for easier travel and trade. Interestingly, the Gap also influences Palakkad's climate, making it drier than the rest of Kerala.Palakkad district is crisscrossed by several rivers and streams, the most significant being the Bharathapuzha (River Nila). The Bharathapuzha originates from the Western Ghats and flows westwards across the district, eventually draining into the Arabian Sea. Other notable rivers include the Kalpathi Puzha, Gayathripuzha, and Kannadipuzha, all of which contribute to the district's irrigation and agricultural needs.Palakkad experiences a tropical wet and dry climate influenced by its proximity to the Arabian Sea and the Western Ghats. The region typically has hot and humid summers, with temperatures often exceeding 35°C during the peak months. Monsoons bring heavy rainfall between June and September, vital for agriculture. Winters are relatively mild and dry.The vegetation of Palakkad district varies from tropical dry broadleaf forests in the foothills of the Western Ghats to agricultural landscapes dominated by coconut palms, paddy fields, and plantations of crops like banana and tapioca. The fertile plains and ample water resources support a diverse range of crops, making agriculture the primary occupation of the local population.palakkad district is culturally vibrant, with a rich heritage of temples, festivals, and traditional art forms. The region's cultural identity is closely tied to its agrarian roots and historical significance. Agriculture remains the backbone of the local economy, supplemented by small-scale industries and tourism, especially eco-tourism focused on the Western Ghats and its biodiversity.

3.5 RAINFALL AND CLIMATE

Palakkad experienced annual rainfall of 2824 mm in the year 2020.Palakkad experiences significant rainfall, especially during the monsoon seasons. The region receives rainfall from both the southwest monsoon (June to September) and the northeast monsoon (October to November). Here are some general statistics on the rainfall in Palakkad.Palakkad receives an average annual rainfall of approximately 2,200 to 2,500 mm.Palakkad receives significant rainfall during the southwest monsoon season. The monsoon is typically heavy, with June and July receiving the most rain. The Western Ghats enhance the rainfall due to orographic lift.This period is crucial for agriculture, replenishing water resources and supporting the lush vegetation.The primary rainy season is Southwest Monsoon:, contributing the majority of the annual rainfall.Northeast Monsoon: Brings additional rain, less than the southwest monsoon, helping to extend the wet season and further support agricultural activities.

The mountain range enhances the rainfall through orographic lift, especially on the windward side. This effect is particularly pronounced in areas like Attappadi and the Nelliyampathy hills.Palakkad Gap,this low mountain pass influences the distribution of rainfall. While the district generally receives ample rain, the presence of the gap can lead to localized variations.

Rainfall of palakkad divided into seasons . 1-Summer (March to May),Minimal rainfall, occasional pre-monsoon showers,2-Southwest Monsoon (June to September) Heaviest rainfall of the year, averaging 1,800 to 2,200 mm,3-Post-Monsoon (October to November)Additional 200 to 300 mm of rainfall from the northeast monsoon.4-Winter (December to February) Minimal rainfall, mostly dry.The rainfall intensity decreasing from west to east . Western areas like Ottapalam regions have high annual rainfall (2500-2800) when it compared to eastern regions of palakkad

3.6 TEMPERATURE

The minimum temperature ranges between 21 and 24 degree Celsius and the maximum between 30 to 32 degree Celsius .The temperature reaches its peak in the month of May and January and February are considered the most pleasant with average temperatures around 25°C .Daytime Temperature Typically ranges from 32°C to 40°C..high temperature mainly concentrated on mid area of Palakkad and it decrease towards north and south sides

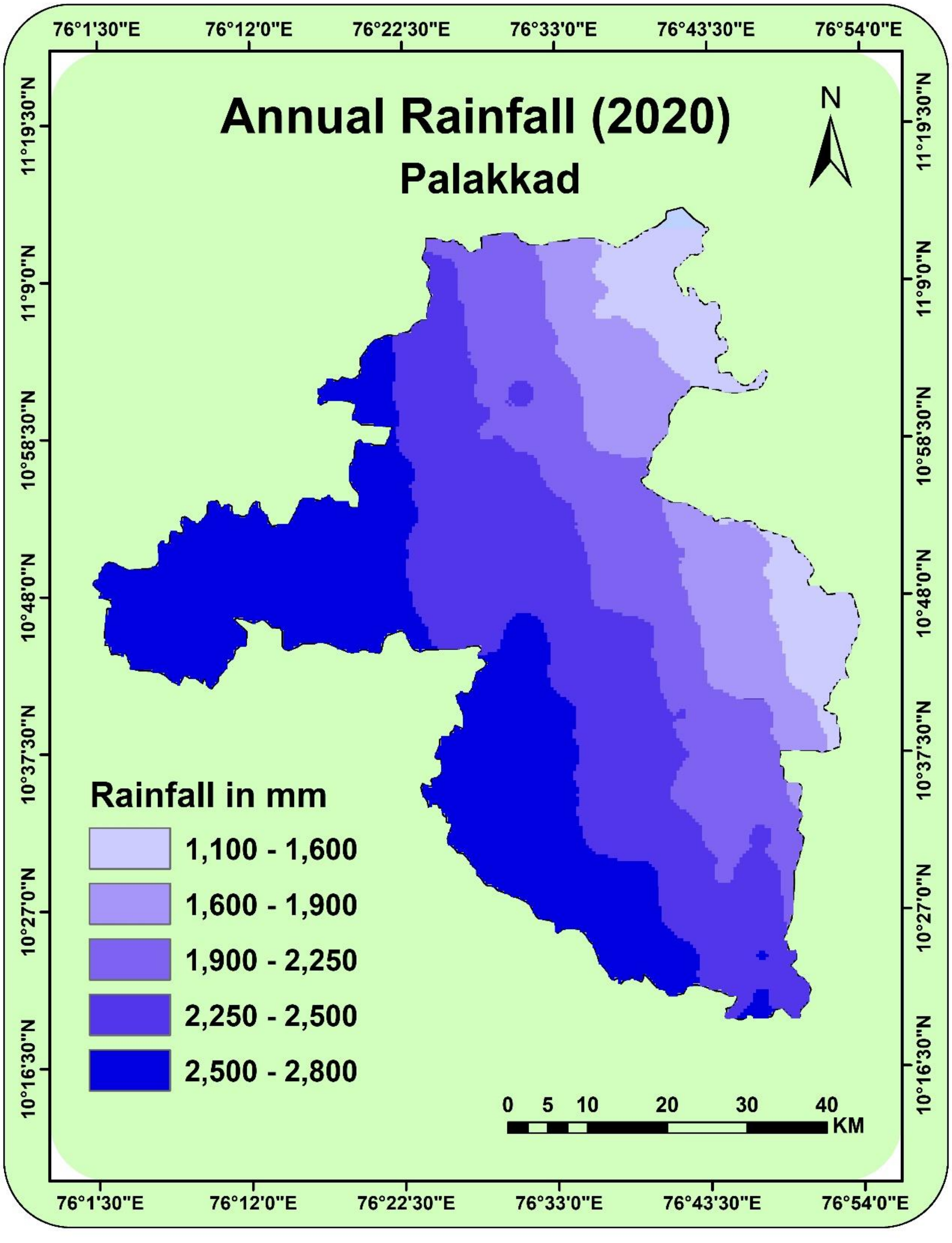

Fig 3.2 Palakkad Annual Rainfall

(Source : Google Earth Engine ,2020)

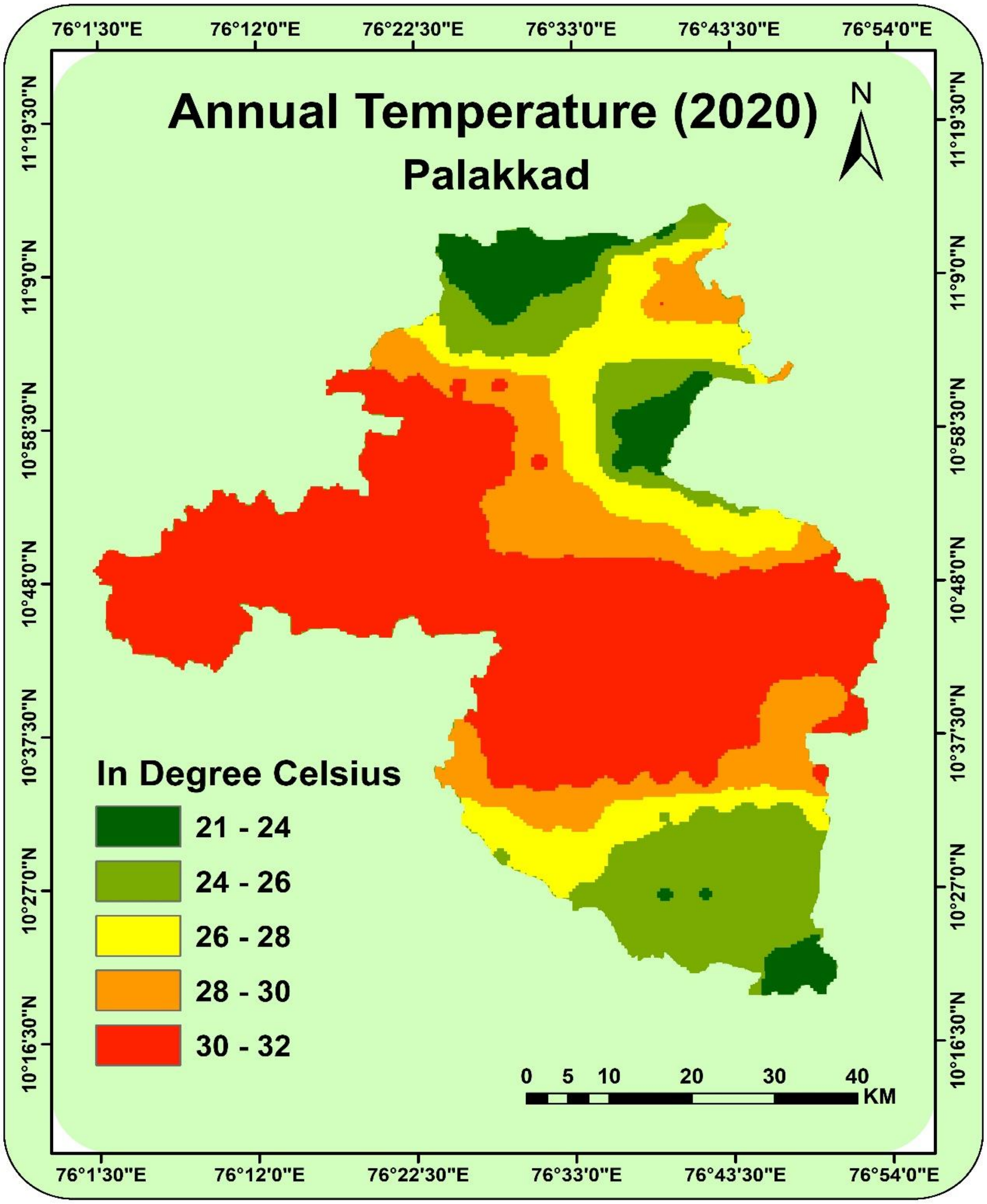

Fig 3.3 Palakkad Annual Temperature

(Source : Google Earth Engine ,2020)

3.7 GEOLOGY

Palakkad district in Kerala, India, exhibits a diverse geological composition with several significant formations. Key geological groups include the Charnockite Group, Khondalite Group, Migmatite Complex, Peninsular Gneissic Complex, and Sathyamangalam Group.The Charnockite Group consists primarily of charnockite, a hard, dark-colored rock containing quartz, feldspar, and hypersthene. Found in the Western Ghats and eastern Palakkad, charnockite forms under high-grade metamorphic conditions and contributes to the district's rugged terrain and elevated landscapes. Khondalite rocks, rich in quartz, feldspar, and garnet, form under intense heat and pressure. These high-grade metamorphic rocks are typically associated with granulite facies and are found alongside charnockites, adding to the region's geological complexity. Migmatites, mixed rocks with igneous and metamorphic characteristics, display alternating bands of light and dark minerals. They form through partial melting and recrystallization during high-grade metamorphism, resulting in a heterogeneous appearance. The Peninsular Gneissic Complex includes ancient gneisses, granites, and schists composed of quartz, feldspar, and biotite. These rocks, formed over 2.5 billion years ago during the Archaean Eon, have undergone multiple phases of metamorphism and deformation, underpinning much of Palakkad's geology. The Sathyamangalam Group, found in the southern and southeastern parts of Palakkad, includes metamorphic rocks like quartzites, schists, and amphibolites. These rocks formed under high temperature and pressure, often associated with charnockites and gneisses, adding to the region's geological diversity.

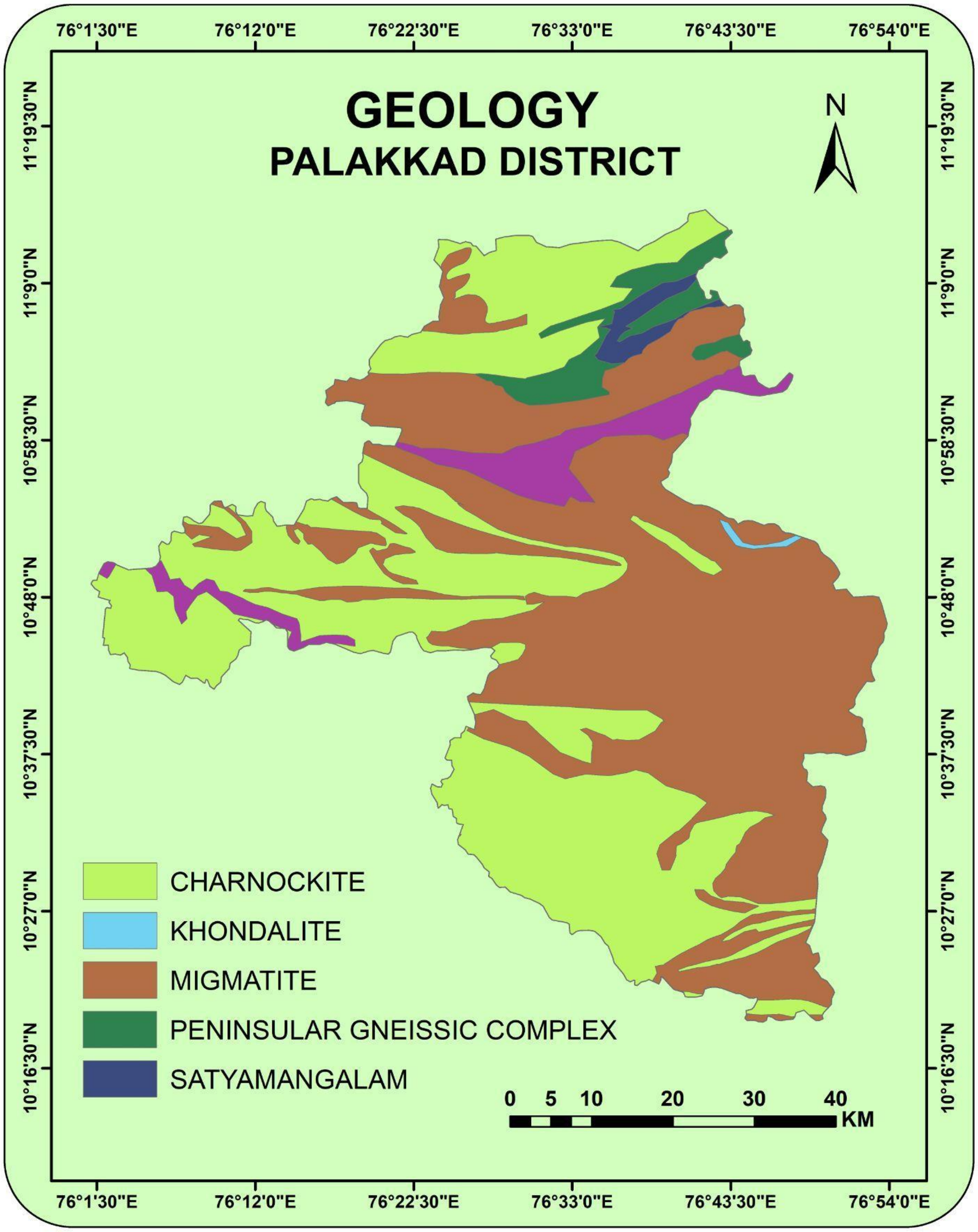

Fig 3.4 Palakkad Geology

(Source: bhukosh, Geological Survey of India)

3.8 GEOMORPHOLOGY

Palakkad, located at the foothills of the Western Ghats in Kerala, has a diverse and complex geomorphology featuring various landforms such as fertile plains, rolling hills, and valleys.Pediments are gently sloping rock surfaces at the base of mountains or hills, formed by weathering and erosion. In Palakkad, these are found at the base of the Western Ghats, transitioning between steep mountain slopes and flatter plains. Over time, multiple pediments merge to form extensive pediplains, which are large, flat land surfaces created by prolonged erosion and weathering. These are typical in the foothills of the Western Ghats. Denudational Hills are residual hills left behind after softer rocks have eroded away. These hills, remnants of older geological structures, are prevalent in Palakkad, showcasing the district's resistance to erosion. Similarly, Denudational Valleys are formed by the removal of surface material through erosion, often by running water. Due to high rainfall and numerous streams, these valleys are common in Palakkad. Structural Hills result from the differential erosion of various rock types, influenced by geological structures like faults, folds, and joints. In Palakkad, the Western Ghats consist of these hills, where harder rocks remain elevated while softer rocks erode away. Structural Valleys are formed along lines of structural weakness, such as faults or joints, and are more easily eroded by water. Palakkad is drained by several important rivers, including the Bharathapuzha (Nila), Kerala's second-longest river. These rivers originate in the Western Ghats and flow westward, creating a network of drainage channels shaping the landscape. Active Flood Plains are areas adjacent to rivers that frequently flood. In Palakkad, these plains are formed by the deposition of alluvium during floods and are highly fertile, supporting intensive agriculture. The flood plains of the Bharathapuzha and other rivers are crucial for the district's agrarian economy. Overall, the geomorphology of Palakkad is characterized by a variety of landforms shaped by denudational and structural processes, including pediments, pediplains, hills, valleys, and fertile floodplains. These features influence the district's agricultural productivity, biodiversity, and ecological health.

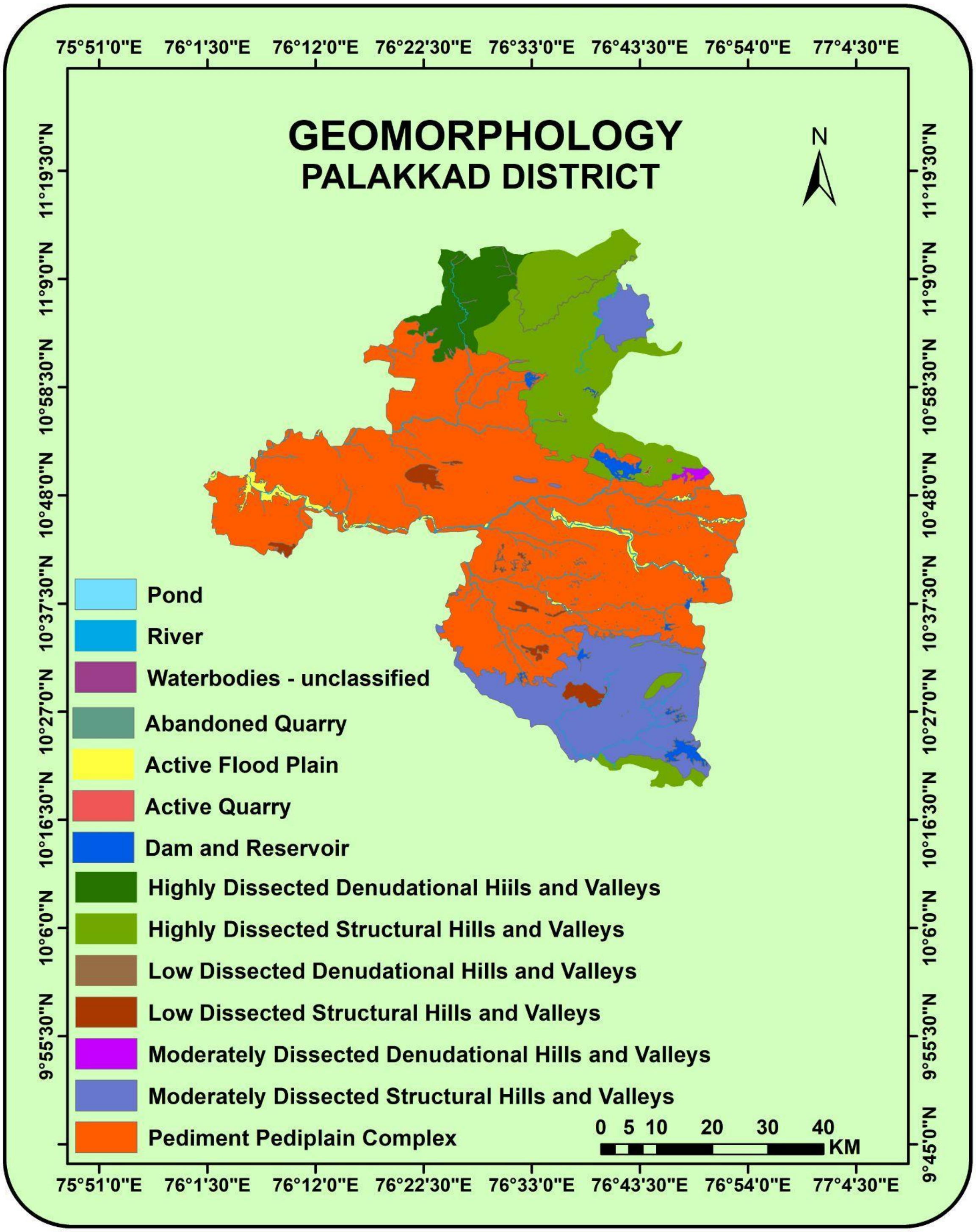

Fig 3.5 Palakkad Geomorphology

(Source: bhukosh, Geological Survey of India)

3.9 SOIL

Palakkad district features a diverse range of soil types, primarily influenced by its varied topography, climate, and underlying geology. The main soil types in the district include Laterite Soil Black Cotton Soil,Mixed Alluvium . Laterite Soil is the most widespread soil type across Palakkad, particularly in the midland and gap areas. It forms from the weathering of the underlying laterite rocks, resulting in a light grey to very dark brown color. The texture can vary from sandy clay loam to clay, with some areas also having sandy loam soils. Laterite soils have a characteristic feature of having a high groundwater table during the rainy season. This soil is Suitable for crops like cashew, coconut, and various fruits and vegetables. They require proper management for pH balance and nutrient supplementation.Its Approximate Coverage About 40-50% of the district's area. Black Cotton Soil Found primarily in the plains of Chittur taluk, these deep, black, and calcareous soils are very fertile. Their texture ranges from clay loam to clay. Black cotton soils are known for their ability to retain moisture and nutrients, making them suitable for various crops.Suitable for cotton cultivation, pulses, and certain types of cereals. However, they require careful water management due to their tendency to crack during dry periods. Its Approximate Coverage Around 10-15% of the district's area..Mixed Alluvium Is a type of soil present in patches within the alluvial plains, terraces, and undulating plains of Chittur taluk. Developed on Khondalite suite rocks, these soils are very deep and have a clay loam to clay texture. The presence of calcium carbonate (calcareous) contributes to their fertility.It Predominantly found in the river valleys and floodplains, especially along the Bharathapuzha River.It is Ideal for the cultivation of rice, banana, sugarcane, and a variety of vegetables due to their high fertility and good water-holding capacity.Its Approximate Coverage Around 20-30% of the district's area

3.10 DRAINAGE

Palakkad district has a well-developed and intricate drainage system, significantly influenced by its topography, geology, and climate. The district's rivers, streams, and canals play a crucial role in agriculture, water supply, and maintaining the ecological balance.. The Bharathapuzha is the second longest river in Kerala, stretching over 209 kilometers. The Height of Origin is Approximately 1,960 meters above sea level It originates from the Anamalai Hills in the Western Ghats and flows westward through Palakkad before emptying into the Arabian Sea.The river is vital for irrigation, supporting agriculture in its basin. It also plays a significant cultural and historical role in the region.Gayathripuzha River is the major tributary of the Bharathapuzha, the Gayathripuzha originates in the Nelliyampathy hills. It joins the Bharathapuzha near Mayannur. It contributes to the irrigation and water supply needs of the areas it traverses.The Height of Origin Approximately 1,500 meters above sea level and Length is About 80 kilometers. Kalpathi Puzha River is Another important tributary of the Bharathapuzha, the Kalpathi Puzha flows through the heart of Palakkad town and merges with the main river.It originate Approximately 1,200 meters above sea level.and Length is 30 kilometers. Thodupuzha River Originating from the Attapadi hills, the Thottapuzha is a tributary of the Bharathapuzha. It flows through a significant part of the district before joining the main river .Height of Origin Approximately 1,000 meters above sea level and Length is About 74 kilometers .Malampuzha River feeds into the Malampuzha Dam, the largest reservoir in Kerala. The river and dam are crucial for irrigation, drinking water supply, and power generation. The Malampuzha River originates from the hills of the Western Ghats near Palakkad.The Height of Origin Approximately 1,150 meters above sea level and Length is About 30 kilometers.

Most of the rivers and streams in Palakkad follow a dendritic drainage pattern, characterized by tree-like branching. This pattern is typical in regions with homogeneous rock types where the rivers cut through the landscape relatively uniformly.In the hilly and mountainous regions, such as the Western Ghats, parallel and trellis drainage patterns are also observed. These patterns are influenced by the structural control of the underlying geology.Malampuzha Dam, built on the Malampuzha River in 1955, is 115 meters high and supports irrigation, drinking water supply, recreation, and 2.5 MW of hydropower.

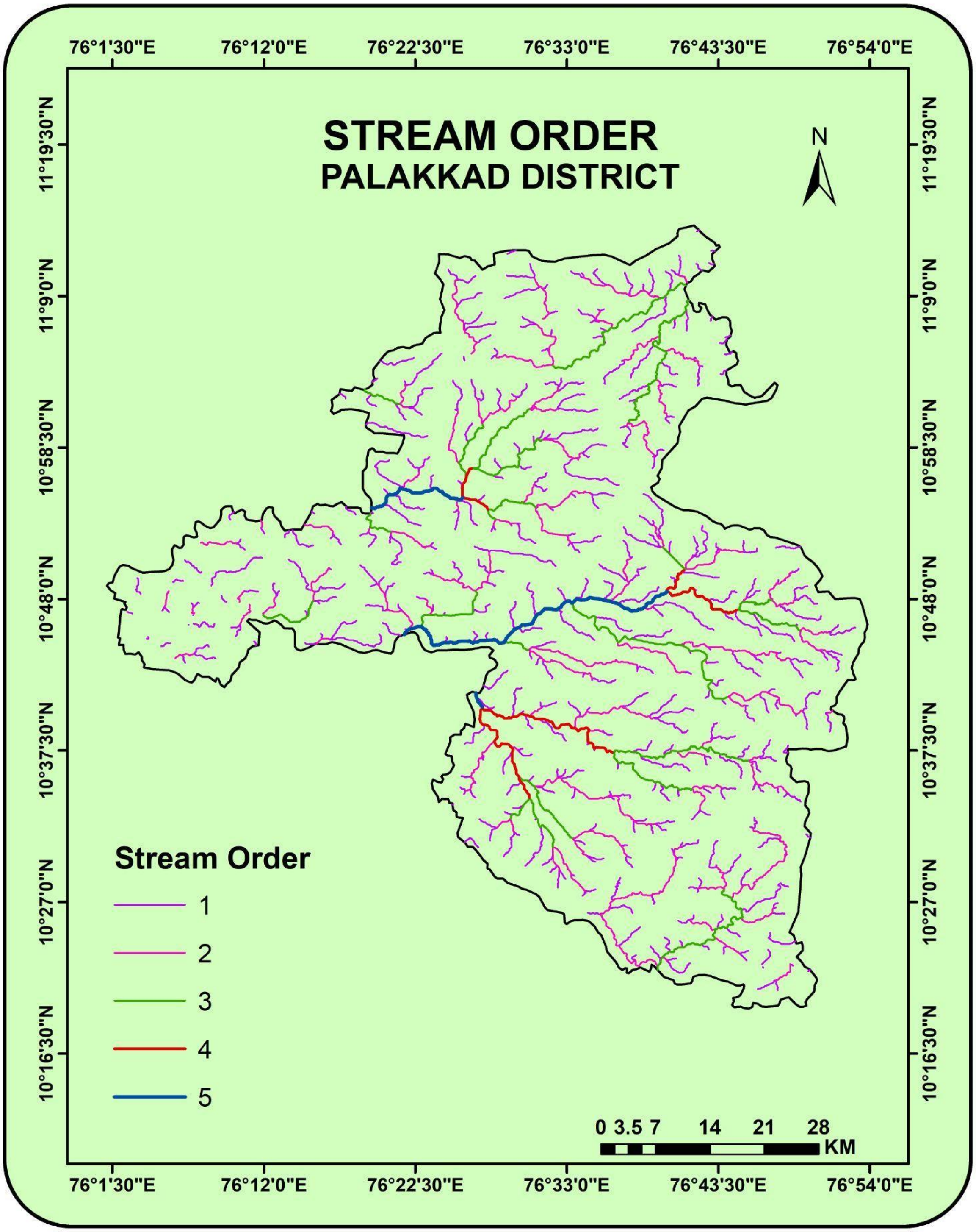

Fig 3.6 Palakkad Drainage

(Source: Srtm DEM,USGS Earth Explorer.2014)

3.11 TRANSPORTATION

The transportation network of Palakkad primarily consists of roadways and railways. Palakkad, located in Kerala, India, is well-connected by National Highways (NH 544 and NH 966) and State Highways. The Palakkad Junction is an important railway station connecting it to major cities across India.NH 544 is important highway connects Palakkad with Salem in Tamil Nadu and Kochi in Kerala. It serves as a major arterial route for both passenger and freight transport, linking Palakkad to key economic hubs.

NH 966 is Connecting Palakkad with Kozhikode (Calicut) and Thrissur in Kerala, NH 966 plays a crucial role in enhancing connectivity within Kerala's Malabar region. It supports regional trade and tourism, providing efficient access to coastal areas and urban centers.Palakkad is crisscrossed by a network of state highways and major roads that facilitate intra-district travel and connect it with neighboring districts and states.

These roads play a vital role in local transportation, ensuring accessibility to rural areas and smaller towns within the district.Palakkad's railway connectivity is centered around the Palakkad Junction, which serves as a pivotal transit point for both passenger and freight traffic.Located on the busy Palakkad-Coimbatore railway line, Palakkad Junction is among Kerala's busiest railway stations.It serves as a gateway for trains traveling between Kerala and Tamil Nadu, providing seamless connectivity to major cities like Coimbatore, Chennai, and beyond.The station handles a diverse range of train services, including express, superfast, and local passenger trains, catering to the needs of commuters and travelers.public transport system primarily relies on buses, ensuring widespread accessibility and connectivity across the district.Despite not having its own airport, Palakkad benefits from proximity to Coimbatore International Airport, serving air travel needs for residents and visitors.

Palakkad's comprehensive transportation network, encompassing road, rail, and air connectivity, plays a pivotal role in facilitating economic growth, tourism, and daily commuting for its residents. The network ensures efficient movement of people and goods within the district and to neighboring regions, contributing to Palakkad's socio-economic development and regional connectivity.

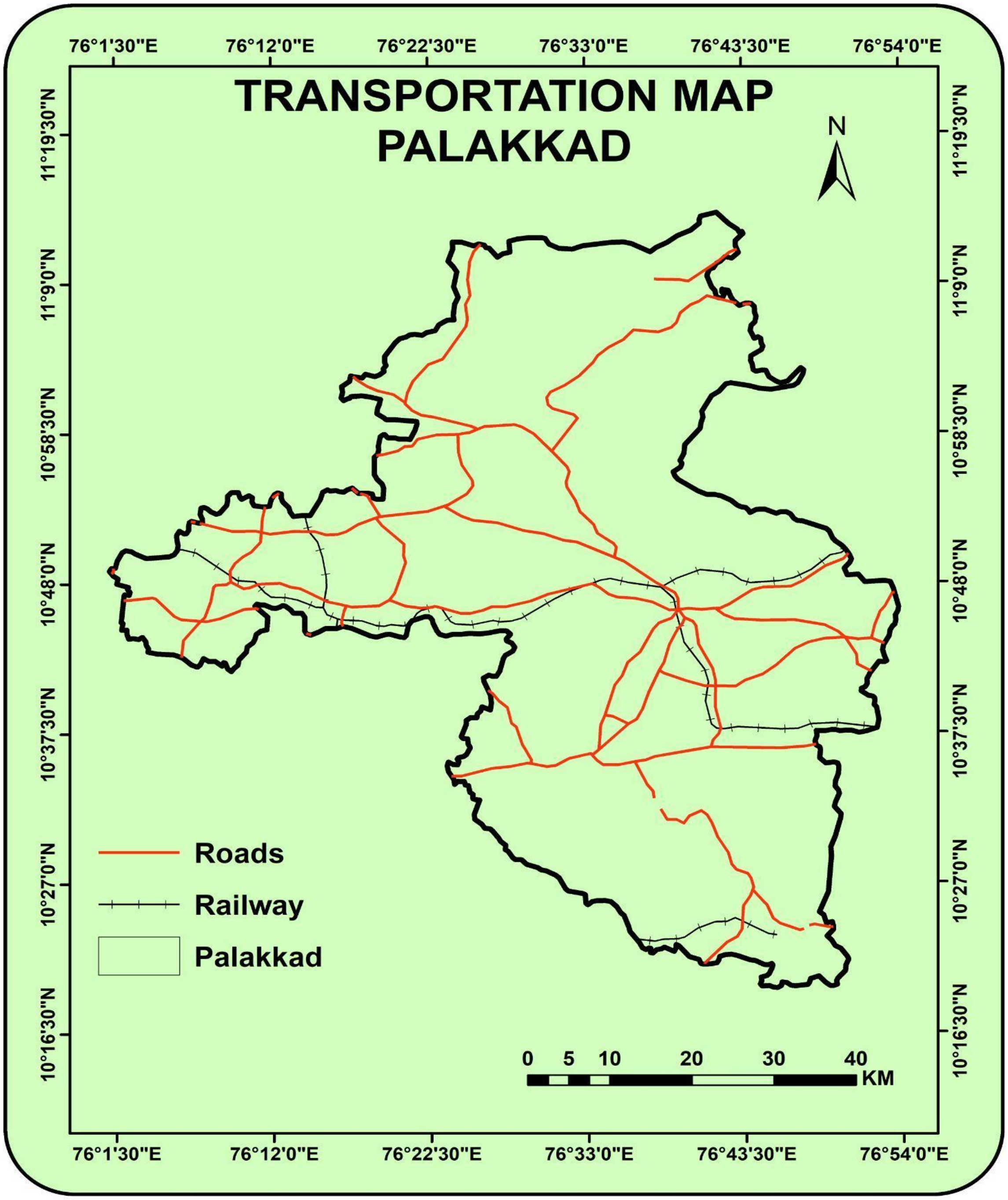

Fig 3.7 : Palakkad Transportation Network

(Source: Survey of India)

CHAPTER 4

ASSESSING POTENTIAL SOLAR SITE SUITABILITY IN PALAKKAD DISTRICT

4.0 INTRODUCTION

The focus of this study is on site suitability mapping for the installation of solar panels in Palakkad district, using the AHP (Analytic Hierarchy Process) method, aided by remote sensing data and GIS techniques. The primary goal of the study is to determine the suitability of various sites for solar panel installation within Palakkad district and its surrounding areas. The study considers five influential factors that affect the site suitability, including solar radiation, , slope, proximity to grid and road. By analyzing the relationships between these factors of Palakkad district location, site suitability maps were generated using AHP operator models.

4.1 SOLAR RADIATION

Solar radiation is a critical factor in determining the site suitability for the installation of solar panels. The amount of solar radiation that a site receives directly affects the efficiency of solar panels, which convert sunlight into electricity. The suitability of a site for solar panel installation is typically evaluated based on its solar irradiance, which is a measure of the amount of solar radiation received at a given location. The amount of solar radiation received can be affected by several factors, including the location of the site, the time of day, the season, and the weather conditions. Ideally, a site with a high solar irradiance is desirable for the installation of solar panels. However, other factors such as shading, temperature, and wind conditions can also impact the performance of solar panels. Therefore, it is important to consider all of these factors when evaluating the suitability of a site for solar panel installation. Additionally, it is important to consider the specific requirements of the solar panels being used, such as their orientation and tilt angle, in order to maximize their performance. The angle and direction of the solar panels should be adjusted to optimize the amount of solar radiation they receive.

Direct Normal Irradiance (DNI) refers to the amount of solar radiation received per unit area by a surface that is always held perpendicular to the incoming rays of the sun. It is a critical measure for evaluating the solar energy potential of a location. DNI is measured in watts per square meter (kWh/m²). It quantifies the solar power available from sunlight that comes directly in a straight line from the sun, without being scattered by the atmosphere. High DNI values indicate high potential for solar energy production. DNI is crucial for the planning and optimization of solar implementation

In table no 4.1, the month of January 7.417 to 6.114 kWh/m² as maximum and minimum were received. In the month of February, the maximum value was 7.437 to 6.481 kWh/m² as minimum value. In the month of March, the maximum value is 6.564 to 5.441 kWh/m² as minimum value. December, January, February, March have high solar radiation in Palakkad district. And June, July, August has the lowest solar radiation received in Palakkad district. These area the seasonal variation in that area

Month	**Maximum (kWh/m²)**	**Minimum (kWh/m²)**
January	7.417	6.114
February	7.437	6.481
March	6.564	5.441
April	6.564	4.236
May	5.926	3.532
June	4.724	1.876
July	4.096	1.876
August	4.544	1.573
September	5.555	2.124
October	4.488	2.87
November	5.746	3.333
December	7.222	5.49
Average	5.857	3.746

Table 4.1 Solar Radiation(DNI) Monthly Minimum Maximum (2019)

(Source : Global Solar Atlas 2019)

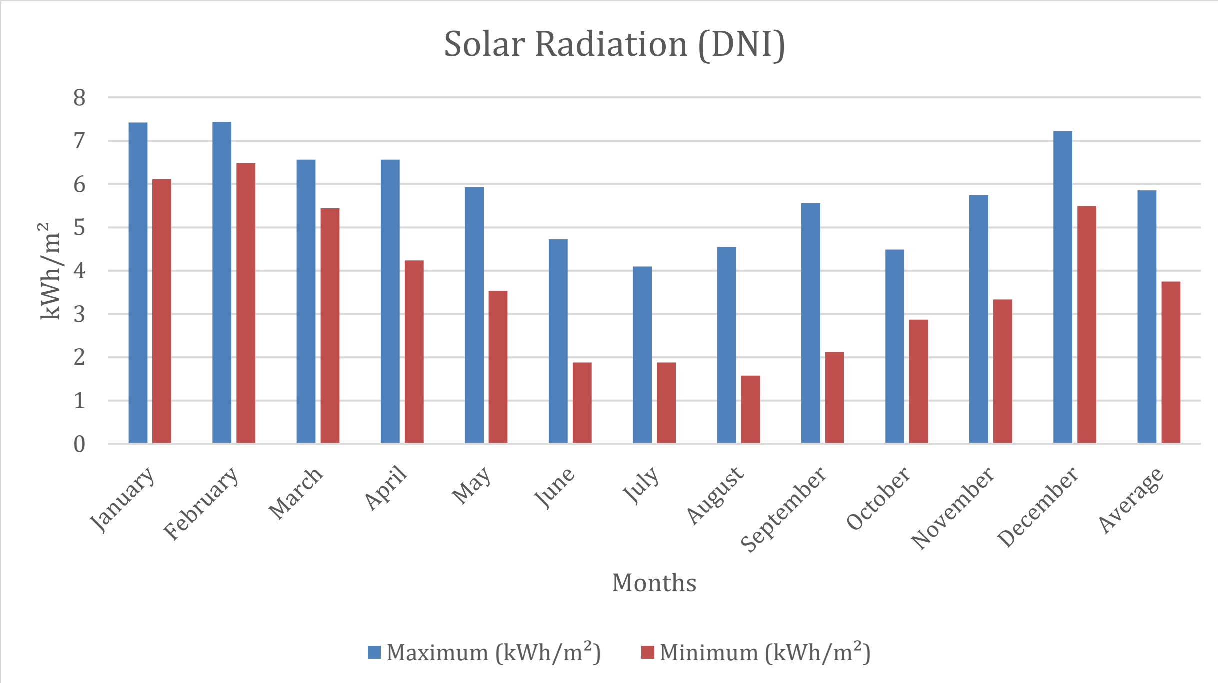

Fig 4.1 Solar Radiation Level (2023)

(Source : Global Solar Atlas,2023)

Palakkad's solar radiation data shows an impressive average of 5.87 kWh/m^2 with a minimum of 3.746 kWh/m^2, making it a favorable location for solar power generation. This high solar radiation can significantly contribute to the efficiency and viability of solar power plants in the region. The radiation mainly focused in the middle portion of Palakkad district and it reduce to north and south direction.

However, it is important to note that solar radiation is not the only factor that determines the suitability of a site for solar panel installation. Other factors, such as the topography of the area, the prevailing weather patterns, and the orientation of the solar panels, can also affect the efficiency and effectiveness of solar power

Average Solar Radiation is 5.87 kWh/m^2/day. This high average solar radiation indicates a significant amount of solar energy is available throughout the year. It means that each square meter of solar panels in Palakkad can receive, on average, 5.87 kilowatt-hours of solar energy per day. This level of solar insolation is among the higher ranges seen in India, making Palakkad highly suitable for solar power generation. And Minimum Solar Radiation 3.746 kWh/m^2/day Even the minimum levels of solar radiation are relatively high, ensuring that solar panels can generate electricity effectively even on less sunny days. This minimum value is crucial for assessing the reliability and consistency of solar power production.

SL NO	Classes	DNI (Direct Normal Irradiance) kWh/day
1	Very High	5.0 - 5.3
2	High	4.8 - 5.0
3	Medium	4.5 - 4.8
4	Low	4.0 - 4. 5
5	Very Low	< 4.0

Table 4.2 Classification of solar radiation

(Source : Students Computation)

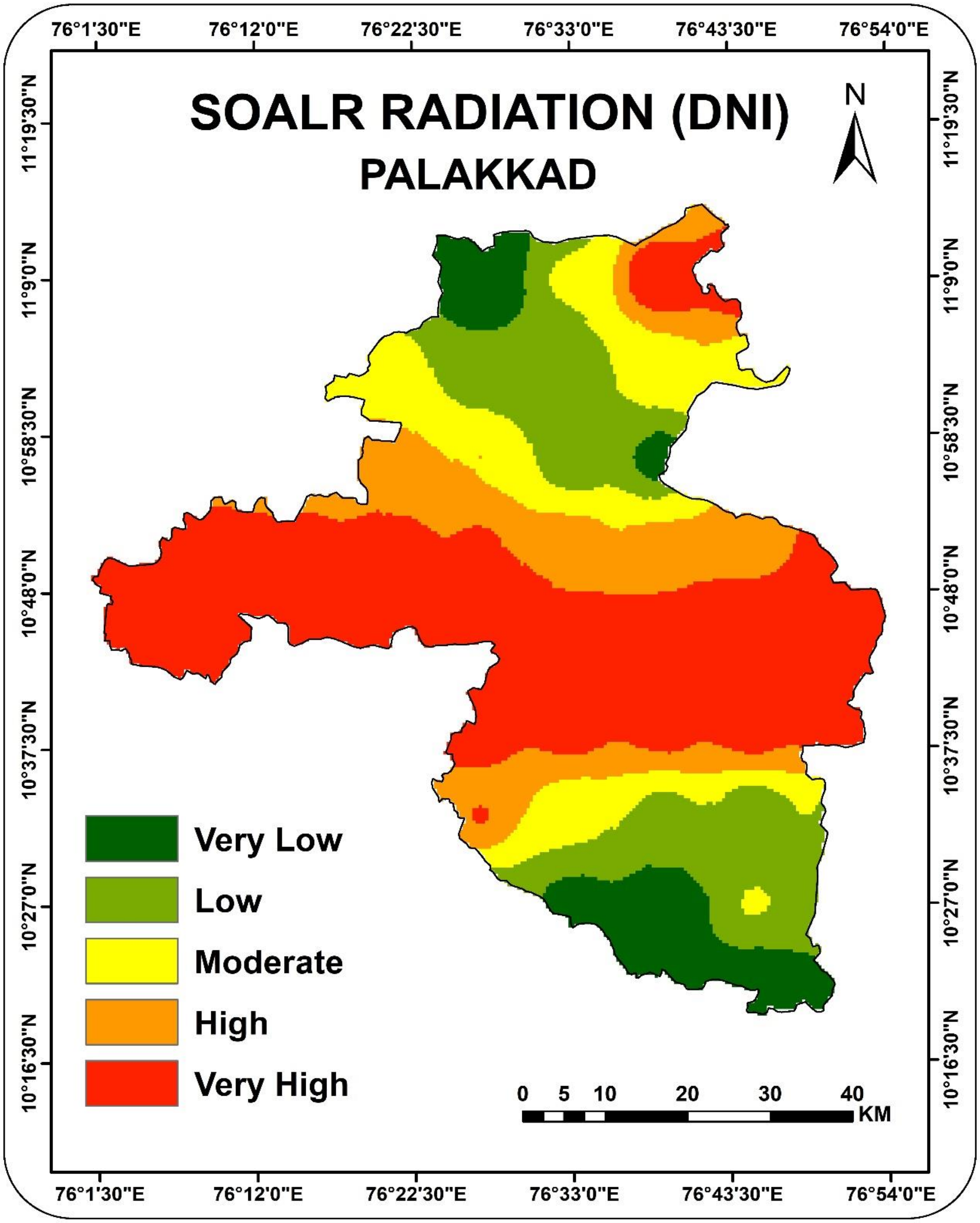

Fig 4.2 Palakkad Solar Radiation

(Source : Global Solar Atlas,2019)

4.2 SLOPE

Slope map gradient is the predisposition to water infiltration into the earth's crust. It is the 2-dimensional representation of the gradient of a surface. It is important to note that slope gradient can play a significant role in the suitability of a site for solar power plant installation. Based on this table 3.5, the slope of study area has been classified into five categories - Very High, High, Medium, Low, and Very Low. The Very Low slope class (1-8 meters) dominates the area, covering 2632 sq.km which is 59% of the total area. This suggests that a significant portion of the terrain is relatively flat or gently sloping. The Low slope class (8-17 meters) accounts for 878 sq.km or 20% of the area. This indicates that one-fifth of the area has moderately steep slopes. The Medium slope class (17-26 meters) covers 529 sq.km or 12% of the area, representing slopes that are steeper but still manageable. The High slope class (26-35 meters) comprises 290 sq.km or 7% of the area. The Very High slope class (35-80 meters) covers 111 sq.km or 3% of the area. These classes indicate the steepest parts of the terrain but collectively make up only 10% of the total area.

In Palakkad district around 79% of the slope is suitable for solar implementation. The slope is high in the north and south sides. The remaining middle portion has moderate slope. This middle portion is more suitable for solar implementation

SL NO	Classes	Slope in Meters	Area in sq.km	Area in %
1	Very Low	1 - 8	2632	59
2	Low	8 - 17	878	20
3	Medium	17 - 26	529	12
4	High	26 - 35	290	7
5	Very High	35 - 80	111	3

Table 4.3 Palakkad Slope Classes

(Source : Students Computation)

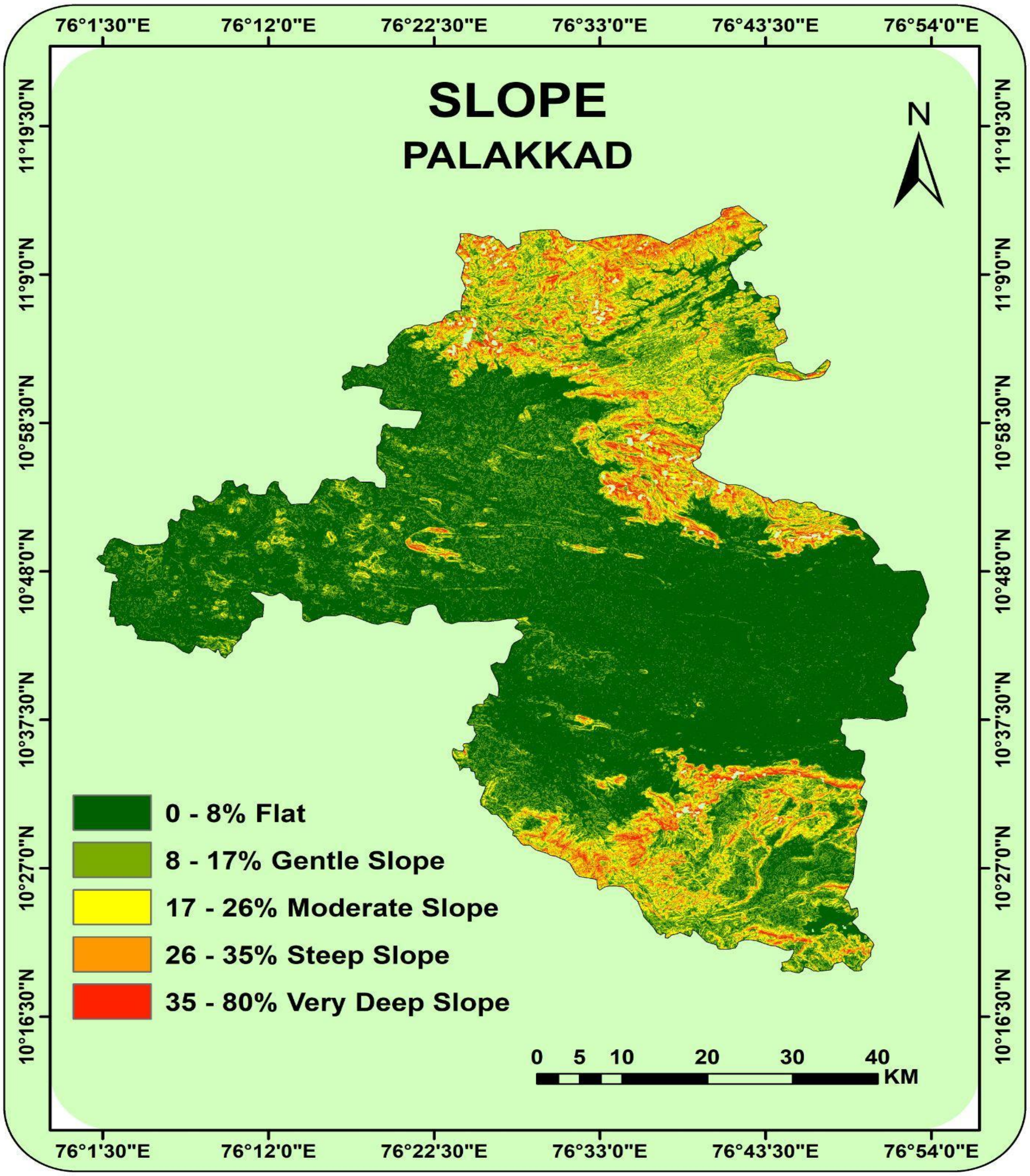

Fig 4.3 Palakkad Slope Map

(Source: SRTM, DEM , USGS Earth Explorer,2014)

4.3 PROXIMITY TO GRID

Proximity to the grid is a crucial criterion when assessing the suitability of a site for solar power generation. This criterion considers how close a potential solar site is to the existing electrical grid infrastructure, such as transmission lines and substations. High-voltage power lines that carry electricity from power plants to substations. These lines are crucial for transporting large amounts of electricity over long distances with minimal losses. Substations Facilities where the voltage of electricity is transformed from high to low or vice versa. Substations are strategically located to ensure efficient distribution of electricity to end-users. Incorporating the KSEB grid network as a criterion for solar potential site suitability. The closer a potential solar site is to the existing grid network, the lower the cost and complexity of connecting the solar plant to the grid. This can significantly impact the feasibility and economic viability of the project. The ability of the nearby grid infrastructure to handle additional power generated by the solar plant is crucial. Areas with robust grid infrastructure and higher capacity can accommodate more solar power without the need for extensive upgrades. Proximity to the grid reduces transmission losses, which occur when electricity is transported over long distances. By minimizing these losses, the overall efficiency of the solar power plant is improved. Sites closer to the grid require shorter transmission lines to connect to the existing infrastructure. This reduces the capital costs associated with building new transmission lines and related infrastructure. It Reduced Maintenance Costs, Shorter transmission distances also mean lower maintenance costs over the lifetime of the solar plant. existing grid infrastructure ensures that the solar plant can provide additional support to the grid, enhancing its stability and reliability.

SL NO	Classes	Distance from Grid (K.M)
1	Very High	0 -1
2	High	1 - 3
3	Medium	3 - 5
4	Low	5 - 10
5	Very Low	>10

Table 4.2 Classification of proximity to grid

(Source : Students Computation)

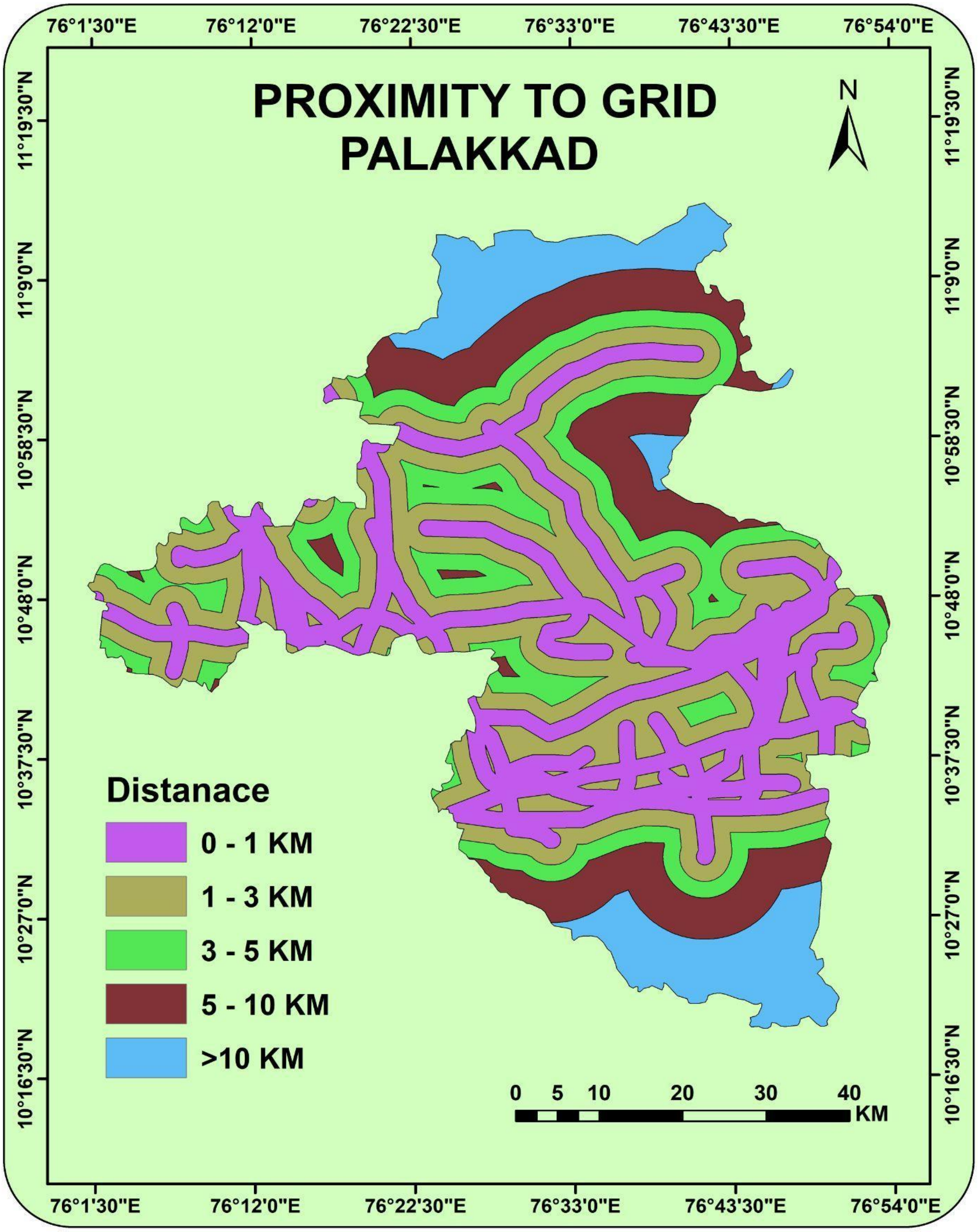

Fig 4.4 Palakkad Proximity to Grid

(Source : Geological Survey of India)

4.4 PROXIMITY TO ROAD

Proximity to roads is another important criterion in assessing the suitability of a site for a solar power plant. This criterion evaluates how close a potential solar site is to existing road infrastructure, considering factors such as construction costs, accessibility for maintenance, and transportation logistics. proximity to roads is critical and how it impacts solar site suitability.IT Lower Construction Costs Sites closer to roads are easier and cheaper to access with construction equipment and materials. This reduces the logistical costs and complexity associated with transporting heavy machinery and solar panels to the site. It Reduced Infrastructure Investment Minimal additional infrastructure is required to create access roads if the site is already near existing roads, leading to significant cost savings. Easy Access for Maintenance Proximity to roads ensures that maintenance teams can easily access the site for routine inspections, repairs, and upgrades. This is crucial for maintaining the efficiency and longevity of the solar power plan. Utilizing existing roads reduces the need for constructing new access routes, thereby minimizing environmental disruption and habitat destruction. Proximity to roads facilitates the efficient delivery of construction materials and solar panels, streamlining the construction process and reducing project timelines. If the site is near to the road it is easy to access for maintenance and construction class very high covers the distance from 0-1 km . its easily accessible compared to others when the site distance is increasing from the road the accessibility decreases

SL NO	Classes	Distance from Road (K.M)
1	Very High	0 -1
2	High	3-Jan
3	Medium	5-Mar
4	Low	10-May
5	Very Low	>10

Table 4.5 Classification of proximity to road

(Source : Students Computation)

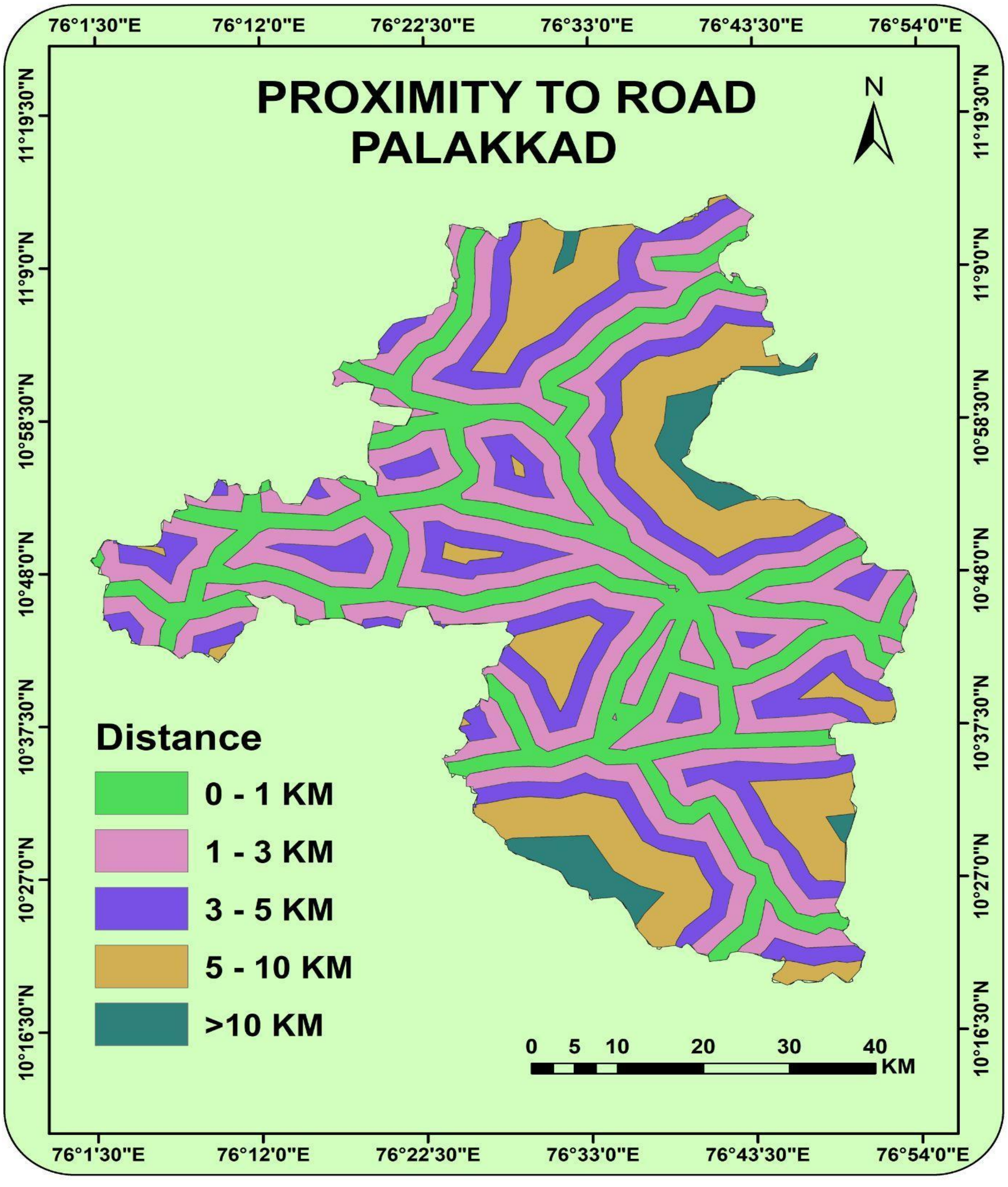

Fig 4.5 Palakkad Proximity to Road

(Source : Geological Survey of India)

4.5 FOREST COVER

Palakkad, situated in Kerala, India, features a variety of forest areas that are part of the Western Ghats mountain range. The district's forest cover is diverse and includes several types of forests. Very Dense Forests have a canopy cover of more than 70%. They are primarily located in the higher elevations and remote areas of the Western Ghats The dense evergreen forests found in the Parambikulam Tiger Reserve and parts of the Silent Valley National Park can be classified as very dense. These areas are characterized by a rich canopy layer and high biodiversity. These forests cover approximately 9-12% of the total forest area in the district. In absolute terms, this translates to around 224 to 299 square kilometers. And Moderately Dense Forests. These forests have a canopy cover ranging from 40% to 70%. They are often found in intermediate elevations and areas where the canopy is not as dense as in the very dense forests. The Nelliyampathy Hills and parts of the Attappady Hills have moderately dense forests. These regions have significant tree cover but with more open spaces compared to the very dense forest areas. These forests typically cover around 40-45% of the total forest area. This means they cover approximately 996 to 1,119 square kilometers.

Forest cover cannot be considered for solar site suitability. Forests play a crucial role in maintaining ecological balance, supporting biodiversity, and providing ecosystem services such as carbon sequestration and water regulation. Therefore, areas with significant forest cover are often protected or restricted from development to preserve these ecological function. forest cover are less suitable for solar power installations because they are typically less accessible and involve more complex land use changes. Clearing forests for solar farms can lead to deforestation, habitat loss, and other environmental impacts. Many regions have regulations that protect forested areas from development. Environmental impact assessments and land-use planning often prioritize conservation, which can limit the suitability of these areas for solar energy projects. Solar projects in forested areas can disrupt local wildlife and plant species. This impact is a critical consideration in environmental assessments and can affect project approval. Trees can significantly reduce the amount of sunlight reaching solar panels, which decreases their efficiency. In moderately dense forests, the shading effect is considerable. Building the necessary infrastructure in forested areas, such as roads and electrical grid connections, can be more complex and costly.

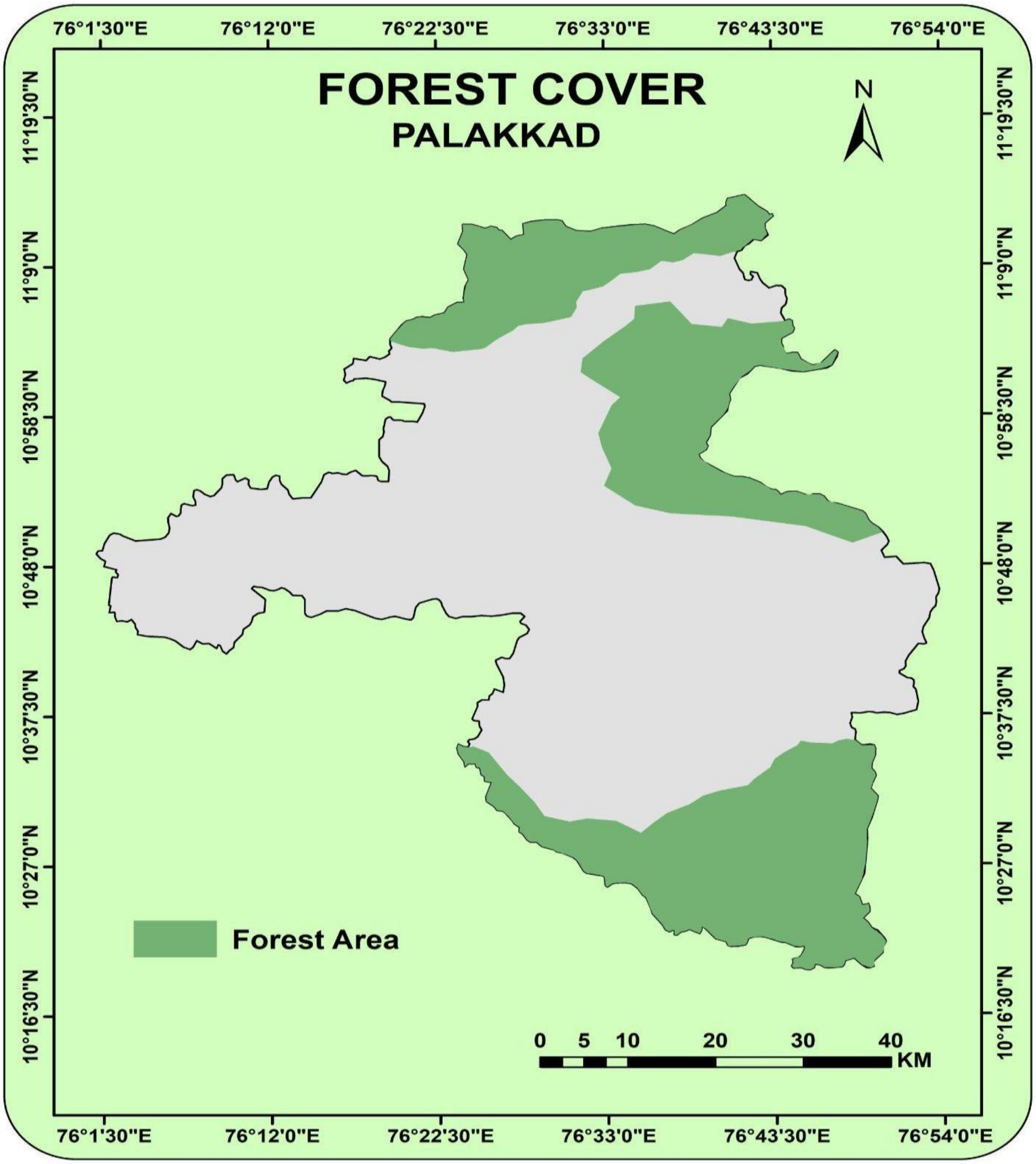

Fig 4.6 Palakkad Forest Cover

(Source : Kerala State Economics and Statics Department)

4.6 ANALYTICAL HIERARCHICAL PROCESS

The Analytical Hierarchy Process (AHP) is a widely used semi-quantitative method in decision-making and prioritization processes. AHP involves breaking down a decision problem into a hierarchy of decision elements and then comparing these elements pairwise in a matrix. This matrix allows the decision-maker to assign weights to each element, determining their relative importance to the decision. The AIP method is based on three principles: decomposition, comparative judgment, and synthesis of priorities. Decomposition refers to breaking down a complex decision problem into smaller, more manageable parts. Comparative judgment refers to the process of comparing pairs of decision elements to determine their relative importance. Synthesis of priorities refers to combining the weights of individual elements to determine an overall prioritization.

AHP has been widely used in the field of solar potential analysis to determine the relative importance of different potential sites . Weighted linear combination (WLC) is a standard concept used to combine maps of landslide controlling parameters. This involves assigning a standardized score to each parameter, which is then combined using a weighted linear combination to generate a composite map that indicates the overall suitability of solar potential sites

Scales	Degree of Preferences	Description
1	Equal	The contribution of the two factors is equally important.
3	Moderate	Experiences and judgment slightly tend to a certain factor.
5	Strong	Experiences and judgment strongly tend to a certain factor.

7	Very strong	A criterion is strongly favored over another, and its dominance is shown in practice.
9	Extreme	The evidence of favoring one criterion over another is of the highest degree possible of an affirmation.
2,4,6,8	Intermediate values	Used to represent compromises between the preferences in weights 1, 3, 5, 7, and 9.

Table 4.6: Description of Scales for Pair comparison with AHP

(Source: Saaty (1980))

4.7 THE RESULT OF AHP

The analytic hierarchy processes(AHP) is a widely used decision making tool that helps to analyze complex decision making problems by breaking them down into smaller components and evaluating the relative importance of each components. We used AHP to evaluate 4 different parameters – direct normal irradiance, slope, proximity to road and proximity grid. Based on the evolution of these parameters, we generated a suitability map that classifies the area into five categories – highly suitable, suitable ,moderately suitable ,less suitable and not suitable . These categories are based on the combination of the four parameters and their relative importance in determining the suitability for solar implementation

In order to determine the most significant factors influencing solar implementation , a model was employed to analyze thematic factors .Based on the table , weights were assigned to each factor in the proposed model , these weights for each factor , as shown in the table

Criteria	Dni	Slope	Grid	Road
Dni	1	5	4	6
Slope	1/5	1	4	3
Grid	1/4	1/4	1	5
Road	1/6	1/3	1/5	1

Table 4.7 : Calculation of prioritized factors weight for AHP Method

(Source : Students Computation)

Criteria	Weightage
DNI	0.5749
Slope	0.2327
Grid	0.13.59
Road	0.0563

Table 4.8 : Represents Criteria and Weightage

(Source : Students Computation)

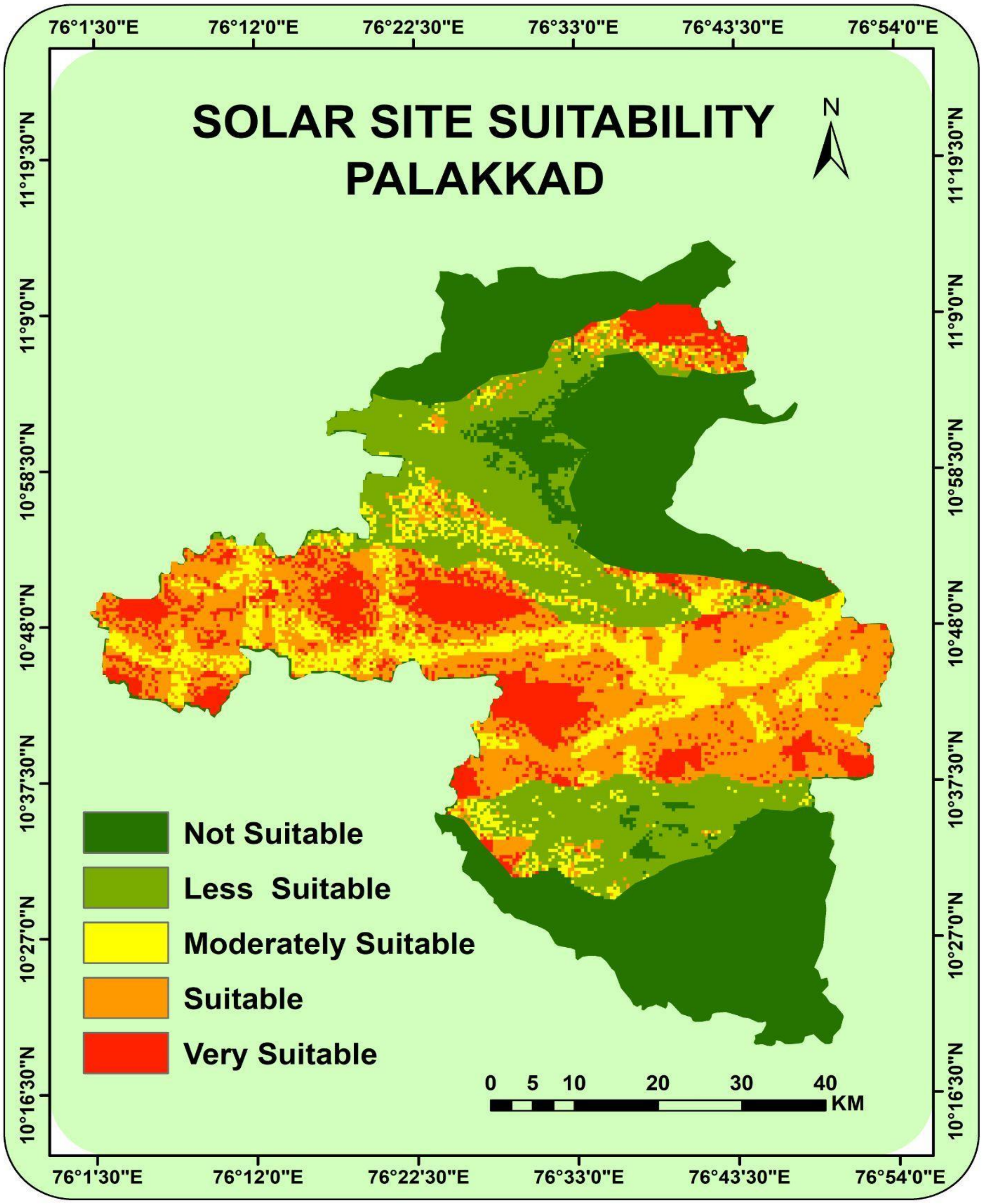

Fig 4.7 : Potential Solar site suitable map AHP ,Palakkad

(Source: Students Computation)

4.8 RESULT ANALYSIS

Our study's findings indicate that the Analytic Hierarchy Process (AHP) is a useful approach for identifying suitable areas for the installation of solar power plants. In other words, the AHP method is effective in helping to determine which areas are most suitable for solar power plant installation. AHP is a decision-making tool that enables individuals to weigh various factors and criteria to make informed choices. In this case, AHP was used to evaluate and prioritize different factors, such as solar radiation, terrain, and land use, to identify the most suitable areas for solar power plant installation. Therefore, the results of our study suggest that AHP can be an effective tool for decision-makers in the renewable energy industry. In the study we found that the northern region and southern region of Palakkad is not suitable for solar implementation due to mountainous terrain and forest cover. solar potential mainly focused in the central part of the district . this area is flat and receiving high amount of solar radiation In this study we estimated that around 471km.sq area is very suitable for solar implementation and 1030km.sq area is suitable for solar implementation .these area mainly concentrated in the mid portion of the district only10.51 percentage of the total area is highly suitable for solar implementation Around 23 percentage of area is suitable for solar implementation . in effect around 32.5 percent area is suitable for solar implementation In summary, the study shows that location plays a critical role in determining the suitability of a site for a solar power plant.

Classes	Area Sq.km	Area in %
Very Suitable	471	10.51
Suitable	1030	22.99
Moderately Suitable	817	18.23
Less Suitable	526	11.74
Not suitable	1636	36.51

Table 4.9 : Suitable Areas in Palakkad

An area of 817km² (18.23%), these zones are moderately suitable for solar installations. They may have minor limitations such as slightly higher slopes or greater distances from roads or grids. The less suitable areas (526 km² or 11.74 %) and not suitable areas (1636 km² or 36.51%) face significant constraints. These regions may have low DNI values, steep slopes, or poor accessibility, making them less favorable for solar power plant development.

In Palakkad districts around 36.5 percentage of the land area is not suitable In this land area majority of the portion is forest cover. Forests are often less accessible, making it difficult to transport materials and equipment for the construction and maintenance of solar power plants. It involves significant land use changes, which can be complex and costly. Clearing forests for solar installations leads to deforestation, which has negative environmental impacts such as loss of biodiversity and increased carbon emissions.

In this study Palakkad mid portion is suitable for solar implementation. In this very suitable area concentrated on where there is consistent soalr radiation in the whole year.Some portion of Alathur and Ottapalam taluk has more portion of suitable areas These are potential areas for the implementation of solar plants

This study effectively identifies and categorizes land suitability for solar power plant installation in Palakkad district using the AHP method. The resulting suitability map provides valuable insights for stakeholders, enabling informed decision-making in the planning and development of solar energy projects. The high-potential areas identified in this study can significantly contribute to the region's renewable energy capacity, promoting sustainable development and energy security.

In the Palakkad district, Ottapalam stands out as the most promising taluk for solar power plant development, boasting the largest "Very Suitable" area of 126.84 sq km and no "Not Suitable" areas, indicating optimal conditions for solar energy generation. Alathur follows closely with 103.54 sq km of "Very Suitable" area and a significant "Suitable" area, showcasing substantial potential for solar projects. Chittur and Palakkad have extensive "Suitable" areas (236.35 sq km and 208.05 sq km respectively), making them favorable for solar development, though they also have significant "Not Suitable" areas (589.41 sq km and 147.61 sq km respectively) that present challenges. Mannarkkad faces the most constraints, with the largest "Not Suitable" area of 723.55 sq km and "Less Suitable" area of 330.00 sq km, due to the high elevation areas and forest cover.

Despite having some "Very Suitable" and "Suitable" areas. Pattambi shows balanced potential with 78.44 sq km of "Very Suitable" and 182.44 sq km of "Suitable" areas, and no "Not Suitable" areas, suggesting minimal land constraints for solar energy projects. Overall, Ottapalam and Alathur emerge as the top candidates for solar power plants, with Chittur, Palakkad, and Pattambi also offering considerable opportunities, while Mannarkkad requires more strategic planning due to its substantial constraints.

	Area in Square kilometre					
Classes	**Alathur**	**Chittur**	**Mannarkkad**	**Ottapalam**	**Palakkad**	**Pattambi**
Very suitable	103.54	54.64	61.00	126.84	45.03	78.44
Suitable	181.29	236.35	41.16	179.96	208.05	182.44
Moderately Suitable	62.92	48.96	33.67	113.14	193.75	73.14
Less Suitable	95.97	201.85	330.00	66.35	119.60	2.58
Not Suitable	173.12	589.41	723.55	nill	147.61	nill

(Table 4.10: Suitable Areas in Palakkad Taluk)
(Source: Students Computation)

CHAPTER 5

5.1 SUMMARY AND CONCLUSIONS

Siting is a crucial component of developing distributed energy resources such as solar. Factors like the amount of sunlight that a solar power plant can receive directly affects its energy output, terrain and topography of the site must be suitable for solar power plant construction as the area should be relatively flat and free from obstruction such as hills, trees, buildings.. Also, the solar power plant should be located near the power grid to minimize transmission losses and ensure the effective distribution of electricity generated. Renewable energy sources are the most necessitated natural energy to reduce fossil fuels globally. Solar energy is the most effective renewable resource for daily use and essential domestic uses. This energy can be harnessed to meet the increasing energy demands. As the world continues to transition towards a more sustainable energy future, solar energy will play an increasingly important role in meeting our energy needs while also mitigating the impacts of climate change. It has a competitive advantage over traditional sources of energy, since it provides a sustainable energy supply.

Palakkad district located in the middle portion of the india state kerala.It situated within the latitudes stretching from 10° 21' to 11° 14' north and longitudes stretching from 76° 02' to 76° 45' east.Palakkad district in Kerala covers an area of approximately 4,482 square kilometers.This geographic location results in a tropical climate with high temperatures and abundant sunshine throughout the year. This makes it an ideal location for solar energy projects, as it receives plenty of sunlight that can be harnessed for renewable energy generation.The most important river that flows through Palakkad is the Bharathapuzha River. It's the second longest river in Kerala and is kind of like the main artery of the district. Many other rivers branch off from it, forming a network that nourishes the land.

The study results shows that the land suitability in palakkad district could be classified into 5 classes : very suitable , suitable ,moderately suitable , less suitable ,not suitable .The middle portion of the palakkad is more suitable for solar implementation . It decreases towards the north and south direction due to increase in the slope and protected forest land . The result of our study demonstrates that AHP method is effective in the identifying areas with installation of solar power plant.We identified several factors include solar radiation ,slope ,proximity to road

,proximity to grid also contributes to the siting of solar power plant.This study identified high amount of solar radiation is received in the middle portion of palakkad districts.and some portion in the north-eastern side of the palakkad.The average solar radiation lies from 3.7 to 4,8. Higher radiation received areas are tend to have higher potential for solar implementation In palakkad district around 20.64 percentage area is suitable for solar implementation.In this 20 percentage only 2 percentage is very suitable for solar implementation

5.2 RECOMMENDATION

When selecting a site for a solar plantation in Palakkad, several factors need to be considered. As a recommendation, Proximity to existing infrastructure such as roads, power lines, and substations is crucial as it can impact the feasibility of the project and reduce the cost of constructing new infrastructure.

- Conduct ground-truthing of the identified suitable and very suitable areas to confirm their practicality for solar power plant installation. This validation will ensure that the theoretical suitability aligns with real-world conditions.
- Include additional criteria such as land use patterns, environmental constraints, and socio-economic factors to refine the suitability assessment. A more comprehensive analysis can provide a holistic view of the potential impacts and benefits of solar power projects.
- Utilize the findings to inform local government and policymakers in planning and promoting sustainable solar energy projects in Palakkad district. Developing supportive policies and incentives can attract investment and expedite the deployment of solar power infrastructure.
- Explore advancements in solar technology that could enhance the feasibility of less suitable areas. Innovations in solar panel efficiency, energy storage, and grid integration can expand the range of viable locations for solar power plants.

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