PARAMETRIC STUDY OF URBAN MORPHOLOGY ON BUILDINGS SOLAR ENERGY POTENTIAL: A CASE STUDY OF MODEL TOWN LAHORE, PAKISTAN

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ABSTRACT: Solar energy is a sustainable and widely available energy resource among renewable energy resources for tackling the long-term issues of the energy crisis. The World Energy Council, the UN Department of Economic and Social Affairs, and the UN Development Programme all estimate that solar energy has a potential of 1,600 to 49,800 exajoules (4.41014 to 1.41016 kWh) annually on a worldwide scale. Although solar PV global electricity generation is only 3.1 per cent. According to media reports, 63 percent population of Pakistan that is approximately 140 million either have no access to the electrical grid or are facing daily load shedding for more than 12 hours. Our region is considered for solar insolation due to its unique geographical location and climate characteristics. Almost all of the country experiences high levels of solar radiation for eight to ten hours every day, thanks to the more than 300 sunny days it receives each year. Hence, this study aims to assess the solar energy potential of Model Town, Lahore, serving as a reference point for all residential areas in Pakistan that constitute 47 per cent of the nation's electricity usage, as stated earlier in research studies. One of the main residential regions of Lahore is Model Town. For the study purpose, a cadastral map is collected from the Estate Man Properties International and a Surface digital model from ALOS is obtained. Solar potential is computed by performing the Area Solar Radiation analysis with the help of selected urban parameters layers such as aspect and slope, integrated through GIS. The results show that the maximum amount of solar radiation is 4459.15 kWh/m^2. The minimum solar radiation, the model town is receiving is 7.65 kWh/m^2 for the current year.

Keywords: Aspect, Morphology, Renewable Resources, Solar potential mapping, Slope, Urban parameters.

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INTRODUCTION

In Pakistan, only 55% of people have access to electricity, with a per capita supply of about 520 kWh and there aren't many petrol and oil deposits in the area. Gas and oil are used to generate 65% of the electricity. Pakistan is so largely dependent on foreign oil (Harijan *et al.*, 2008; Khatri *et al.*, 2023). Pakistan's dependence on foreign fuels has resulted in an unpredictable state of power supply. It has significantly hampered the nation's socioeconomic development. (Raheem *et al.*, 2016; Xin *et al.*, 2022; Song *et al.*, 2023). Pakistan has to import a lot of energy to keep up with its expanding industrial capability. Many significant possibilities such as preservation programs, utilization of energy efficiently and orienting renewable energy resources, are available to obtain an autonomous and sustainable energy future.

To achieve the 2 °C target outlined in the Paris Agreement, fossil fuels must be gradually phased out and replaced by low-carbon energy sources (Creutzig *et al.*, 2017). It is critical to look into expanding current energy supplies and researching new ones to support developing countries like Pakistan's growth objectives. These nations' persistent energy problems may be resolved with the help of renewable energy sources and technology (Chaudhry *et al.*, 2009). To solve the energy crisis, more sustainable and renewable energy sources must be used. Pakistan has an abundance of renewable energy resources, including biomass, solar, hydro, and wind. These resources might have a major impact on the country's efforts to mitigate climate change, generate sustainable energy, and create a future energy production matrix (Raheem, *et al.*, 2016). There is currently a 5000–8000 MW imbalance between Pakistan's power supply and consumption, and this gap is growing steadily at a rate of 6–8% annually. It results in several hours of power cuts. To solve the issue, more renewable and sustainable energy sources are needed. (Raheem, *et al.*, 2016). That is why we chose the Model Town to measure the Solar Potential. Because of its geographic location and climate, the nation has a large potential for solar energy, which emphasizes the necessity of planning solar energy projects that take solar resource appraisal into account (Tahir and Asim, 2018).

Renewable energy sources are significant components of climate change mitigation measures because they are seen as vital policy tools for lowering greenhouse gas emissions. However, renewable energies may also be crucial for efforts to adapt to climate change since they can reduce the vulnerability of energy systems to catastrophic events (Eitan, 2021). Renewable energy sources are significant components of mitigation measures to reduce climate change because they are seen as vital policy tools for lowering greenhouse gas emissions. However, as renewable energies can lessen the vulnerability of energy systems to catastrophic events, they may also be essential for efforts to adapt to climate change (Raheem, *et al.*, 2016). When combined with other renewable energy sources, solar energy is a potential and cost-free energy source that can help address long-term energy crisis issues. The massive energy demand, the depletion of fossil fuels, and the high cost of alternative energy sources have all contributed to the global growth of the solar business (Kannan and Vakeesan, 2016). As a long-term energy source, solar energy is gaining importance. Even though fossil fuels generate energy, solar energy and other renewable resources are unevenly distributed across huge areas with low geographic density (Mansouri Kouhestani *et al.*, 2019).

To protect the environment for future generations, humanity's primary and shared aim must be the development of sustainable energy. The reason solar energy is the most abundant and equally dispersed in nature compared to other renewable energy sources like wind, geothermal, hydro, wave, and tidal energy is why it is ranked first (Şen, 2004). The majority of energy use is concentrated in cities as the world is becoming more urbanized. This rising energy need might be supplied by a clean, abundant, and efficient energy source (Brito *et al.*, 2017). The global high-intensity solar irradiation zone is primarily centred between 10° and 35° north latitude, with annual sun irradiation intensities ranging from 1800 to 2600kWh/m2 (Zhao *et al.*, 2018). Luckily for Pakistan, the country has year-round surface warming from the sun, providing a substantial possibility for the production of solar energy. December saw the highest solar radiation intensity (339.25 W/m2) and the lowest (76.49 W/m2) at Cherat and Gilgit, respectively. According to Adnan *et al*. (2012), the monthly solar radiation intensity in the nation ranges from 136.05 to 287.36 W/m2. According to the National Electric Power Regulatory Authority's (NEPRA) 2020 annual report, there is 38700 MW of installed power generation capacity in Pakistan. Of this, 57% comes from thermal energy (fossil fuels), 31% from hydropower, 4% from renewable energy sources (wind, solar, and bagasse), and 8% from nuclear power.

MATERIAL AND METHODS

Study Area: As indicated in **Fig. 1**, Model Town, Lahore is the study region for the present research. Model Town is the most developed and organized town in Lahore, Punjab. Model Town, established in 1921 and comprising 56 per cent of the residential area seeks attention to the electricity consumption of this area in the current study. About 100,000 people live in Model Town overall. It is regarded as the town's upscale neighbourhood and features a distinctive housing area layout. In contrast to previous housing designs, each block features its market, playground, mosque, triangle parks, etc. Model Town Society occupies 1463 acres (5.9 km2) in total. Ten blocks comprise this area (A, B, C, D, E, F, G, H, J, K). The Model Town's outer blocks, designated as Blocks L, M, N, P, Q, R, and S, are under the management of the Lahore Development Authority (LDA). The entire area is broken down as follows:

- Residential 3.31 km^2 = 56%
- Roads 1.13 km^2 = 19%
- Green area (parks): 1.13 km^2 = 19%
- Commercial 0.12 km^2 = 2%
- Nurseries and playgrounds 0.24 km^2 = 4%

Almost every part of the country receives 8 to 10 hours of solar radiation per day in more than 300 sunshine days in a year.

Data and its Sources

Primary Data: For this research study, the primary data source includes Building footprints that were generated from the cadastral map as a raster layer in ARC GIS (Kodysh *et al.*, 2013; Catita *et al.*, 2014; Santos *et al.*, 2011; Nasrallah *et al.*, 2022).

Secondary Data: Secondary Data Sources include a cadastral map and a Digital surface model (DSM). Firstly, a cadastral map is collected from an open-access source **(Fig 2).** This cadastral map is being used to create a vector layer in ArcGIS for making building footprints and further analysis **(Fig 3).**

Additionally, the satellite imagery of the Digital Surface Model (DSM) is obtained from the ALOS Global Digital Surface Model "ALOS World 3D - 30m (AW3D30). From Japan Aerospace Exploration Agency (JAXA) **(Table 1).** A Digital Surface Model (DSM) is necessary to perform analysis and obtain accurate results. It provides critical elevation and topographic information necessary for accurately assessing the feasibility of solar energy projects and optimizing their performance (Aslani and Seipel, 2023). DSM data is frequently available, easily processed, and widely acknowledged as dependable data sources for spatial applications that necessitate elevation information (Lingfors *et al.*, 2017; Gawley *et al.*, 2022).

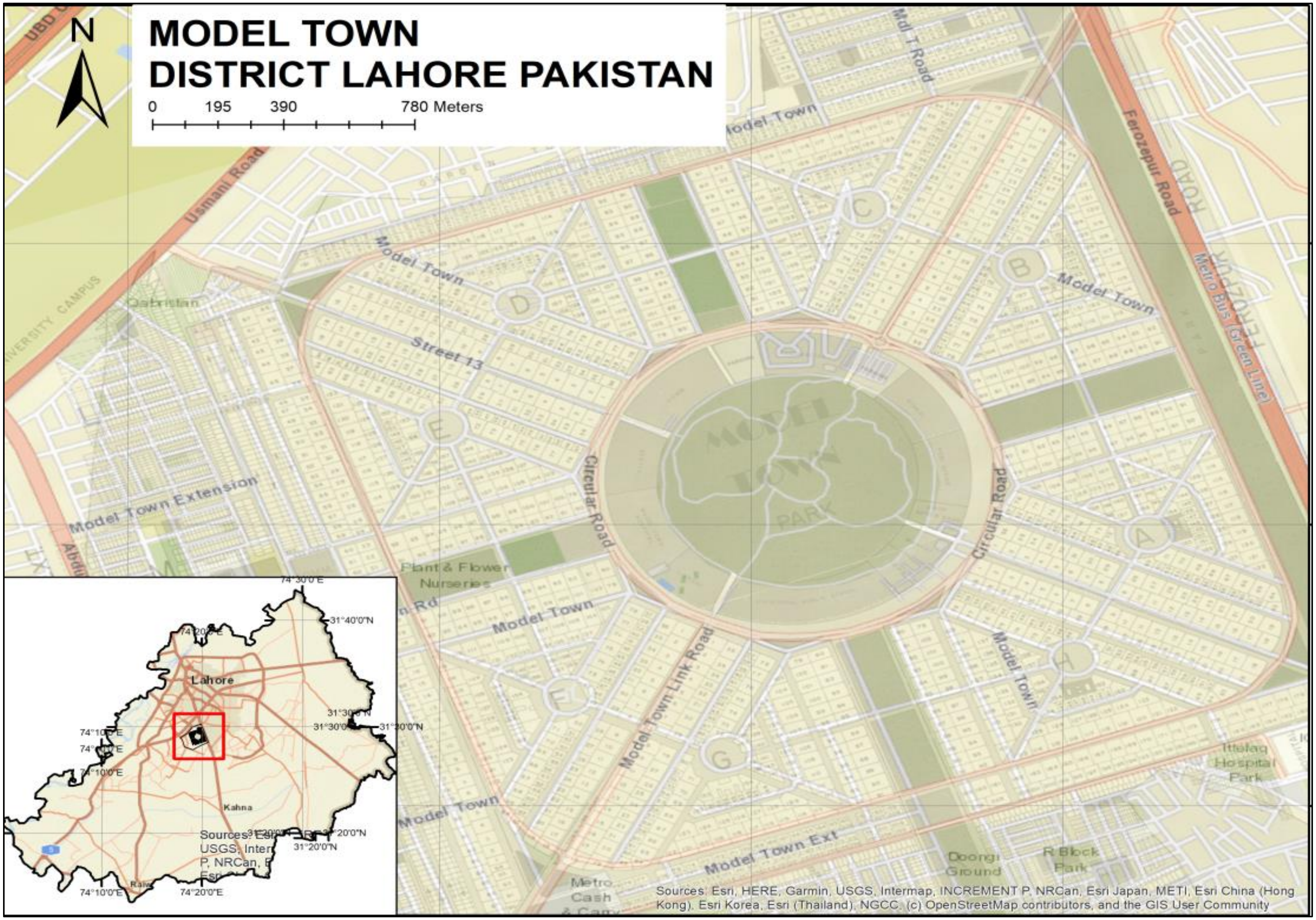

Fig: 1. Study is the map of Model Town

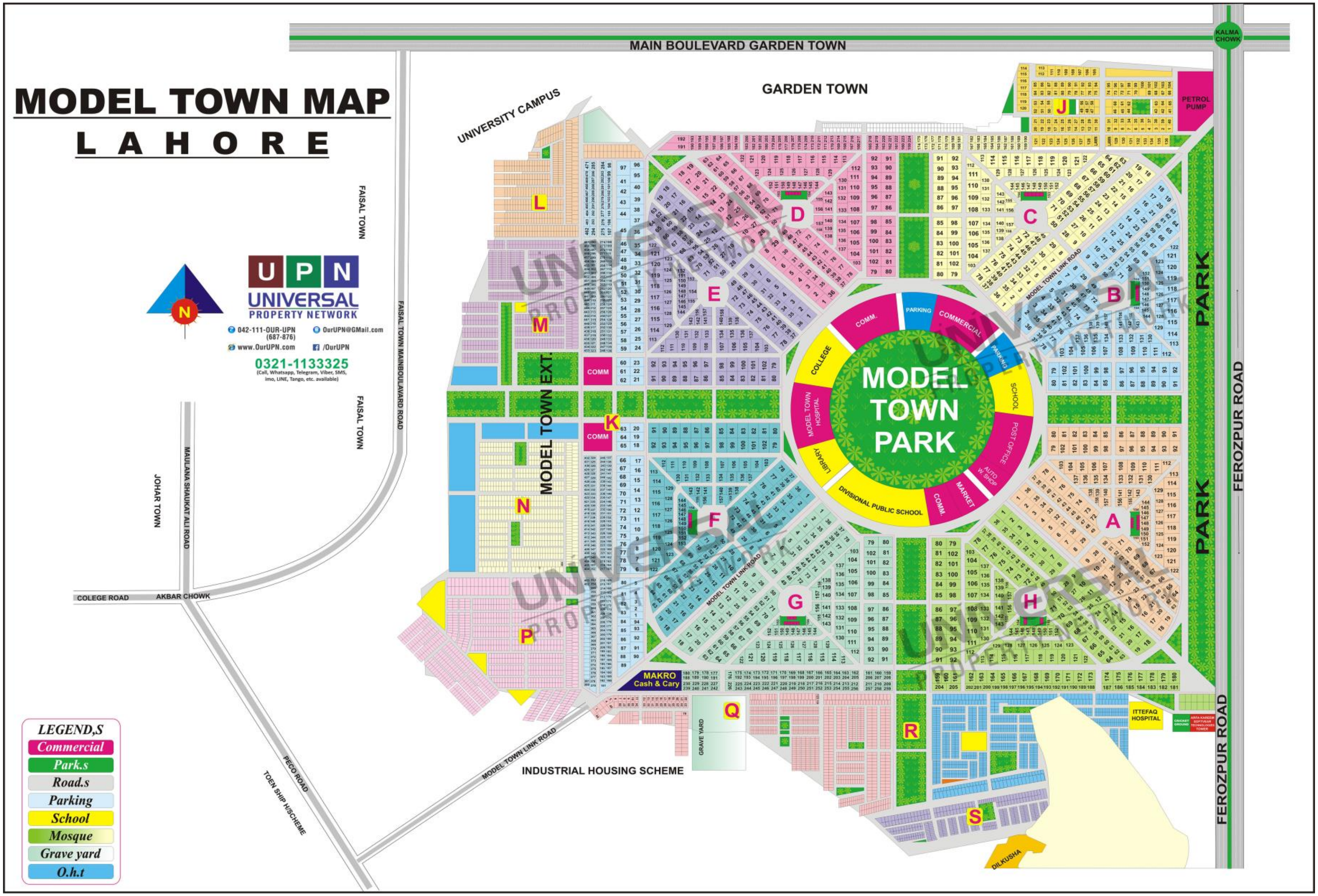

Fig: 2. Cadastral Map of Model Town, District Lahore

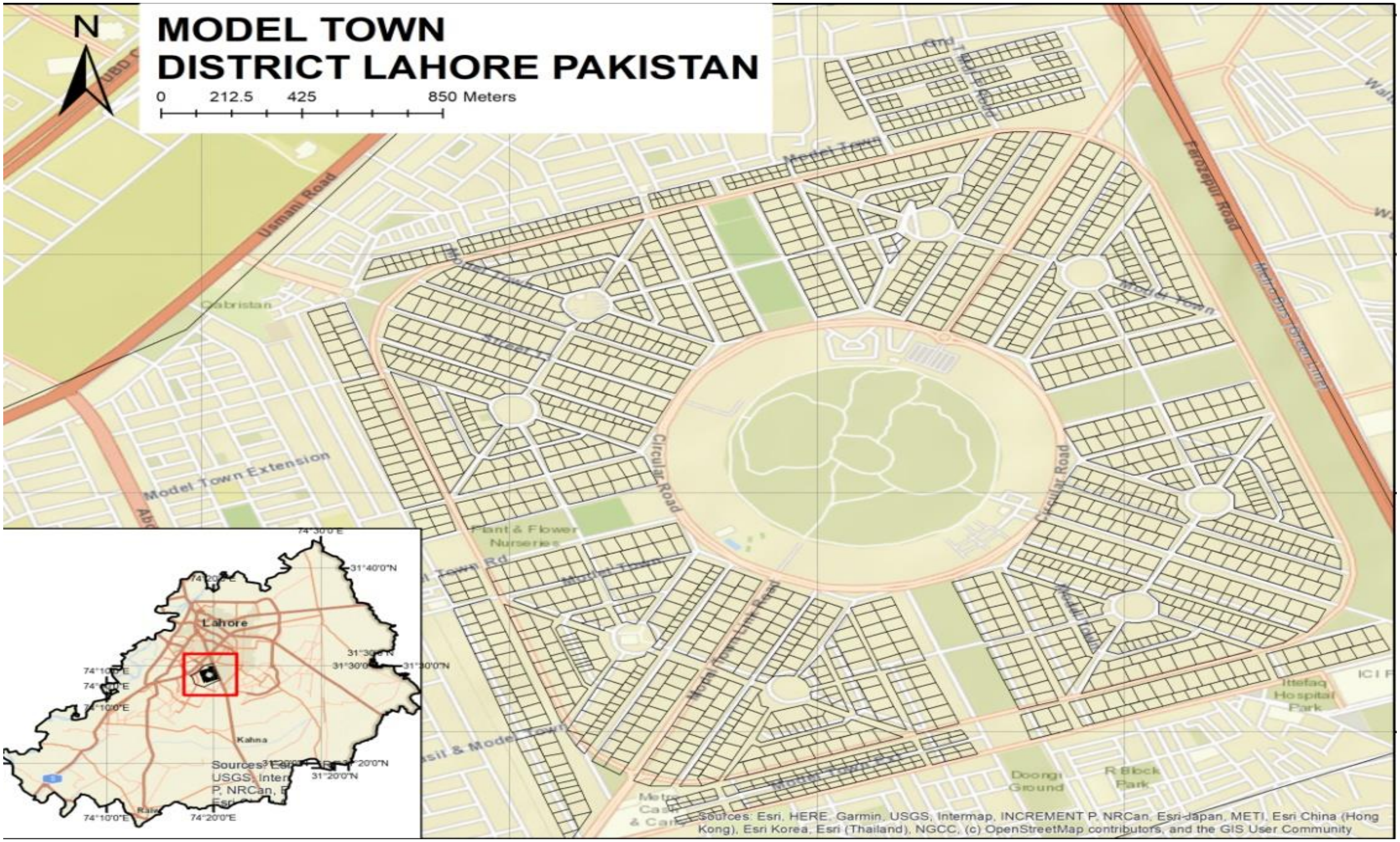

Fig: 3. Digitized building footprints of Model Town

Table 1: Specifications of Digital Surface Model.

Sr. no.	Tile	Pixel Spacing	Resolution	Date
1.	ALPSMLC30_N031E074	5 m mesh	2.5m	22-04-2022

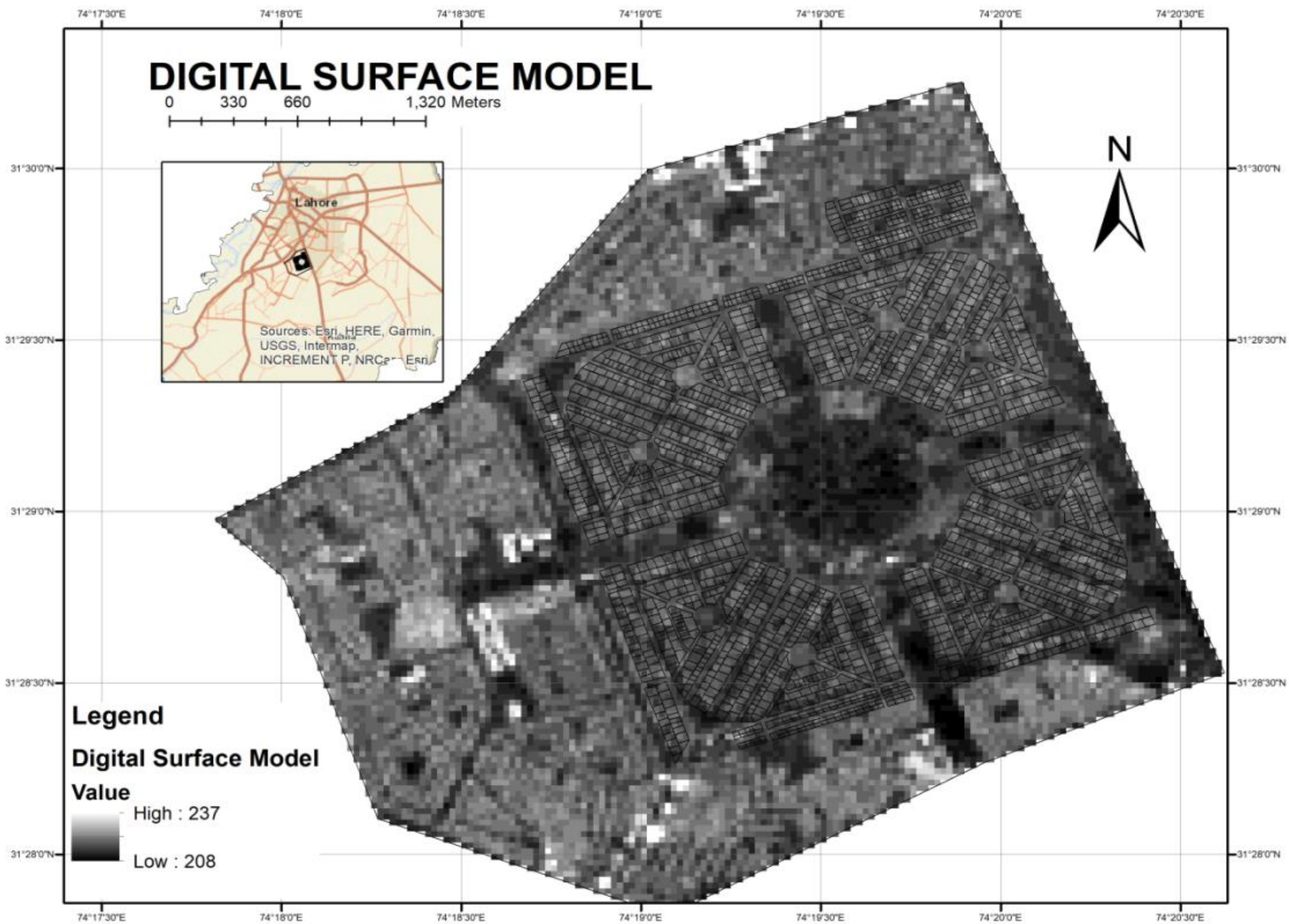

Fig. 4. Digital Surface Model

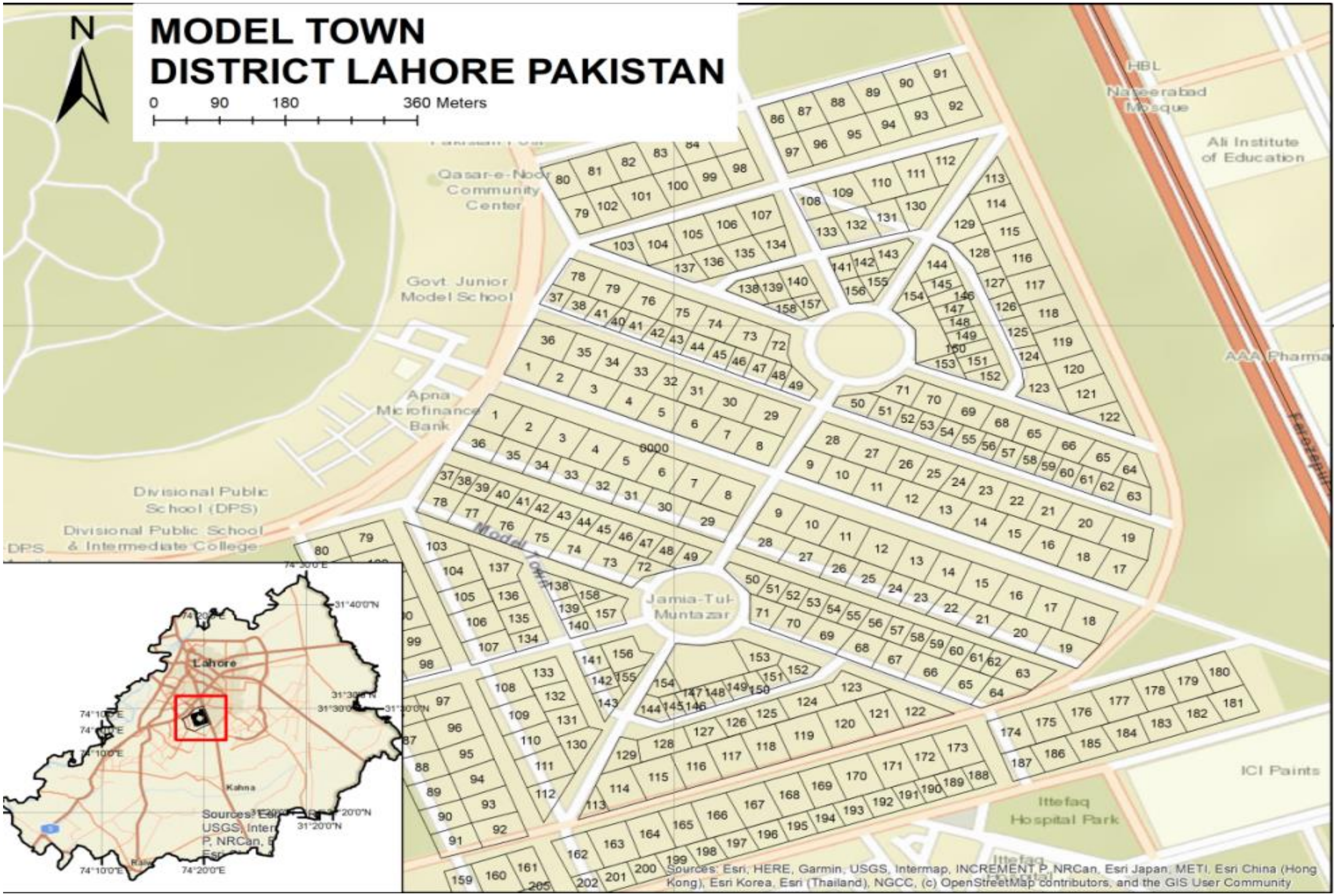

Fig 5. Allocated numbers to houses and plots block-wise in Model Town

Data Processing

Georeferencing: Firstly, a cadastral map of the model is added that needs to align with the projected data. Control points are created to link with known projected maps (Das *et al*., 2022; Nagashree *et al*., 2022). According to the map situation relative geo-referencing was performed.

Allocation of Plot and House numbers: World street base map layered with the geo-referenced to digitize building footprints with a transparency of 60%. By using the polygon editor every house, block and park was marked. Each polygon was also marked by plot number in the attribute table as shown in **Fig 5**

Data and Analysis: This section provides a structured approach to estimating solar power potential using GIS and spatial analysis techniques. It involves data acquisition, preprocessing, terrain analysis, solar radiation modelling, building integration, site suitability analysis, visualization, results interpretation, and reporting.

Compute Urban Parameters: In this section, we employed surface parameter tools to visualize the chosen urban parameters, which include hillside, slope, and aspect of buildings. Firstly, a hillshade raster layer was generated to create a realistic shading effect, illustrating elevation. Subsequently, the DSM layer was adjusted to 40 per cent transparency, imparting a three-dimensional appearance. Additionally, building footprints (see **Fig. 3**) were overlaid to enhance the clarity of the neighbourhood's surfaces.

Map solar energy by area solar radiation tool: As seen in **Fig. 5**, a solar radiation map was produced for the current investigation using the Area Solar Radiation tool. For the current year, it calculated the sun's radiation across a whole year. For each day sampled, the amount of solar radiation was calculated by this tool once every 30 minutes. If a roof surface had solar panels installed, more electricity could be produced from it the more solar radiation it gets.

Identification of suitable rooftops by three criteria

- 45 degrees or less is a suitable slope for rooftops because steeper slopes tend to receive less sunlight.
- Appropriate rooftop solar radiation levels should be at least 800 kWh/m2.
- Suitable rooftops shouldn't face north because rooftops that do so in the northern hemisphere receive less sunshine.

Compute the total amount of solar radiation per building based on suitable rooftops: The solar radiation raster is measured in watt-hours per square metre. Kilowatt-hours per square metre (kWh/m2) is the resultant conversion. Certain cells (denoted with the notation e+06) have values greater than one million. Kilowatt-hours per square metre (kWh/m2) is the resultant unit of measurement for the raster layer. This phase reduces the values and makes them easier to understand. This is accomplished by using the Raster Calculator, a spatial analysis tool. An equation that divides current cell values by 1,000 is used to change the units of measurement because there are 1,000 watts in a kilowatt.

RESULTS AND DISCUSSION

Aspect: Rooftops facing northward are not ideal in the northern hemisphere since they receive less sunlight. Making an aspect raster layer is required to ascertain rooftop orientation. According to **Fig. 6**, each cell has a value that represents orientation in degrees, with 0 being absolute north and 180 representing absolute south.

Maximum houses showing red colour, which means they are oriented towards North (0-22.5). Some are in the Northeast with the angle of (22.5-67.5). Plots are in the East indicating the angle of (67.5-112.5). In the Southeast, the angle of plots is (112.5-157.5). Plots in the South show their orientation towards the South with the angle of (157.5-202.5). The southwest angle of plots is (202.5-247.5). In the west, it is (247.5-292.5). The Northwest angle of plots is (292.2-337.5). In north the angle of orientation is (337.5-360).

Slope: This layer's cells each have a slope value between 0 and 90 degrees. Darker hues indicate steeper slopes, whereas lighter hues indicate gentler slopes.

Rooftop Solar Energy Map: Higher levels of solar radiation are shown in red colours, and lesser levels are indicated in yellow and blue tones. These are a few qualities of rooftops that are good candidates for solar energy.

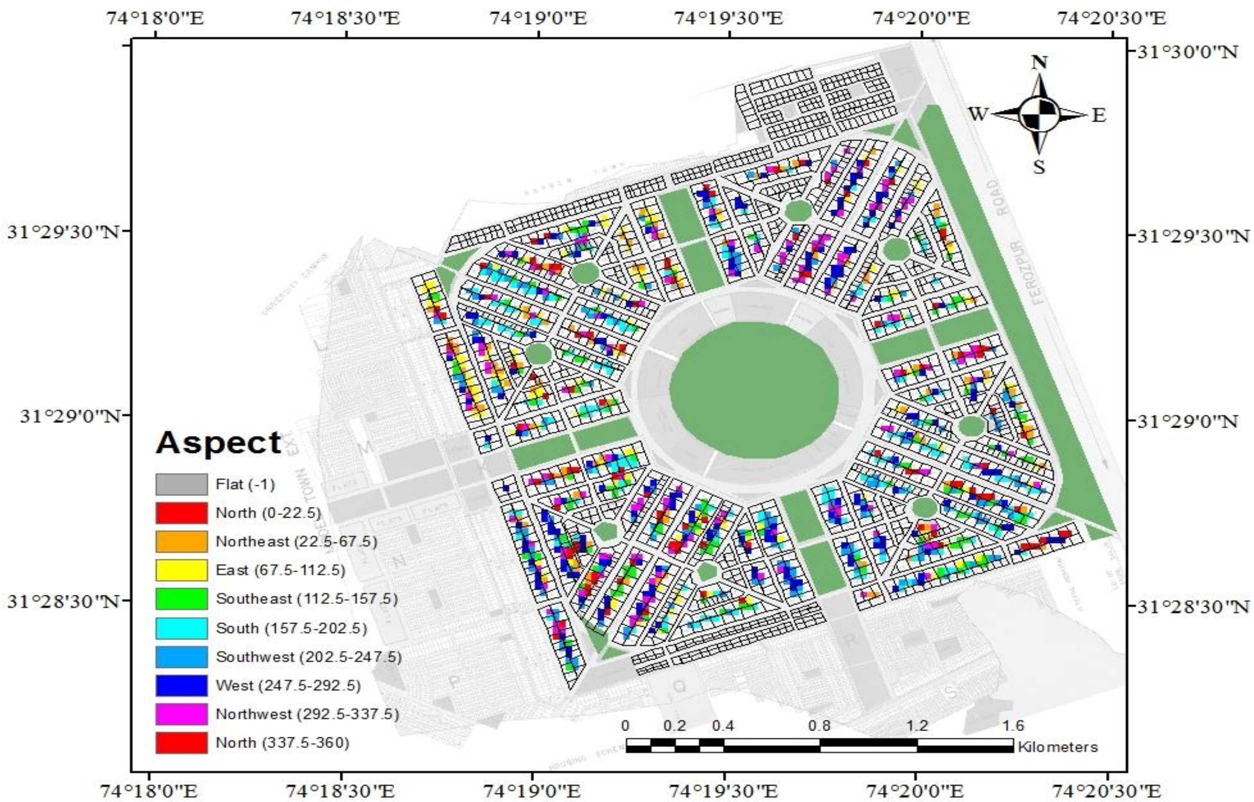

Fig 6. Aspect of Model Town

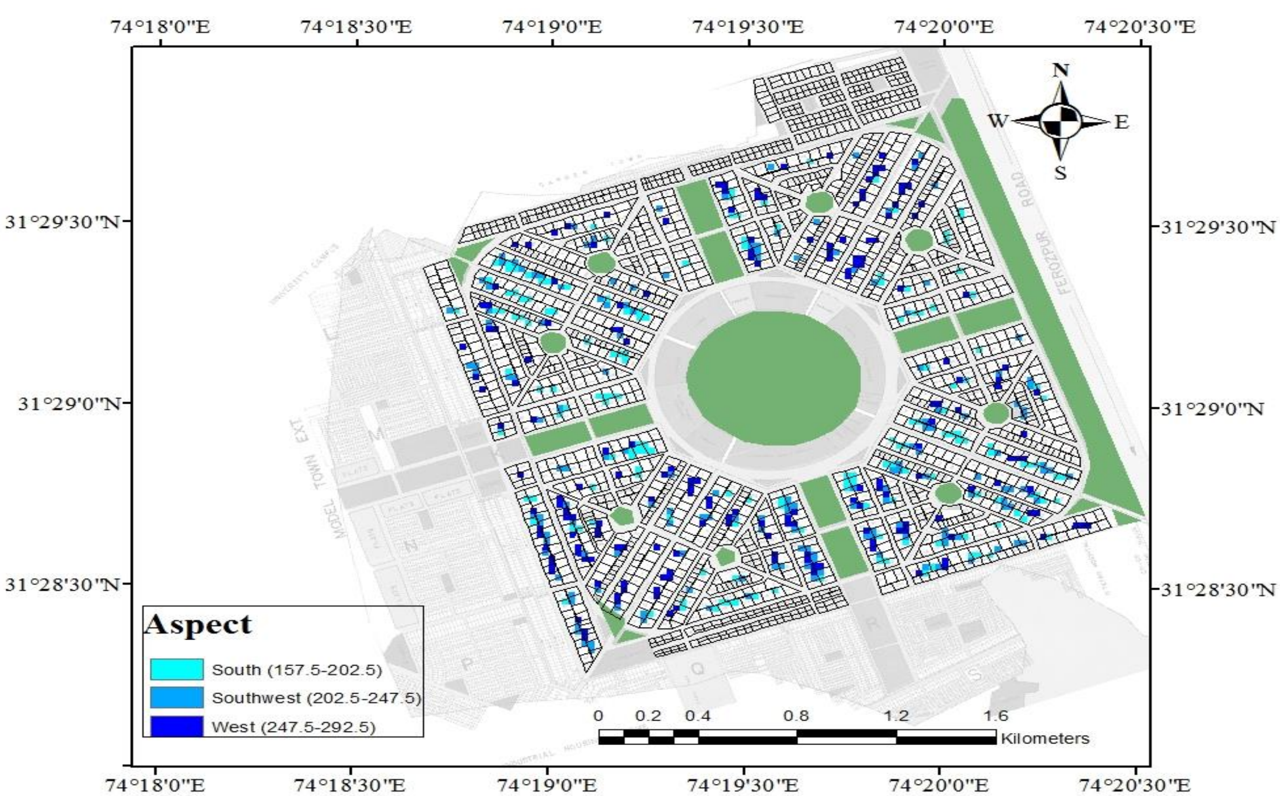

Fig: 7. Most Suited Aspect of Model Town

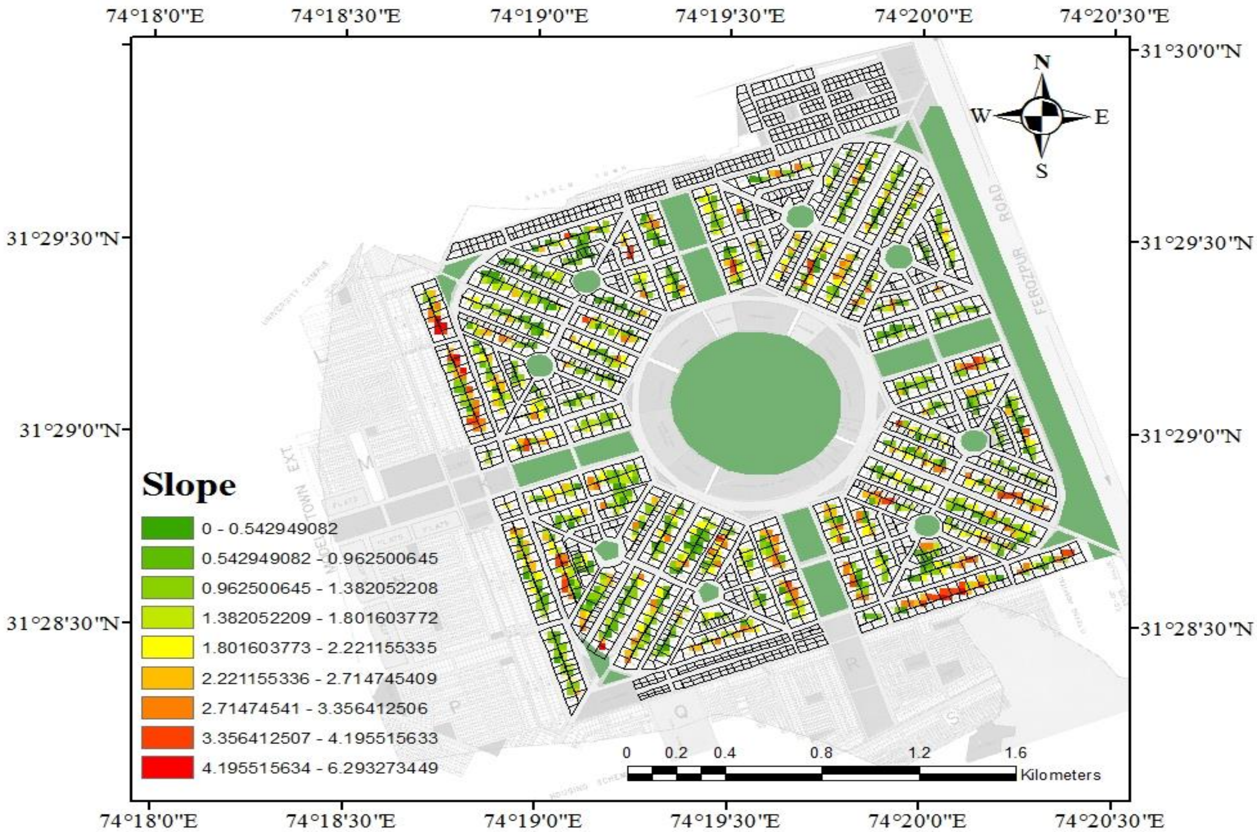

Fig: 8. Slope of Model Town

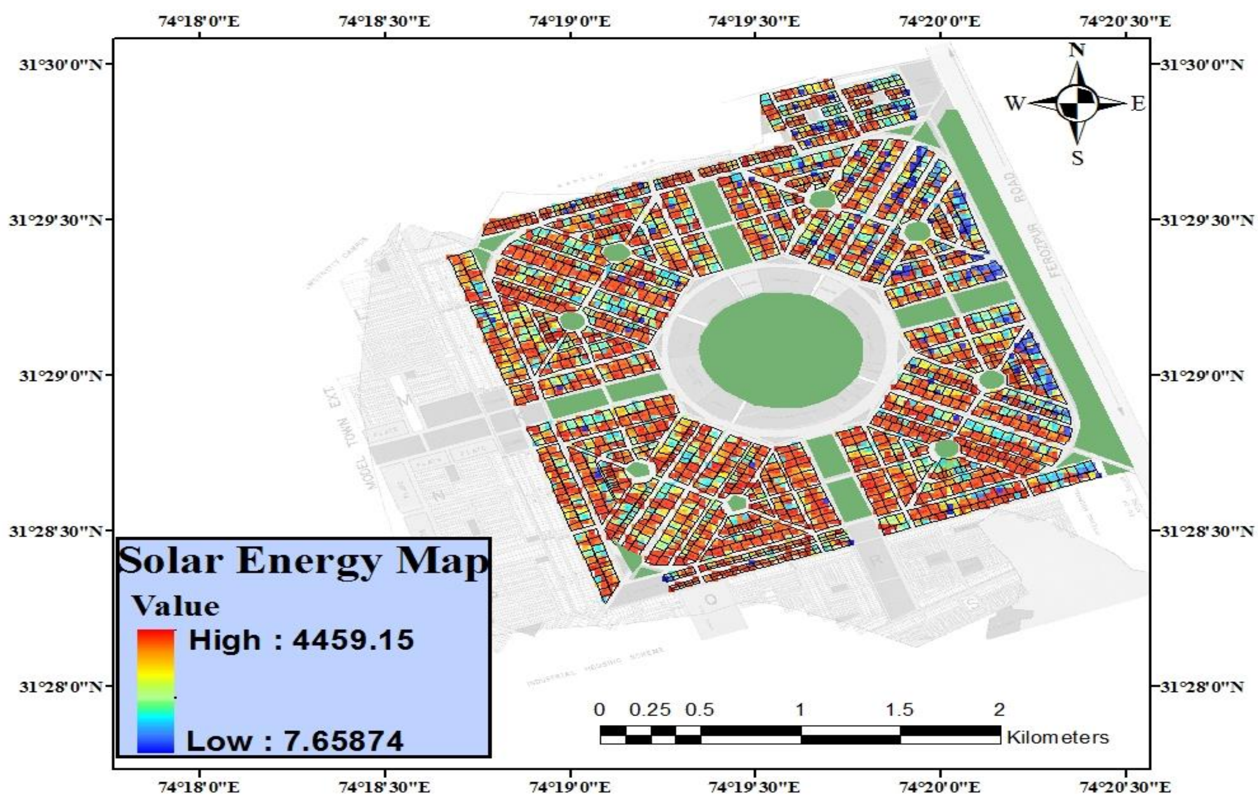

Fig: 9. Rooftop Solar Energy Map of Model Town

CONCLUSION

The sources of electricity and energy production are changing worldwide because power and energy costs have gone high worldwide, and Pakistan is not an exception. All the countries of the world are moving to the safest, cheaper and renewable resources to produce energy. An appropriate and dependable energy source is solar energy. In Pakistan, 65% of electricity generation is based on Oil and Gas. Because the country mainly depends on imported oil due to its low domestic gas and oil sources, there is a significant power shortage in the nation. The current economic condition of the country is not in favour of fulfilling these imported sources for electricity generation. To solve the energy crisis, more sustainable and renewable energy sources are needed. In Pakistan, there are several renewable energy sources available, such as biomass, solar, hydro, and wind. These resources could be of tremendous assistance to the country in its attempts to battle climate change, improve its energy production matrix for the future, and produce sustainable energy sources. The present study examined the rooftop solar energy potential and urban morphology parameters of the model town, Lahore. The maximum amount of solar radiation is 4459.15 kWh/m^2 and the minimum amount of solar radiation is 7.65874 kWh/m^2. Under the significance of results, the installation of PV panels to produce energy and electricity, on rooftops rich in solar energy potential, over the whole city is considered to be the most effective arrangement. More sustainable and renewable energy sources, including solar energy, are required to address the energy crisis since they can address the persistent energy issues that emerging nations face. Since renewable energy sources like solar are regarded as essential policy instruments for reducing greenhouse gas emissions, they play a crucial role in climate change mitigation strategies.

Conflict of interest: There is no conflict of interest among the authors.

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