Solar potential assessment and its feasibility using semi-automatic feature extraction and pyranometer for smart cities

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Abstract

The over-exploitation of non-renewable resources for energy demands is a serious issue. Convergence towards renewable resources such as solar energy is need of the day. Solar energy is the cleanest form of energy available on Earth. The objective of this research is to extract the building rooftop from the satellite images using a k-means clustering algorithm to identify the usable area for solar potential assessment. The scenes of WorldView-3 and Google Earth are segmented into nine parts and the algorithm implemented in Matlab is applied to the individual parts for better utilization of computing resources. This approach has been applied to the Har Ki Pauri, Haridwar that is situated in the northern part of India for solar potential assessment in a fast and accurate manner. The Global Horizontal Irradiance (GHI) data obtained from the database of National Renewable Energy Laboratory (NREL), United States have been used in the solar potential assessment. The validation of the solar potential obtained has been performed using pyranometer data. For the validation purpose, the above-mentioned algorithm has been compared with the digitization in QGIS software. The results obtained from the above-mentioned algorithm developed have extracted 85% to 90% of the features in the satellite image. The developed algorithm has given best results with the WorldView-3 (high-resolution image) than the other coarser resolution scenes. The developed approach is helpful in evaluating the feasibility of the large areas for solar potential assessment. This methodology is useful for the implementation of different government's solar energy generation schemes for rural and hilly areas. It helped in estimating the solar potential of the large hilly area for electricity generation.

This approach is useful for a larger area as it computes the usable area by dividing the scenes into smaller parts and applies the algorithm individually to each part of the scene.

Keywords
k-means clustering, GHI, rooftop, solar potential, Google Earth, WorldView-3

1. Introduction

Remote Sensing is helping us in many applications such as feature extraction, classification, etc. Satellite images of various resolutions are available through many remote sensing satellites. The satellite images are of different resolutions that range from some centimeter to meters. Centimeter level resolution images are known as high resolutions images. High-resolution images contain the information of easily extractable features such as rooftops, buildings, roads, and trees. Therefore these high-resolution images have been used by many researchers to extract rooftops using segmentation, image processing techniques, remote sensing, and Geographic Information System (GIS) analysis [1]–[5].

In the early stage of Geomatics, feature extraction has been performed using manual digitization process [6], [7]. This is not only an accurate method of feature extraction from the satellite images but also highly skilled manpower is needed for the same.

Rayleigh scattering and aerosols play an important role in determining the solar irradiance reaching the Earth's surface. Most of the energy radiations coming from the Sun are in the wavelength range of 300 nm to 2400 nm as shown in Figure 1 [8]–[10]. Solar irradiance has been analyzed and predicted by many researchers to predict solar potential available at the location [11], [12]. The best way to convert the solar energy into electricity is through Solar Photovoltaic (SPV) panels [4], [5], [13]–[16].

Pyranometer has been utilized to predict the solar potential of the small and large area for solar plant feasibility studies [13], [14]. The pyranometer data provides the validation of the predicted and calculated Global Horizontal Irradiance

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(GHI) values [13]. In this study, the pyranometer data has been used to compare the results obtained using GHI data from National Renewable Energy Laboratory (NREL), United States [17]–[20]. The pyranometer used in this study works in the wavelength range of 305 nm to 2800m.

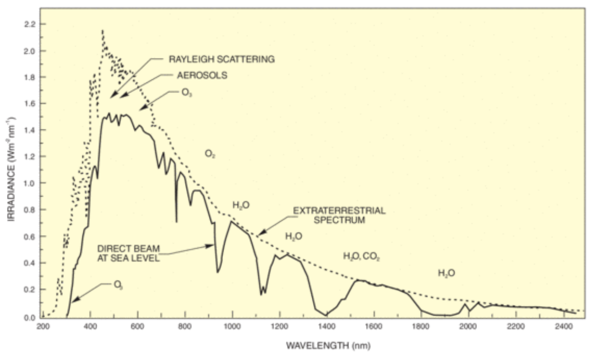


Fig. 1 Solar irradiance enters into the Earth's atmosphere. The dotted line shows extraterrestrial irradiance [21]

The rest of the paper is organized into four sections. The study area has been shown in section 2. Methodology and its flowchart are described in section 3. Results have been shown in section 4 with a discussion about the results obtained. Conclusions of this study have been analyzed in section 5 with future scope for related studies.

2. Study area

Har Ki Pauri has been selected as the study area for this study (Figure 2). This place is located in the holy city of Haridwar, Uttarakhand, India [22]. The central coordinates of this location are latitude 29.958506°, longitude 78.172681°, and altitude 286m [23]. The area and perimeter of the study area are 276142 m^2 and 2061 m respectively. Socioeconomic data has been used to estimate the energy requirement of the study area [24].

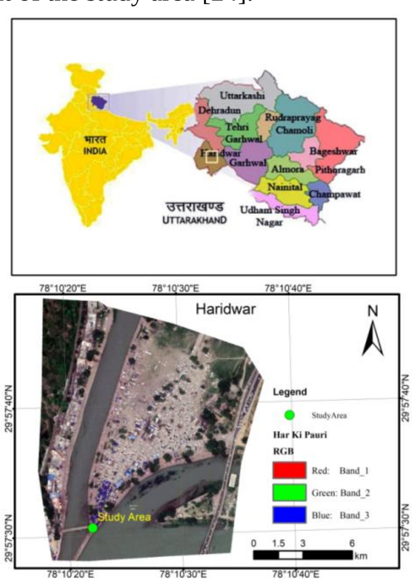


Fig. 2 Study area selected for this study

3. Methodology

Semi-automatic rooftop extraction approach has been applied to assess the solar potential of the selected study area described in the previous section (Figure 3). High-resolution satellite images of this study area have been downloaded from the Google Earth and SGIS tools [23], [25]. Complete study area in high-resolution images is too big to process the k-means clustering algorithm on it using processor i7 (8^{th} generation) and 8GB RAM. It is recommended from this study that segmentation is a good approach to process the larger area for the k-means clustering algorithm. Therefore this study area has been divided into nine parts for algorithm processing. Image segmentation has been performed to segment it into nine parts.

Blue coloured rooftops of the selected study area have been extracted using k-means clustering shown in algorithm 1. This semi-automatic approach algorithm has been utilized to extract rooftops in the Matlab programming environment [26].

Algorithm 1: k-means clustering [27]

a. Input the coloured image (jpg format)
b. Convert the image to RGB to L*a*b* color space
c. Apply k-means algorithm to classify the colours in a*b* space
d. Tag the pixels using k-means results
e. Images have been produced using segments of H&E colours
f. The result is a segmented image

K-means clustering algorithm has been performed on the individual part to extract blue coloured rooftops for usable area calculation. The algorithm has been implemented using Matlab on each segmented part of the study area to extract rooftops. Out of the nine-segmented parts, seven parts contain the rooftop information. These segmented parts then combined together to analyze the complete usable area available for solar potential assessment. This algorithm has extracted almost most of the blue coloured rooftops at this location. The value of the usable area has been calculated using high-resolution satellite imagery mosaic and GIS analysis in ArcMap 10.3 [28].

GHI from NREL has been obtained to assess the solar potential assessment on the rooftops at Har Ki Pauri, Haridwar. This GHI has been converted into the tilted GHI for utilizing the maximum solar irradiance falling on the SPV panels [29]. An algorithm has been implemented using Perl programming language to convert GHI (H) into tilted GHI (H_T). Equation 1 has been utilized to convert GHI into tilted GHI. H_b, H_d, and H_r are the beam, diffuse and reflected irradiance respectively used for this study. The tilt factors for the beam, diffuse, and reflected irradiance are R_b, R_d, and R_r respectively.

$$H_T = H_bR_b + H_dR_d + H_rR_r \quad (1)$$

Researchers have mentioned 10-15% of uncertainty in the satellite-based GHI calculation [30]. Pyranometer data have been utilized for solar potential assessment for this study. Instantaneous GHI values from pyranometer have been used to calculate solar potential at an instance for validation purpose. Pyranometer readings have been analyzed to predict the solar potential at an instance for this study. The outputs of this pyranometer are GHI (W/m^2) and Daily Horizontal Irradiance (Wh/m^2). GHI is the sum of the diffuse and beam irradiances [8], [15], [31]. In this pyranometer, GHI has been calculated using equation 2 mentioned below[32].

$$E_e = DDP/S \tag{2}$$

E_e = Irradiance (W/m^2)
DDP = Multimeter has been used to calculate the potential difference (μV)
S = Constant used in this equation i.e. 15.20 μV (W/m^2)

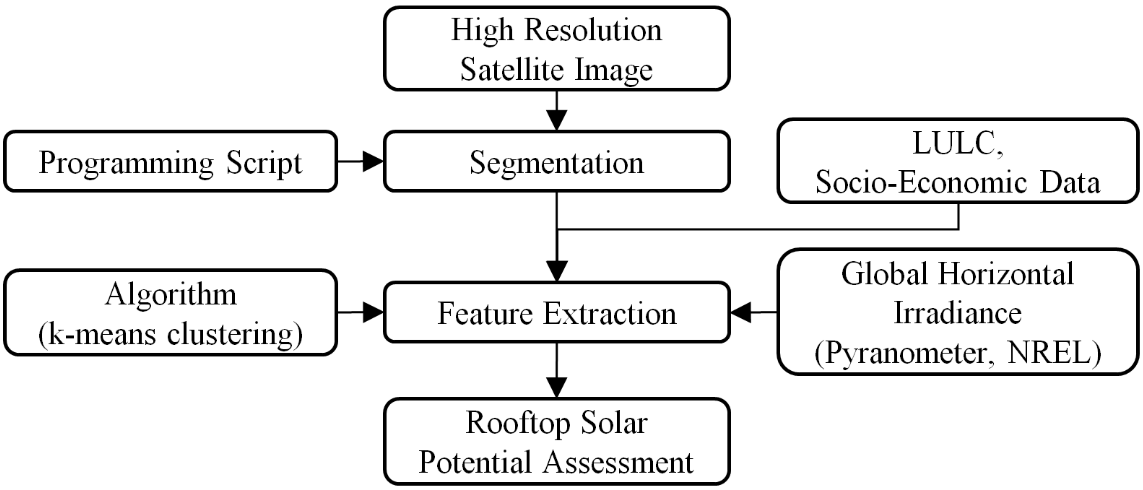
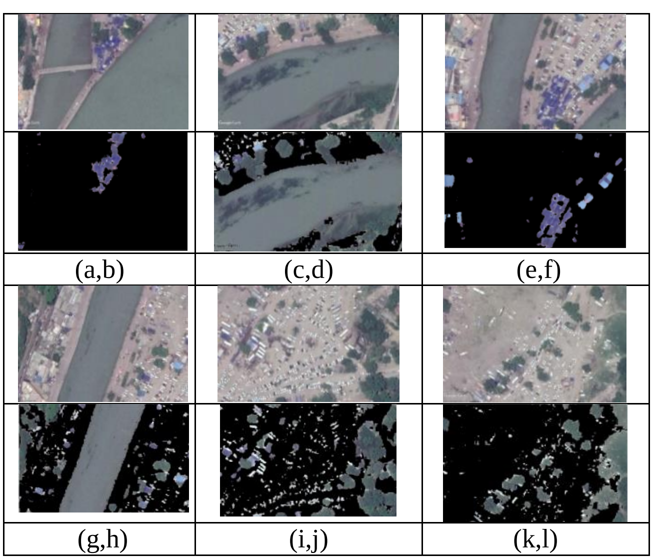


Fig. 3 The methodology adopted for the study

4. Results

It has been found from the results that almost 90% of the rooftops have been extracted using a k-means clustering algorithm (Figure 4). It has been found from the results that out of nine segmented parts, seven parts contain the rooftop information.



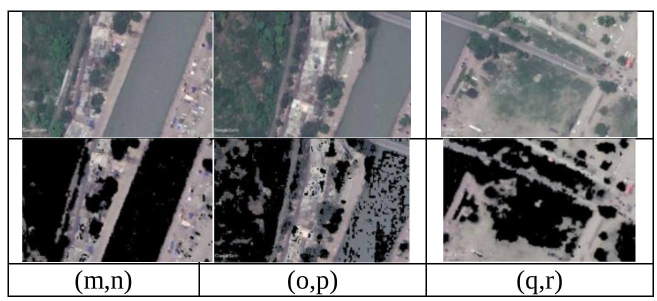


Fig. 4 (a to r) (a) Segmented part of the study area and (b) Extracted rooftops using semi-automatic rooftop extraction approach applied on nine segmented parts, respectively

The complete rooftop areas of the study area have been developed by combining the outputs of the semi-automatic rooftop algorithm (Figure 5). This figure shows the extracted blue coloured rooftops. The shape, colour, size, and texture information have been used to identify the features as rooftops. GIS technology and outputs have been analyzed in ArcMap 10.3 to calculate the value of the rooftop's area for SPV installations (Figure 6). The total rooftop area for this study is 4228 m^2. Parameters such as SPV infrastructure and maintenance have been taken into consideration for the usable areas to install the SPV panels. This usable area is the actual calculated area after taking care of all the parameters described above. Therefore out of the total rooftop area, 85% i.e. 3594 m^2 has been considered for solar potential assessment.

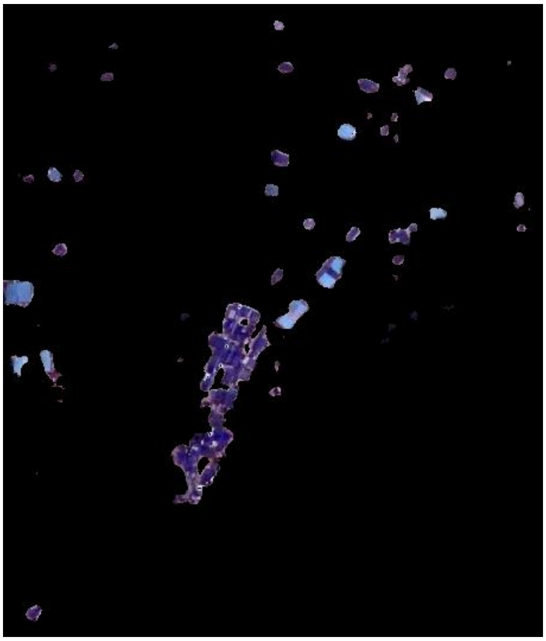


Fig. 5 Extracted rooftops over the complete study area selected for this study

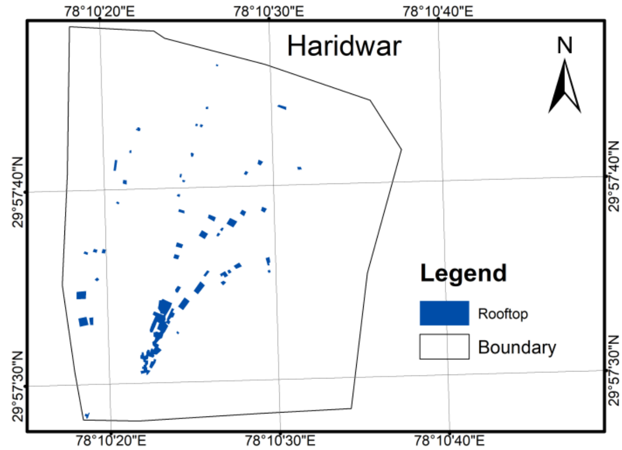


Fig. 6 Rooftops extracted using GIS analysis for usable area calculations

The parameters such as GHI, tilted GHI, and tilt angle considered for solar potential assessment in this study are shown in Table 1. The average monthly solar potential assessed is 20.8413 MW

Table 1 Solar potential assessment over Har Ki Pauri rooftops

Year	Month	GHI ($kWh/m^2/day$)	Tilt Angle (degree)	Tilted GHI ($kWh/m^2/day$)	Solar Potential (MWh)
GHI Average Data 2002-2008	January	3.284	19.96	4.175	15.005
	February	4.433	19.96	5.286	18.998
	March	5.889	19.96	6.559	23.573
	April	6.781	19.96	7.100	25.518
	May	7.411	19.96	7.469	26.844
	June	6.516	19.96	6.453	23.192
	July	5.532	19.96	5.510	19.803
	August	5.239	19.96	5.362	19.271
	September	5.317	19.96	5.745	20.648
	October	5.213	19.96	6.104	21.938
	November	4.206	19.96	5.342	19.199
	December	3.406	19.96	4.481	16.105
	Annually	5.270	19.96	7.056	25.360

The value of GHI obtained by pyranometer is 724 Wh/m^2 (Table 2). This value has been converted into the tilted GHI i.e. 738.74 Wh/m^2. The solar potential for an instance using pyranometer is 2.655 MW. This value shows it is feasible to install solar potential at this location and also validates the results obtained using tilted GHI data.

Table 2 Solar Potential assessed using pyranometer data (instance)

Date/ Time	GHI (Wh/m^2)	Tilt Angle (degree)	Tilted GHI (Wh/m^2)	Solar Potential (MW)
11-09-18 /14:18:53	724	19.96	738.74	2.655

Energy requirements for this study area have been calculated using India census 2011 data and software tool [24], [33]. The value of total energy consumption for this location is 1.53 MWh (Table 3). This value shows that it is feasible to obtain the required electricity by installing the rooftop solar plant.

Table 3 Energy requirements of the selected study area using India Census 2011 data

#	Houses	Population	Requirement (per capita, kWh)	Total Energy consumption (MWh)
1	70	280	5.46	1.53

5. Conclusions

The main objective of this study was to estimate the usable area and feasibility study of the solar plant at Har Ki Pauri, India. The semi-automatic feature extraction approach helped in extracting the rooftops. These extracted rooftops along with GIS analysis have been utilized to calculate the rooftop's area. The semi-automatic feature extraction approach helped in extracting approximately 90% of the rooftops. The solar potential assessment and energy requirement analysis of this location showed it is feasible to install SPV panels for electric power generation. GHI from pyranometer at the local level and GHI [NREL] extracted using satellite images have been utilized in this study. In this study, the semi-automatic feature extraction approach has been combined with the feasibility study for solar potential assessment using Big data cloud environment. These types of solar potential assessments help government bodies in smart city policy making and providing subsidies to the people living in the rural or hilly terrains.

The results of this semi-automatic approach can be improved by using higher resolution satellite image for accurate prediction and assessment. Vegetation, trees, shadows have not considered for this study. These parameters can be taken into consideration in related studies.

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References

[1] A. A. F. Husain, W. Z. W. Hasan, S. Shafie, M. N. Hamidon, and S. S. Pandey, "A review of transparent solar photovoltaic technologies," *Renew. Sustain. Energy Rev.*, vol. 94, no. July, pp. 779–791, 2018.

[2] M. Ghanea, P. Moallem, and M. Momeni, "Automatic building extraction in dense urban areas through GeoEye multispectral imagery," *Int. J. Remote Sens.*, vol. 35, no. 13, pp. 5094–5119, 2014.

[3] G.- Data, *GIScience Remote Sensing Retrieval of High Resolution Land Surface Temperature Using Landsat 5 TM and*. 2017.

[4] I. Gherboudj and H. Ghedira, "Assessment of solar energy potential over the United Arab Emirates using remote sensing and weather forecast data," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 1210–1224, 2016.

[5] R. M. Moharil and P. S. Kulkarni, "A case study of solar photovoltaic power system at Sagardeep Island, India," *Renew. Sustain. Energy Rev.*, vol. 13, no. 3, pp. 673–681, 2009.

[6] O. Sharma, D. Mioc, and F. Anton, "Polygon feature extraction from satellite imagery based on colour image segmentation and medial axis," *Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 37, no. B3a, pp. 235–240, 2008.

[7] B. Liss, M. D. Howland, and T. E. Levy, "Testing Google Earth Engine for the automatic identification and vectorization of archaeological features: A case study from Faynan, Jordan," *J. Archaeol. Sci. Reports*, vol. 15, no. September, pp. 299–304, 2017.

[8] A. Kazantzidis, E. Nikitidou, V. Salamalikis, P. Tzoumanikas, and A. Zagouras, "New challenges in solar energy resource and forecasting in Greece," *Int. J. Sustain. Energy*, vol. 37, no. 5, pp. 428–435, 2018.

[9] Z. Qu *et al.*, "Fast radiative transfer parameterisation for assessing the surface solar irradiance: The Heliosat-4 method," *Meteorol. Zeitschrift*, vol. 26, no. 1, pp. 33–57, 2017.

[10] M. Taylor, P. G. Kosmopoulos, S. Kazadzis, I. Keramitsoglou, and C. T. Kiranoudis, "Neural network radiative transfer solvers for the generation of high resolution solar irradiance spectra parameterized by cloud and aerosol parameters," *J. Quant. Spectrosc. Radiat. Transf.*, vol. 168, pp. 176–192, 2016.

[11] X. Zhou, J. Yang, F. Wang, and B. Xiao, "Economic analysis of power generation from floating solar chimney power plant," *Renew. Sustain. Energy Rev.*, vol. 13, no. 4, pp. 736–749, 2009.

[12] I. Kougias *et al.*, "The potential of water infrastructure to accommodate solar PV systems in Mediterranean islands," *Sol. Energy*, vol. 136, pp. 174–182, 2016.

[13] C. A. Bode, M. P. Limm, M. E. Power, and J. C. Finlay, "Subcanopy Solar Radiation model: Predicting solar radiation across a heavily vegetated landscape using LiDAR and GIS solar radiation models," *Remote Sens. Environ.*, vol. 154, pp. 387–397, 2014.

[14] M. A. Martínez, J. M. Andújar, and J. M. Enrique, "A new and inexpensive pyranometer for the visible spectral range," *Sensors (Switzerland)*, vol. 9, no. 6, pp. 4615–4634, 2009.

[15] C. F. Peruchena and A. F. Amores, "Uncertainty in monthly GHI due to daily data gaps," *Sol. Energy*, vol. 157, no. August, pp. 827–829, 2017.

[16] Y. Su, "A Comparative Analysis of the Performance of a Grid-Connected Photovoltaic System Based on Low-and High-Frequency Solar Data," *Int. J. Green Energy*, vol. 12, no. 12, pp. 1206–1214, 2015.

[17] NREL, "Inventory of Solar Radiation / Solar Energy Systems Estimators, Models, Site- Specific Data, and Publications," 2016.

[18] J. R. Janke, "Multicriteria GIS modeling of wind and solar farms in Colorado," *Renew. Energy*, vol. 35, no. 10, pp. 2228–2234, 2010.

[19] M. Sengupta, P. Gotseff, M. Sengupta, and P. Gotseff, "Evaluation of Clear Sky Models for Satellite-Based Irradiance Estimates Evaluation of Clear Sky Models for Satellite-Based Irradiance Estimates," no. December, 2013.

[20] M. Kapoor and D. Bassir, "Climate change for agriculture, forest cover and 3D Urban models," in *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, 2014, vol. 40, no. 8, pp. 787–791.

[21] Newport, "Introduction to Solar Radiation," *Newport Corporation*, 2018. [Online]. Available: https://www.newport.com/t/introduction-to-solar-radiation. [Accessed: 01-Sep-2018].

[22] Wikipedia, *Har Ki Pauri*. Haridwar, 2018.

[23] Google Earth, "Google Earth," 2018. [Online]. Available: https://earth.google.com/web/. [Accessed: 30-Jan-2018].

[24] Census Population Data, "Haridwar District Population Census 2011, Uttarakhand literacy sex ratio and density," *Census Population Data*, 2015. [Online]. Available: https://www.census2011.co.in/census/district/586-haridwar.html. [Accessed: 02-Sep-2018].

[25] Elshayal, "Elshayal Smart GIS 18.022," 2018. [Online]. Available: https://freesmartgis.blogspot.com/.

[26] Mathworks, "Deep Learning with Matlab," *Introd. Deep Learn. with MATLAB*, p. 15, 2017.

[27] MathsWorks, "Color-Based Segmentation Using K-Means Clustering - MATLAB & Simulink Example - MathWorks India," *MathsWorks*, 2018. [Online]. Available: http://in.mathworks.com/help/images/color-based-segmentation-using-k-means-clustering.html;jsessionid=274172036a725ca7bc89020ded9e. [Accessed: 16-Aug-2018].

[28] Esri, "ArcGIS 10.3.1 for Desktop quick start guide—Help | ArcGIS Desktop," 2018. [Online]. Available: http://desktop.arcgis.com/en/arcmap/10.3/get-started/quick-start-guides/arcgis-desktop-quick-start-guide.htm. [Accessed: 01-Sep-2018].

[29] S. P. Sukhatme and J. K. Nayak, *Solar Energy: Principles of Thermal Collection and Storage*, Third. New Delhi: Tata McGraw-Hill Education, 2008.

[30] PV-Tech, "The art and science of pyranometers," *PV-Tech*, pp. 48–51, 2015.

[31] T. Muneer, X. Zhang, and J. Wood, "Evaluation of an innovative sensor for measuring global and diffuse irradiance, and sunshine duration," *Int. J. Sol. Energy*, vol. 22, no. 3–4, pp. 115–122, 2002.

[32] DeltaOHM, "LP PYRA 03 - Datasheet." pp. 1–12, 2007.

[33] M. Kapoor and R. D. Garg, "Cloud computing for energy requirement and solar potential assessment," *Spat. Inf. Res.*, vol. 26, no. 4, pp. 369–379, 2018.