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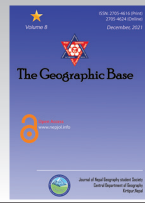

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Assessment of Solar Photovoltaic Potential of Building Rooftops Using Photogrammetry and GIS

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Abstract

As conventional non-renewable energy is becoming increasingly scarce, the development of renewable energies, such as solar energy, has become a major priority in today's world. In this study, it has developed an approach to simulate solar radiation on rooftops of Paschimanchal Campus and estimate the solar photovoltaic (PV) potential using Photogrammetry and GIS techniques. The object-based method was used to extract and classify buildings using very high-resolution data: orthophoto, the UAV-derived Digital Surface Model, and Digital Terrain Model raster layers. For more accurate estimation of solar panel installations, the evaluation of solar radiation is essential and the amount of solar radiation that was converted into solar PV potential depends upon the technical characteristics of the panel (technology used: monocrystalline or polycrystalline). Subsequently, the evaluated cost of solar panel installation was compared to the cost of grid-based electricity of the study area. The result obtained shows that 18 rooftops of the buildings are the most suitable place for solar panel installation and their usable area is 4303.67m².

For polycrystalline and monocrystalline technologies, the annual PV power generation in the study area is 868 MWh/yr and 1274 MWh/yr respectively. It was found that 1428.42m² of the suitable area was enough to fulfill the yearly demand of Paschimanchal Campus. For polycrystalline technologies, around 876 panels costing NRS.1,57,68,000 are required The cost analysis of 10 years concludes solar energy will be cheaper than grid-based electricity by NRS.1,04,10,785.

Introduction

Carbon-based energy production that is widely employed in all parts of the world is of significant interest. The stakes are high: rising the carbon dioxide concentrations of the atmosphere due to GreenHouse Gases (GHGs) emissions, environmental safety of energy production techniques, energy price volatility, and degradation of fuel reserves. To reduce global warming, renewable energy has appeared as an important constituent of energy strategy for governments at all levels: national, regional, and municipal (Ordóñez et al., 2010). Therefore, fossil fuels should be replaced with renewable energies (i.e., solar, wind, hydropower, nuclear) (Ramachandra & Shruthi, 2007). Solar energy has the highest rate of energy output and the lowest operational expenses of all the renewable resources available (IRENA, 2019).

Solar energy is radiant light and heat released from the sun. It is a renewable energy source that is natural, unlimited, clean, and reliable. Solar energy is a very flexible energy technology growing better in terms of both cost and applications. Furthermore, compared to traditional energy production methods, solar energy requires significantly less labor. Solar energy has a significant advantage over other traditional power producers in that sunlight can be transformed directly into solar energy utilizing the tiny photovoltaic cells (PV solar cells) (Shaikh et al, 2017). Solar panels have photovoltaic cells that convert sunlight into direct current, which is subsequently converted to alternating power by an inverter (Fonash et al., 2020). Solar PV potential depends upon solar radiation and the type of photovoltaic system to convert solar energy into electrical energy (Energy, n.d.). The technology for producing electrical energy with a photovoltaic system has advanced rapidly in recent decades (Kumar, 2020).

The solar panel performance is determined by the specific location of panels while installing it. Solar energy has traditionally been utilized through the installation of photovoltaic (PV) systems on building rooftops. Once installed, it lasts for 20-25 years with low care (Kumar & Sreedevi, 2018). It is still a problem to make optimum use of solar energy and meet the energy demands of both commercial and residential structures. As a result, it's vital to assess solar energy potential and look at how it's allocated throughout a building's roofs. Due to significant spatial and temporal changes in solar radiation, that are influenced by a variety of elements including roof structures, inclined faces, shadowing impacts, geographical positions, and topographic characteristics, estimating solar energy potential becomes difficult. To determine the energy potential of building roofs, several methodologies and techniques have been examined so far (Tiwari et al., 2020). Recent technological advances such as remote sensing, aerial photogrammetry, LiDAR, GIS etc., have greatly eased data acquisition, construction, and visualization (Fan et al., 2014). Aerial Photogrammetry was adopted in the study as the use of an unmanned aerial vehicle (UAV) enables the rapid, precise, and cost-effective capture of enormous areas (Sullivan, 2019). Similarly, the study used Geographic Information System (GIS)-based methodologies since they are the most practical, exact, and effective techniques for estimating usable roof characteristics that enable us in correct modeling and spatial analysis (Kouhestani, 2018).

This research assesses the possibility of estimating the solar PV potential of building rooftops and analyzes, estimates and locates the best maximum potential rooftop for solar panel installation which can be used in housing, schools, hospitals, college apartments. It also compares solar PV energy with the national grid system in terms of cost and benefits. Therefore, we devise a method for assessing PV solar potential at Paschimanchal Campus located in Gandaki Province, Pokhara, Nepal, by retrieving rooftop features using Photogrammetry and GIS.

Methods and Materials

Paschimanchal Campus premises was chosen for the study covering an area of 47,956.44 m² (96.26 *ropani*) due to easy access for the extraction of data and offering various types of roofs in different inclinations and orientations. So far, no comprehensive assessment of rooftop photovoltaic solar potential has been carried out in the study area.

The peripheral area of Paschimanchal Campus was selected for study area because of its infrastructure and resources available for research. As this research is not restricted to the number of buildings it can be applied to the large geographical areas for finding the best buildings that provide the highest solar energy. The study area was analyzed based on the slope aspect map, ESRI's Solar Analyst toolbox, Current electricity bill and solar panel installation rate on the current market scenario. The solar radiation was calculated at specific times and statistics that have been created are visualized with tables and maps.

For the study, two separate data sources were used. The first is photos obtained from UAVs, which were used to create DSM, Orthophoto, and DTM. The second is the electricity consumption bill of Paschimanchal Campus for cost analysis.

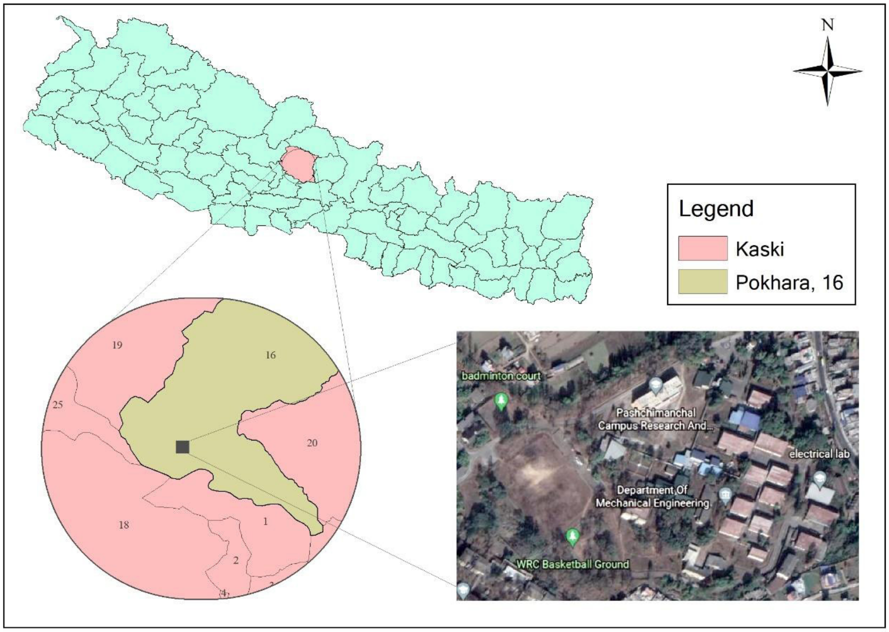


Figure 1. Study area

Orthophoto of 1cm/pixel resolution, DSM of 1cm/pixel resolution, and DTM of 0.96 m/pixel resolution were generated after performing image processing in Pix4DMapper software. These data were then utilized to extract buildings for further examination. An object-based classification using a machine learning algorithm was used to detect buildings inside the research region with the help of eCognition Developer 9. The object-based method begins with the creation of segmented objects that contain clusters of pixels with consistent feature values. To restructure the image segments, this research used a multi-level segmentation hierarchy, performing Level I and Level II classification (Tiwari et al., 2020). The orthophoto, DSM, DTM, slope, and nDSM were used to create the Level-I multi-resolution segmentation. For the creation of a segmented layer the parameters used in the multi-resolution technique are scale parameter of 10, shape factor of 0.5, and compactness of 0.7. Elevated structures such as buildings, trees, bushes were extracted from Level-I classification excluding ground features. The object-based classification's primary goal is to solely retrieve buildings. Therefore, a few additional elements were added due to the presence of vegetation on some elevated structures to attain the Level-II classification. Finally, the building's footprints of the study area were derived and outline breakages of extracted features were fixed with the help of available open-source GIS platforms (QGIS).

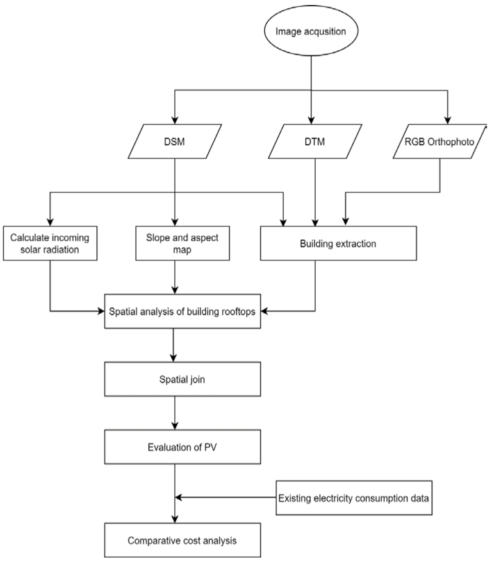


Figure 2. Flowchart of solar PV potential calculation.

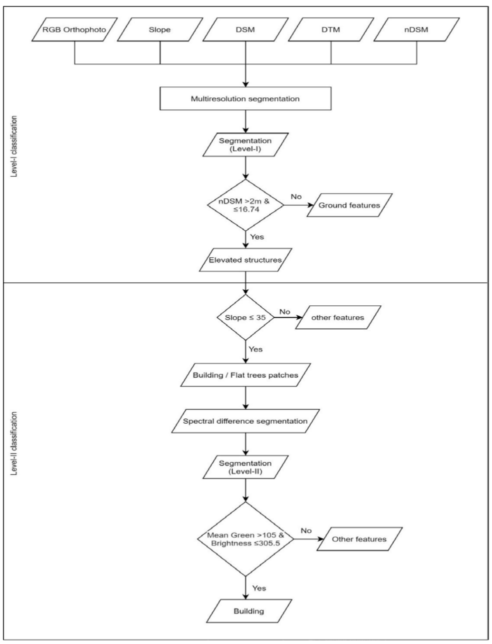


Figure 3. Methodology to achieve level-I and level-II classification

The amount of sunlight available at a given place and time are an essential requirement to design photovoltaic systems. Solar Radiation in watt-hours per meter square (wh/m²) was calculated using the area solar irradiation tool and then expressed as kilowatt-hours per meter square (kwh/m²).

For a better estimate of PV potential, a spatial analysis was undertaken over the building roofs. The slope, aspect, and solar radiation raster layer generated from DSM were incorporated for spatial analysis. The following four criteria were considered to determine suitable rooftops for solar panels installation.

1. Rooftops with a slope of 45 degrees or less are ideal, as steeper slopes receive less sunshine.

2. Rooftops for solar panel installation should receive at least 800 KWh/m² of solar radiation.

3. Suitable rooftops should not face north as such rooftops tend to receive less sunlight. 4. Usable roof surface should cover more than 20 m² area.

The usable solar radiation was then converted into electric power generation potential. The amount of power that solar panels can generate is determined by two technological parameters in addition to solar radiation (conversion efficiency, performance ratio). Based on the two current technologies on the market: - high performance (Monocrystalline) and standard yield (Polycrystalline), it is possible to calculate the entire yearly electricity production (Saadaoui et al., 2019). The electric power production potential (E) is expressed as:

E (KWh/year) =Area * Mean * PR * Nm

where, Area = Building's suitable area (m^2)

Mean = Average solar radiation for each building (KWh/m^2)

PR= Performance Ratio (%)

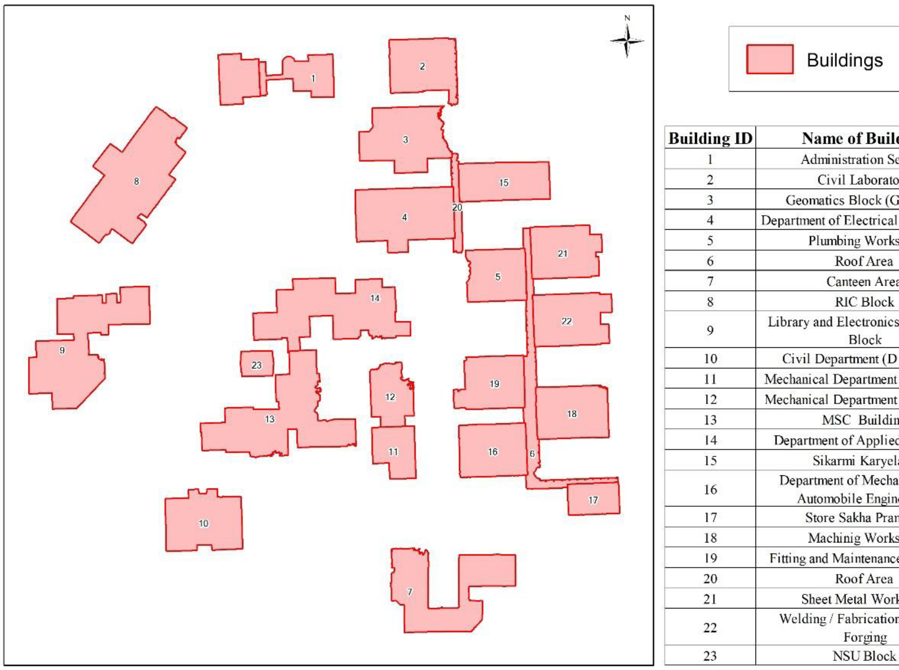
Nm= Conversion efficiency of the panel System (%)

Results and Discussion

The results showed significant PV Potential on the building rooftops of Pashchimanchal Campus.

Building extraction result

23 buildings covering an area of 13437.47 m^2 were extracted. Figure 4 shows extracted building footprint present in the study area.



Building ID	Name of Building
1	Administration Section
2	Civil Laboratory
3	Geomatics Block (G-Block)
4	Department of Electrical Engineering
5	Plumbing Workshop
6	Roof Area
7	Canteen Area
8	RIC Block
9	Library and Electronics, Computer Block
10	Civil Department (D - Block)
11	Mechanical Department (C - Block)
12	Mechanical Department (C - Block)
13	MSC Building
14	Department of Applied Sciences
15	Sikarmi Karyelaya
16	Department of Mechanical and Automobile Engineering
17	Store Sakha Pramukh
18	Machinig Workshop
19	Fitting and MaintenanceWorkshop
20	Roof Area
21	Sheet Metal Workshop
22	Welding / Fabrication Founder Forging
23	NSU Block

Figure 4. Extracted buildings in Paschimanchal campus

Slope and aspect

In our study, slope and aspect were measured in terms of degrees. In Figure 5, slope values were categorized into five different classes (0-10°, 10°-26°, 26°-46°, 46°-70°, 70°-89°) where 0° degree corresponds to a flat surface, while a 90°value specifies a completely vertical surface. In Figure 6, the aspect map was categorized into eight quadrants: North (0°), Northwest, West (270°), Southwest, South (180°), Southeast, East (90°), and Northeast. If a surface is flat, the aspect value was assigned as −1.

Figure 5. Slope from DSM

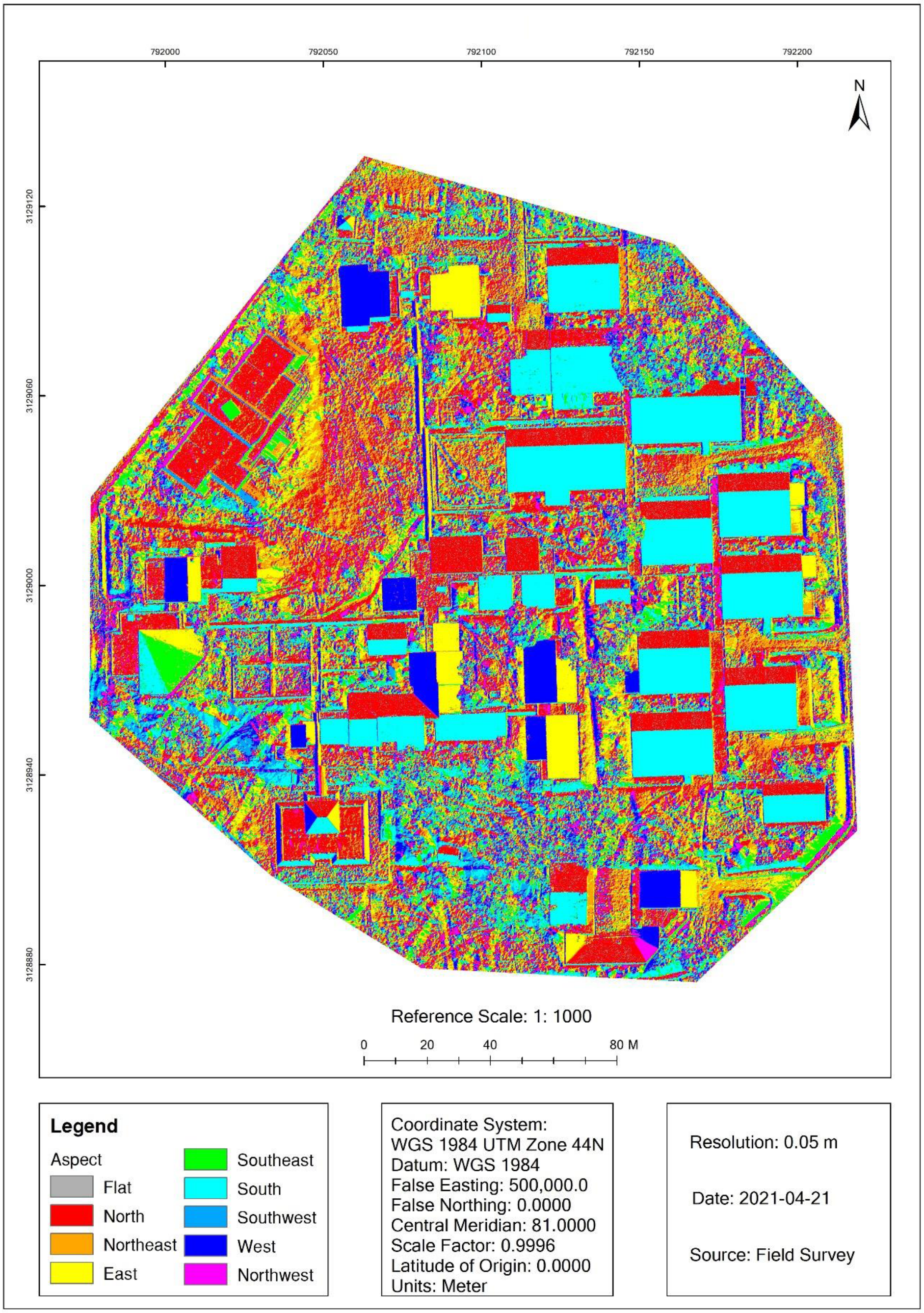


Figure 6. Aspect from DSM

Distribution of solar radiation

Figure 7 represents solar radiation distribution in the study area. The solar radiation values were scaled from 0 to 1745 KWh/m² which was further categorized into five different classes (0-674, 674-1063, 1063-1349, 1349-1582, 1582-1745). South-facing hipped roofs tend to receive more solar radiation than north-facing hipped roofs in the study area. Further, flat roofs also receive less solar radiation.

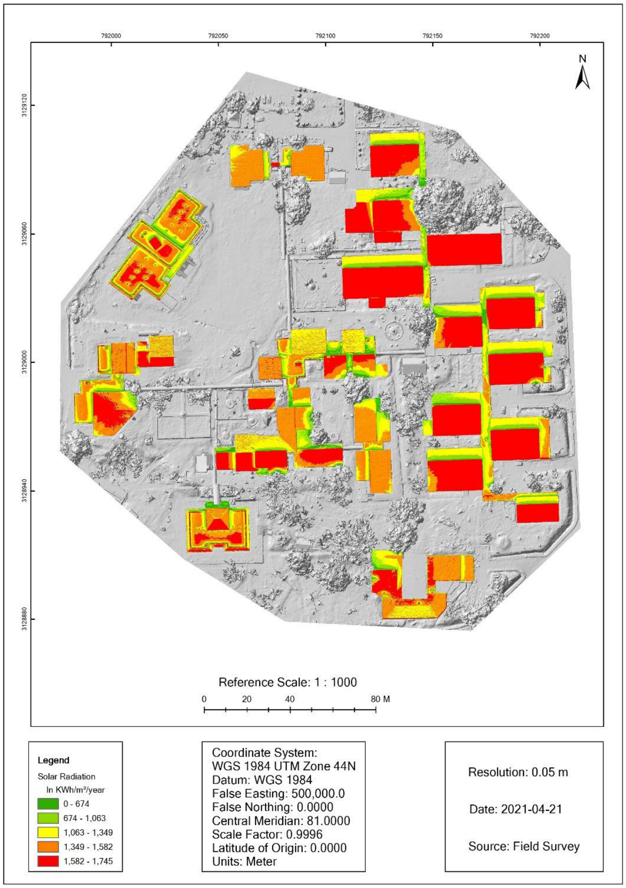


Figure 7. Solar radiation generated from GIS

Suitable building detection

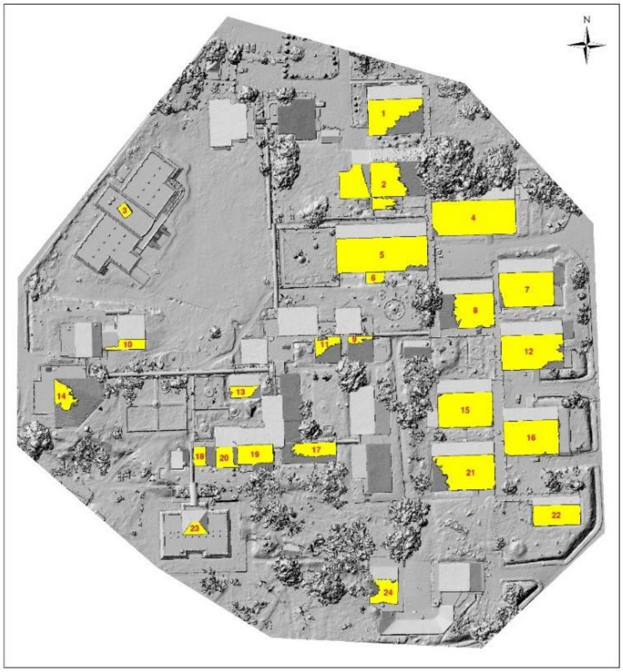
Out of 23 buildings, only 18 buildings were chosen for further research after applying four criteria for solar panel placement. Figure 8 shows the most suitable area in the Paschimanchal Campus's rooftops for solar panel installation where the yellow portion in each building indicates its suitable area. These chosen sections cover an area of more than 20 m² in the building rooftop, do not face north, have a slope less than 45°, and solar radiation greater than 800 Kwh/m². The summation of the usable area of 18 buildings is 4303.67 m².

Conversion of solar radiation to electric power

To convert the solar radiation to the quantity of electricity that can be generated by solar panels, PV Technologies (monocrystalline and polycrystalline) along with its solar panel's efficiency and the installation performance ratio are described in (Table. 1). The values of conversion efficiency and performance ratio depends upon the technology used (mono, poly), the brand of panel used.

(Table 2.) represents the detailed calculation of solar PV potential of each building (23 buildings) evaluated for both Monocrystalline and Polycrystalline technologies along with their respective total usable area for solar panel installation, and the table 2 links (Figures 4. and 8.).

The total annual electric power production potential for Monocrystalline and Polycrystalline are found to be 1274 MWh/yr and 868 MWh/yr respectively.



ID	Usable Area (m²)	Total Solar Radiation for each Building's Usable Area (MWh/ yr)
1	224.23	375.976
2	360.365	601.108
3	20.962	34.895
4	486.99	830.576
5	515.497	883.787
6	33.591	56.377
7	311.982	533.055
8	223.457	376.567
9	22.32	37.187
10	53.212	91.185
11	48.316	80.387
12	336.095	575.894
13	46.215	77.111
14	70.88	117.713
15	317.815	539.884
16	319.191	547.365
17	93.753	157.134
18	40.053	67.101
19	114.991	197.57
20	65.003	110.743
21	309.321	527.673
22	163.683	283.645
23	35.914	62.037
24	89.834	151.789

Figure 8. The most suitable area in Paschimanchal campus rooftops for solar panel installation

Table 1. PV technologies and features

Technology	Monocrystalline	Polycrystalline
Classification	Silicium (c-Si)	Silicium (mc-Si)
Dimension (mm)	1046*1559*35	1650*992*35
Power (W)	345	265
Conversion efficiency (%)	21	15
Performance ratio (%)	83	79
Brand	Sunpower X21 - 345	Trinasolar TMS - 265PDO5

Source: (Saadaoui et al., 2019)

The results show the highest PV potential values from Monocrystalline than Polycrystalline panels. The table also shows the suitability of each building for solar panel placement. The Department of Electrical Engineering located on the northeast side of the study area and RIC located on the northwest side of the study area is found to have the highest and lowest electric power production capacity respectively.

In the context of Nepal, Polycrystalline is most widely used because of its cost-effective property as compared to Monocrystalline. Thus, in our study, Polycrystalline was further considered for analysis. (Figure 9.) shows the annual electric production capacity greater than 4 MWh/yr for Polycrystalline technology.

Table 2. Detailed calculation of solar PV potential of each building

Building ID	Name of building	Area of building (m²)	ID of usable area	Usable area of each building (m²)	Electric potential using mono crystalline (MWh/ yr)	Electric potential using poly crystalline (MWh/ yr)	Remark
1	Administration section	560.63	*	*	*	*	Not suitable
2	Civil laboratory	528.16	1	224.23	66	45	Suitable
3	Geomatics block (G-Block)	673.31	2	360.37	105	71	Suitable
4	Department of Electrical Engineering	780.19	5,6	549.09	164	112	Suitable: highest
5	Plumbing workshop	438.74	8	223.46	66	45	Suitable
6	Roof area	429.63	*	*	*	*	Not suitable
7	Canteen area	869.36	24	89.83	26	18	Suitable
8	RIC block	1165.85	3	20.96	6	4	Suitable: lowest
9	Library and electronics, computer block	1084.99	10,14	124.09	37	25	Suitable
10	Civil Department (D - Block)	607.01	23	35.91	11	7	Suitable
11	Mechanical Department (C - Block)	287.96	*	*	*	*	Not suitable
12	Mechanical Department (C - Block)	329.80	*	*	*	*	Not suitable
13	MSC building	1112.46	17,18,19,20	313.80	92	63	Suitable
14	Department of Applied Sciences	1006.09	9,11	70.64	20	14	Suitable
15	Sikarmi karyelaya	500.33	4	486.99	145	98	Suitable
16	Department of Mechanical and Automobile Engineering	513.22	21	309.32	92	63	Suitable

17	Store Sakha pramukh	232.97	22	163.68	49	34	Suitable
18	Machinig workshop	542.17	16	319.19	95	65	Suitable
19	Fitting and maintenance workshop	484.03	15	317.82	94	64	Suitable
20	Roof area	104.32	*	*	*	*	Not suitable
21	Sheet metal workshop	507.46	7	311.98	93	63	Suitable
22	Welding / fabrication founder forging	561.11	12	336.10	100	68	Suitable
23	NSU block	117.70	13	46.22	13	9	Suitable
Total		13437.47		4303.67	1274	868	

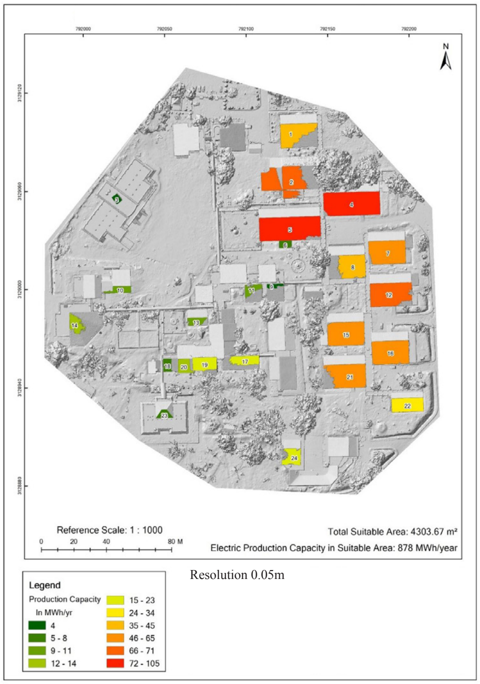


Figure 9. Annual electric production capacity of the most suitable buildings for polycrystalline

Source: Field Survey, 2021

Comparative cost analysis

The demand units per year consumed by the entire Paschimanchal campus is 288.096 MWh and the total charge per year is NRS. 38,57,162.52 approximately. The detailed solar panel installation analysis is explained in Table 3. The approximate cost per panel installation was based on the study of an installed solar power plant in Butwal. Thus, the total cost for the installation of panels (876 panels) for fulfilling the demand of the whole Paschimanchal Campus is found to be NRS 1,57, 68,000. From Figure 8 and Table 2, it is concluded that installing solar power panels in the Department of Electrical Engineering (ID 5, Usable Area 515.50 m²), Sikarmi Karyalaya (ID 4, Usable Area 486.99 m²), Geomatics Block (ID 2, Usable Area 360.37 m²) and Welding and Fabrication Founder Forging (ID 12, Usable Area 336.10 m²) with its total electric power production capacity of 342 MWh/ yr is found to be sufficient to fulfill yearly demand of electricity consumed by the college per year.

Table 3. Solar panel installation analysis

Solar panel installation analysis	
Total suitable area (square meter)	4303.67
Total production capacity (Mwh/ Year)	868
Total demand per year in Paschimanchal Campus (Mwh)	288.096
Total area to cover for demand (square seter)	1428.42
Model area (square meter)	1.63
Model power (Wh)	265
Total number of panels required to meet demand	876
Approx. cost of panel installation (NRS)	18000
Total cost of installation (total panel * per panel cost) (NRS)	15768000
Per year average solar panel maintenance cost (NRS)	1000
Per year total solar panel maintenance cost (NRS)	876000

From the 10-years of cost analysis between the solar panel installation and the national grid-based electricity, it was found that solar energy would be cheaper than national grid by NRS. 1,04,10,785.

Conclusion

Since the energy demand is increasing day by day, solar energy is a very promising, effective and beneficial source of energy. This research is primarily focused to determine an appropriate location for solar panel installation by maximizing the amount of energy. Accurate assessment of slope, aspect, the orientation of the building rooftops is key points for the determination of solar energy which were extracted based on cost-effective orthophoto and object-based methods. By avoiding the expensive lidar technique, this algorithm promises a better result for estimation of solar energy that yields on flat, pitched surface and classified the best building to put solar panels in order to meet the user energy requirements over the specific period with a limited amount of resources.

The results demonstrate that the derived method of calculation can accurately predict the solar radiation, exact slope and aspect at which building rooftops will generate high solar energy throughout a year. These results also show that solar panels installation is cost-effective when used for a longer period if the selection of the building and direction are as guided by the algorithm of this research.

The lack of cloud cover analysis and rooftop type analysis is the limitation of the current study Still, the proposed method can be applied for the accurate solar panel sizing for commercial use, households use and other private housing investors with the effective consumption of the renewable source of energy without worrying about a large amount of cost in comparison of current grid electricity charges.

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