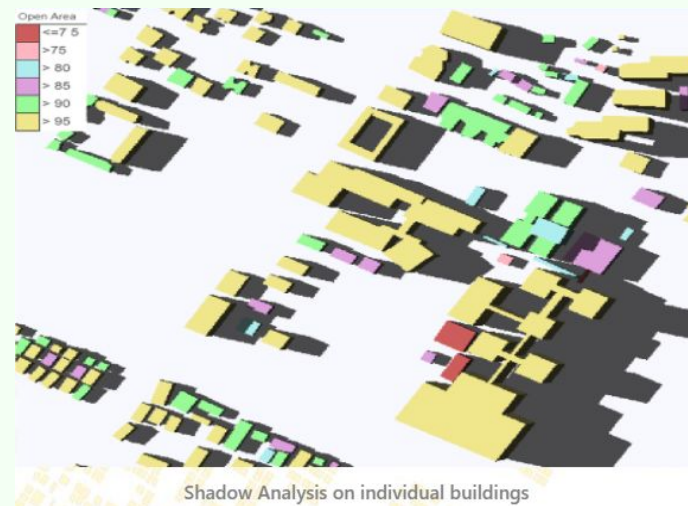


Integrated approach of Deep Learning & 3D GIS for characterizing Building Rooftop Solar Energy Potential in Cities

Supporting National Priorities and the SDGs | 12th October, 2022

Author: Kriti Rastogi



Current Status of Solar Energy in India

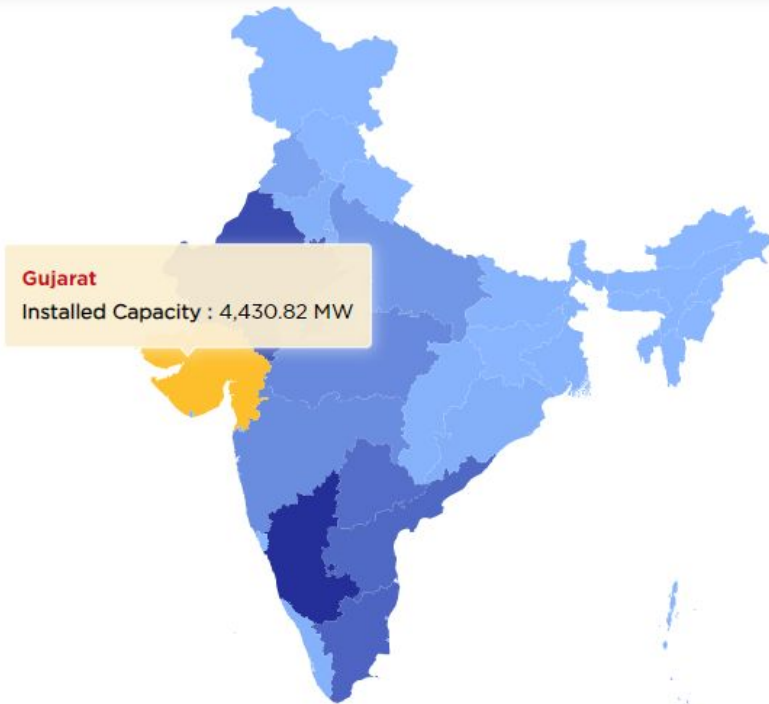
Menu



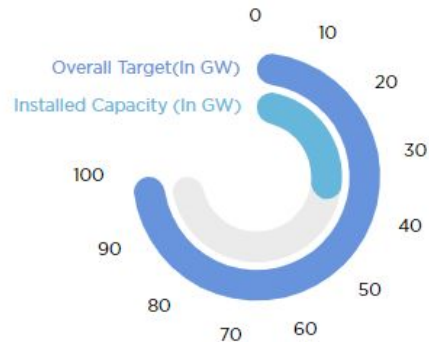
GOVERNMENT OF INDIA
MINISTRY OF NEW
AND RENEWABLE ENERGY



En हि - A + Subscribe



As on 31st March 2021



Offgrid Application



National Priorities for Solar Energy

- The Ministry of New and Renewable Energy (MNRE) initiated a programme on “Development of Solar Cities” aiming to meet a minimum 10% of their projected demand of conventional energy through increasing renewable energy sources and energy efficiency measures. However, it remains obscure how much of the solar energy resource exists over these cities, which can be tapped for meeting their energy demand.
- As the world becomes more urban, with an expected influx of 2.5 billion people into urban areas by 2050, an increase in built infrastructure to support this influx is expected, rendering urban areas as critical venues for distributed supplier of solar energy power generation.
- Locating suitable rooftops, particular attention has been focused on urban areas for their high density of rooftops.
- Characterization of solar energy incidents building rooftop is critically important for promoting the wide penetration of renewable energy in high-density cities. However, it has been a long-standing challenge due to the complex building shading effects and diversified rooftop availability.



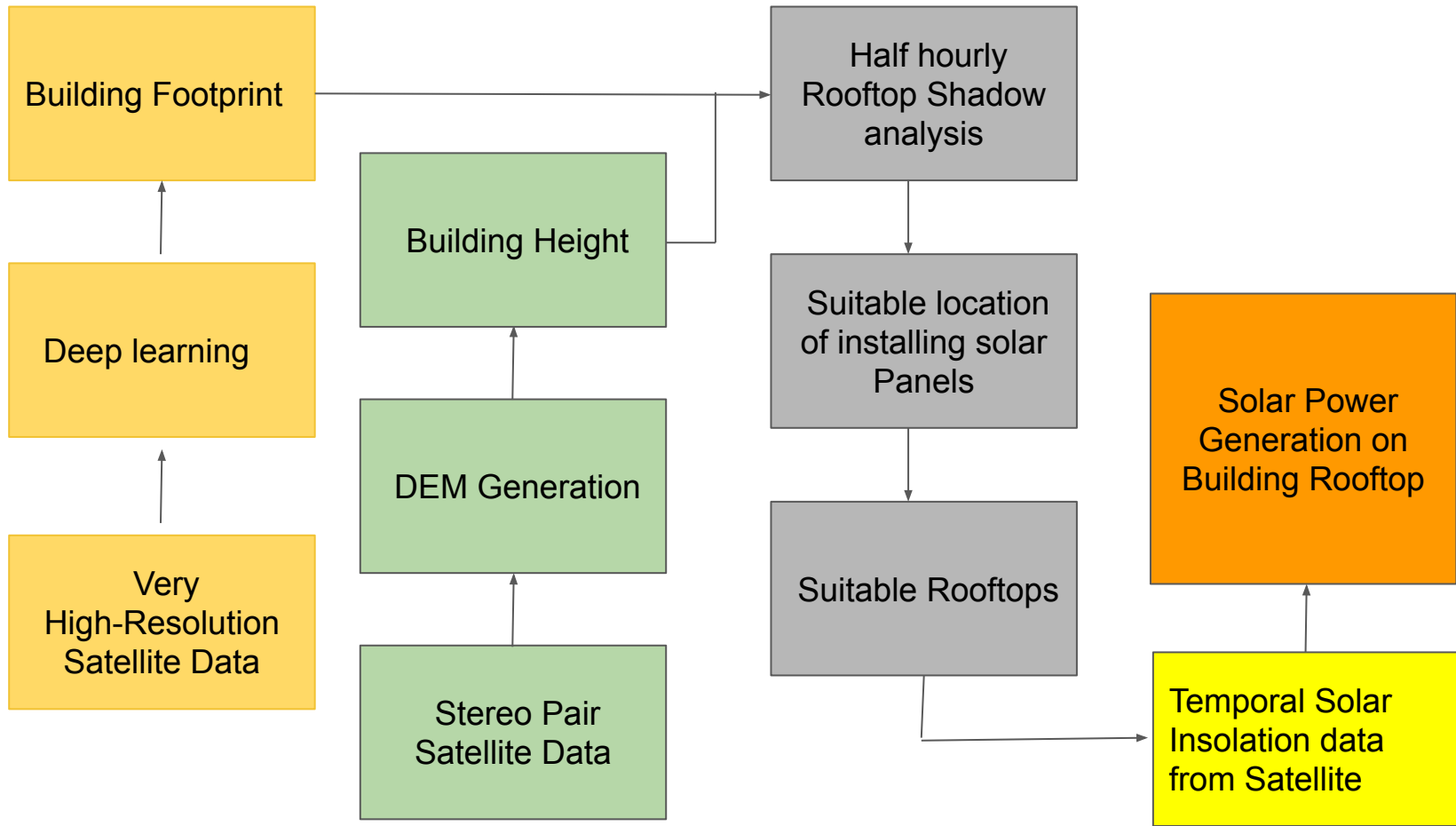
SUSTAINABLE DEVELOPMENT GOALS



Introduction

- Solar energy potential characterization is critically important for promoting the wide penetration of renewable energy in cities.
- This study proposed an integrated approach of 3D-geographic information system (GIS) and deep learning, for characterizing building solar rooftop energy potential in urban regions,
 - In this framework, **deep learning is used to identify the rooftop availabilities.**
 - **3D GIS based Digital Surface Models (DSMs) is used to extract height information of buildings.**
 - In this study, we overcome **challenges of complex building shadow effects on rooftop, by taking shadow effects of surrounding into account.**
 - **Technical Solar energy potential on rooftop from high density cities.**
 - Proposed framework helps to meet conventional energy usage in cities and improves the target of increase in usage of solar renewable energy sources in urban environment.

Framework for characterizing Solar Potential on Rooftop



Dataset Used

Building Footprint

Cartosat- 3 Data

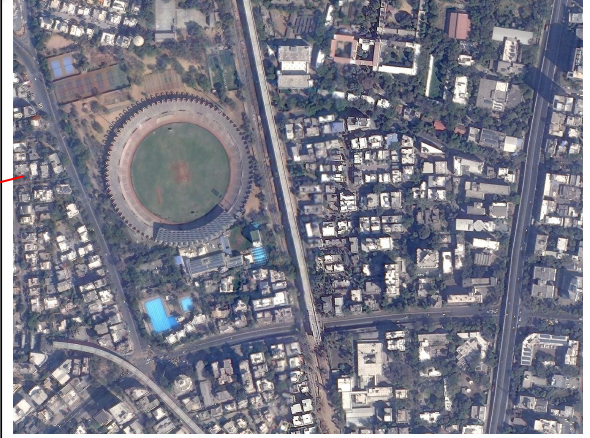
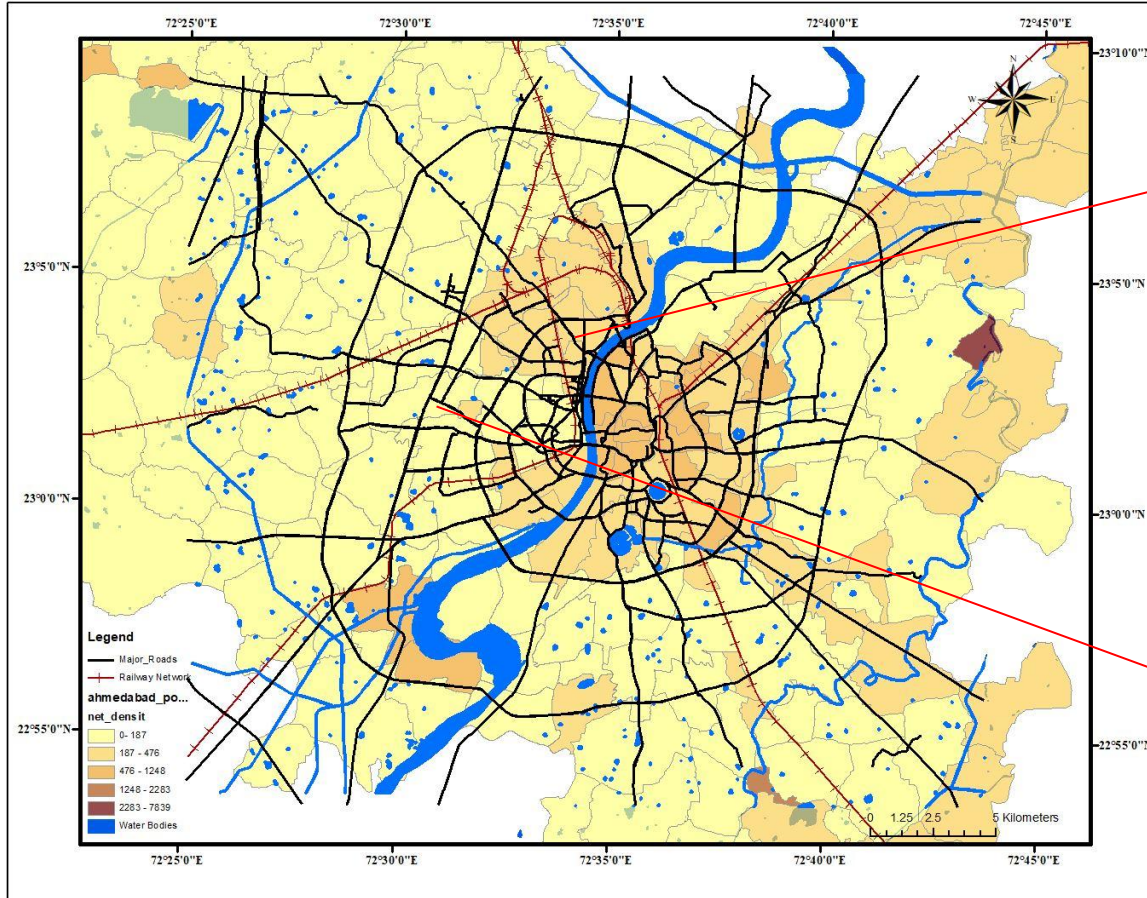
- **Multispectral Data and PAN (0.28m Spatial Resolution)**
- **Spectral band width**
Band 1:450 - 520 nm
Band 2:520 - 590 nm
Band 3: 620 - 680 nm
Band 4: 770 - 860 nm

Building Height

Cartosat-1 Stereo Pair

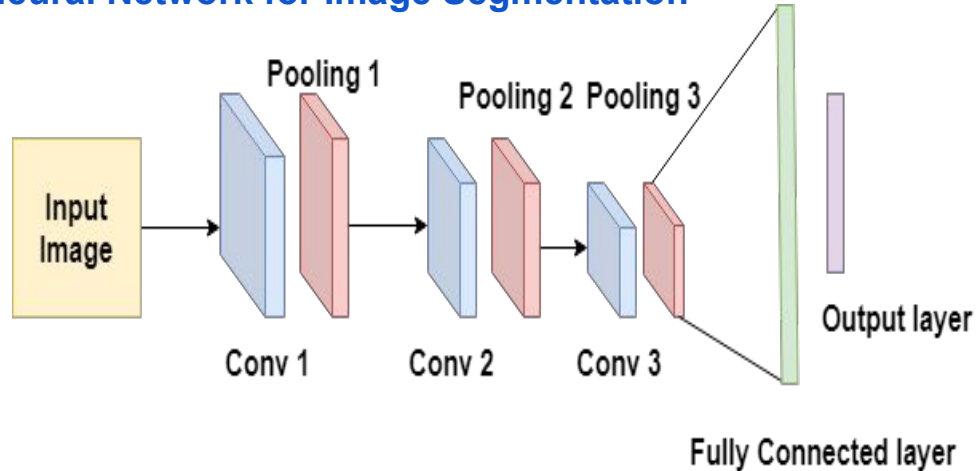
- **Panchromatic Data with 500-800 nm.**
- **Spatial resolution of 2.5 m**
- **Have Aft angle of 5 degrees and fore angle of 26 degrees.**

Study Areas- Ahmedabad, Gujarat



Artificial Intelligence based Deep Learning Neural Network

Convolutional Neural Network for Image Segmentation



CNN being one of the most used deep learning networks for image segmentation. CNNs incorporate convolutional layers with a set of feature maps that are convolved with a large number of filters subjected for training and these are then passed through some non-linear activation function for creating new feature maps. These feature maps are down-sampled by pooling layers. Passing through various layers, higher level features get encoded and in the last stage, output feature maps have most discriminative features for representing image classification, the structure of standard CNN.

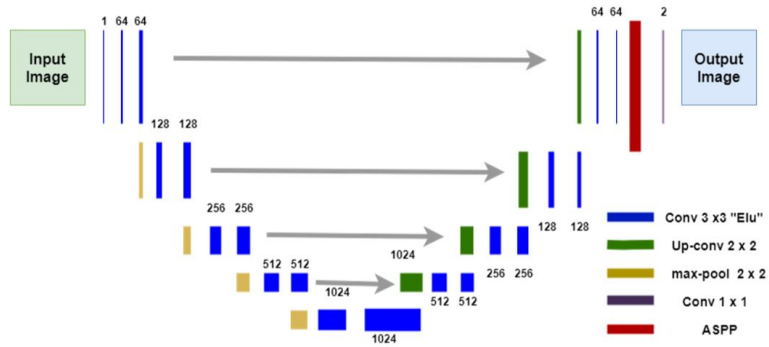
Training Set Generation for Network

- The building footprint in OSM are in vector format (polygons), are used and corrected according to building shape and georeferenced with reference to satellite image of the study area.
- The training dataset comprises a heterogeneous set of buildings within urban areas including isolated buildings, dense built-up and slums. Isolated buildings.
- The dense built-up areas cover the major part of the city in and around the central building district comprising commercial and residential areas. The slums are present within and outside the city with low spectral reflectance and isolated buildings situated in city periphery and vacant land.



Building Footprint Extraction

A deep learning framework was developed to identify the rooftop availabilities.

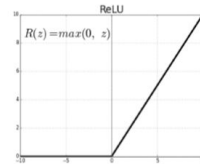


UNet-AP Network with ASPP layer

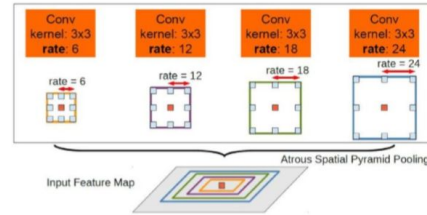
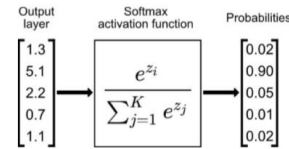
Cross Entropy loss function

$$\text{Loss} = - \sum_{i=1}^{\text{output size}} y_i \cdot \log \hat{y}_i$$

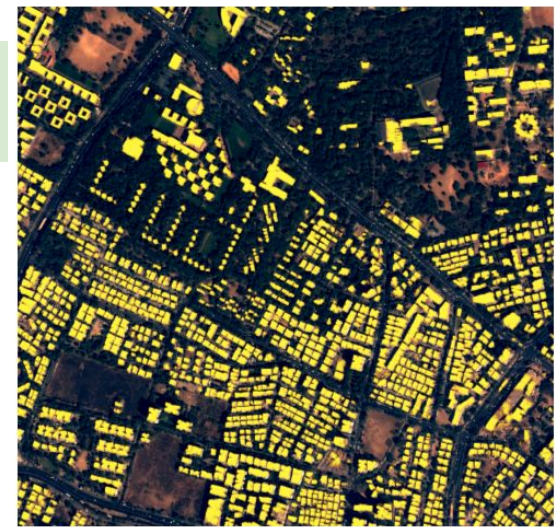
Relu Activation Function



Softmax function



ASPP (Atrous Spatial Pyramid Pooling)



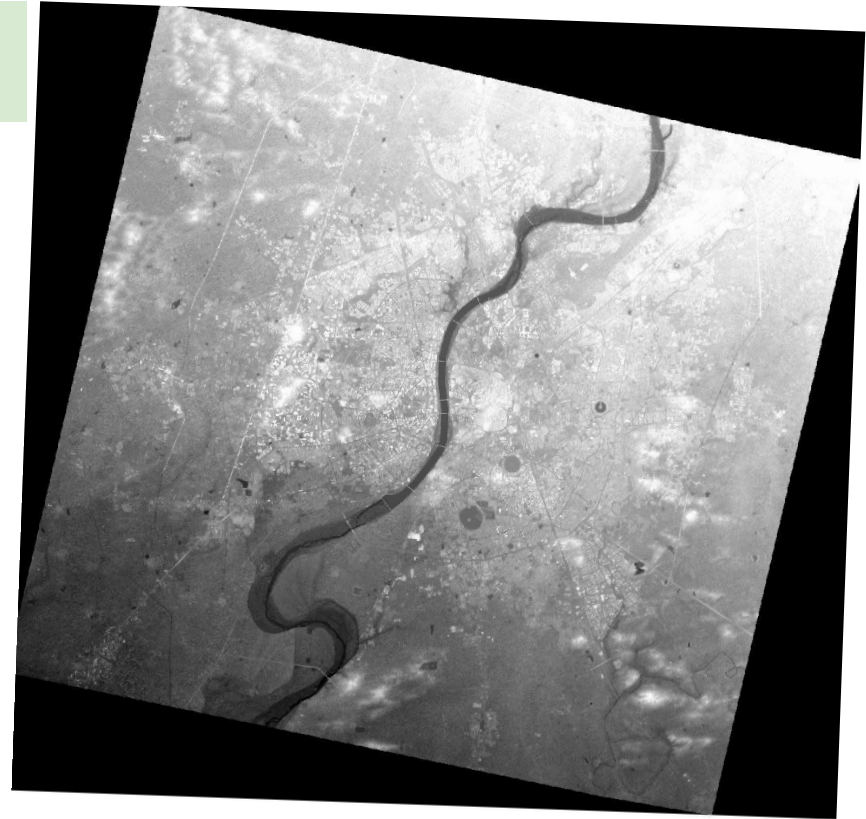
Building Height Delineation

Photogrammetric Terrain Independent Model

To define the relationship between the ground and the image, vice-versa, an abstract model is commonly defined using a series of coefficients derived from what known as rational functions (Rational Polynomial Coefficients).

$$r_n = \frac{p1(X_n, Y_n, Z_n)}{p2(X_n, Y_n, Z_n)} = \frac{\sum_{i=0}^{m1} \sum_{j=0}^{m2} \sum_{k=0}^{m3} a_{ijk} X_n^i Y_n^j Z_n^k}{\sum_{i=0}^{n1} \sum_{j=0}^{n2} \sum_{k=0}^{n3} b_{ijk} X_n^i Y_n^j Z_n^k}$$

$$c_n = \frac{p3(X_n, Y_n, Z_n)}{p4(X_n, Y_n, Z_n)} = \frac{\sum_{i=0}^{m1} \sum_{j=0}^{m2} \sum_{k=0}^{m3} c_{ijk} X_n^i Y_n^j Z_n^k}{\sum_{i=0}^{n1} \sum_{j=0}^{n2} \sum_{k=0}^{n3} d_{ijk} X_n^i Y_n^j Z_n^k}$$



where (r_n, c_n) are the normalized row (line) and column index of pixels in image space (X_n, Y_n, Z_n) are normalized coordinate values of object points in ground space; polynomial

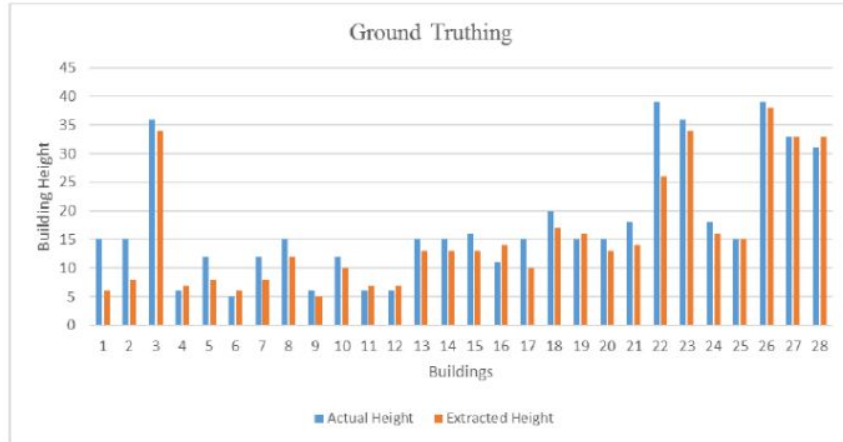
Accuracy Assessment

Building Extraction

| Building Type | Dense Built-up | Slums | Isolated Buildings |
|-----------------|----------------|-------|--------------------|
| IOU | 0.80 | 0.70 | 0.90 |
| F1-Score | 0.82 | 0.71 | 0.92 |
| Accuracy | 0.87 | 0.76 | 0.95 |

DEM Accuracy

| Accuracy | Northing | Easting | Elevation | Building elevation difference |
|----------|----------|---------|-----------|-------------------------------|
| DEM | 0.96 | 1.28 | 1.7m | 3 m |



Shadow Footprint on Rooftop Analysis

$$\text{Shadow footprint} = \frac{\text{Building height}}{\tan(\text{sun elevation}_i)}, \quad r \leq i \leq s,$$

where, $i = 30 \text{ min}$

$r = \text{sunrise time}$

$s = \text{sunset time}$

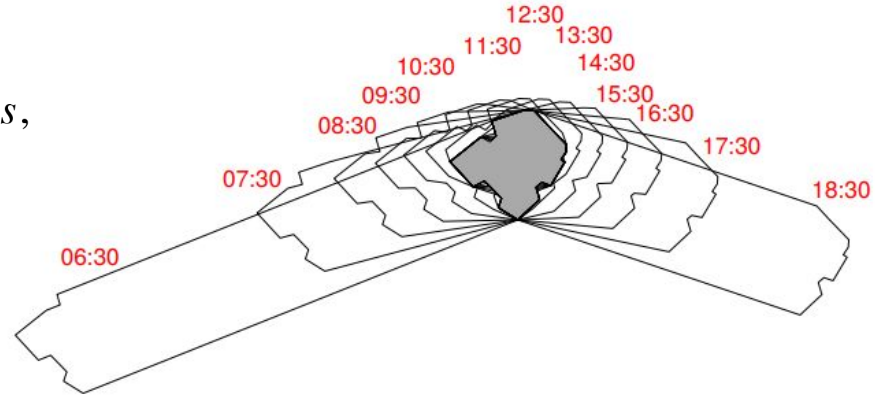
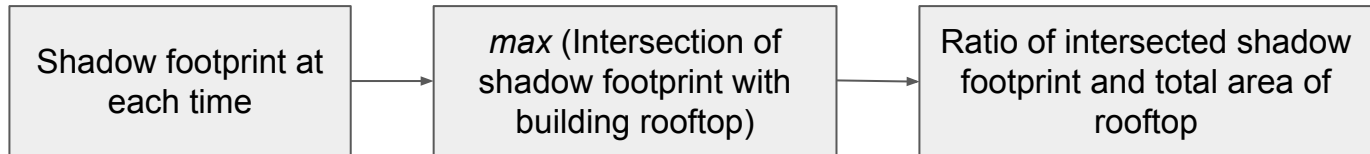
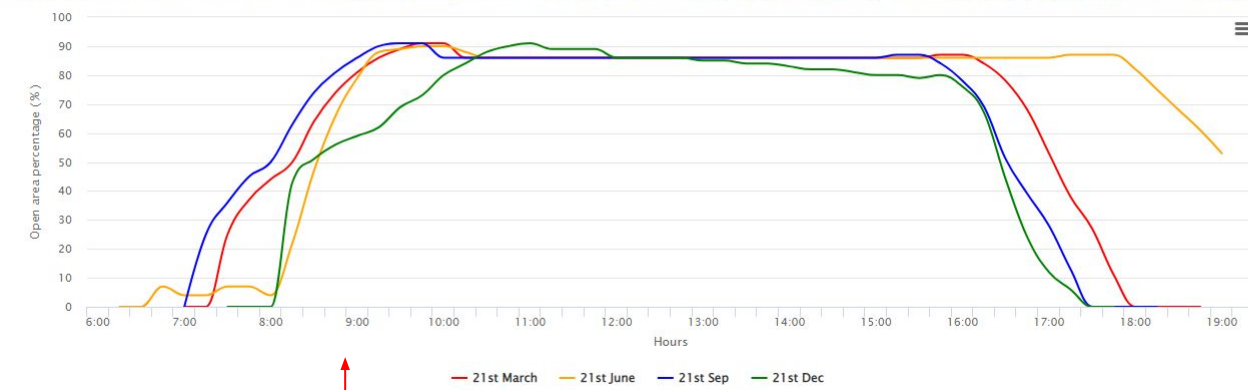
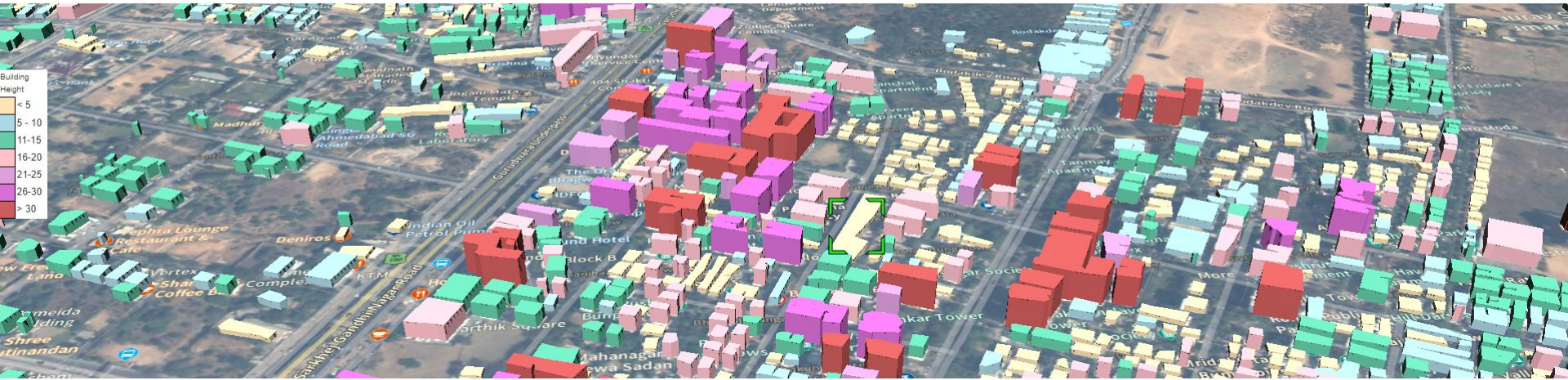


Figure: Shadow footprint of a building at every 30 minutes interval from sunrise to sunset

Open Area Percentage on Rooftop



Date for Shadow Analysis: 29/09/2022 | Time for Shadow Analysis: [Slider] | Height: [Dropdown] | Cartosat-3 Satellite Image: [Checked] | Solar Potential Suitability: [Off]



Half hourly profile of solar energy available

| Building Information | |
|----------------------|--|
| Address | Bodakdev Road, Surya Bungalows, Bodakdev, Ahmedabad, Gujarat. Pin-380054 (India) |
| Height (m) | 4 ← Height |
| Latitude | 23.04090 |
| Longitude | 72.51719 |
| 21 March | 65.8% (7.9 / 12 hrs) |
| 21 June | 69.6% (9.1 / 13.5 hrs) ← Duration of Solar Energy Available |
| 21 September | 67.0% (7.7 / 12 hrs) |
| 21 December | 60.7% (6.7 / 10.45 hrs) |
| Average | 65.8% (7.8 / 11.98 hrs) |

Solar Panel location Suitability on Building Rooftop



Ahmedabad 3D-City Model



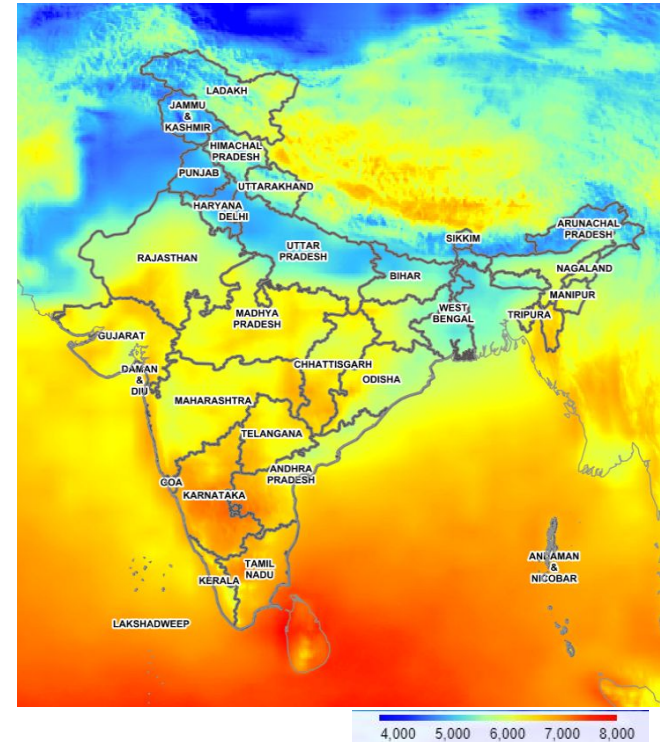
Date for Shadow Analysis: 29/09/2022 Time for Shadow Analysis: Height: Cartosat-3 Satellite Image: Solar Potential Suitability:



Rooftop Solar Potential

- INSAT 3DR Insolation data at 4 km spatial resolution from year 2016 to 2021 is used in study to evaluate solar potential.
- Suitable Building for Installing Solar Panels:
 - Area of building rooftop $\geq 10 \text{ m}^2$
 - Building height $> 2 \text{ m}$
 - Solar energy available for more than 50 % of the time of the day.
- Solar potential calculated as area of building multiplied by annual solar insolation and its efficiency (16%).
- Annual solar energy potential for the entire set of buildings due to shadow effect by 29%.
- Solar power generated by buildings is 11.85 TWh annually.

Average Insolation (2016-21) (kWh/m^2)



Conclusion

- Urban environments can be considered as high-potential energy producers.
- A Framework is developed using AI and photogrammetric techniques, considering shadow effect for characterising solar potential on building rooftops.
- This study overcomes the challenges of limited building rooftop data available and estimation of height of individual buildings.
- Effect of Shadow significantly impacts the total energy potential, therefore it cannot be considered separately but simultaneously.
- The results are also available on web https://vedas.sac.gov.in/vstatic/3D_CITY/index.html, with location and value for each building.

Future Development

- With the availability of LIDAR data for entire city, centimeter level accuracy of building heights to be calculated.
- Other structures in urban environment such as bridges, trees to be considered for shadow analysis to assess its impact on building rooftop.
- Variables affecting amount of solar energy such as optimal tilt angle of solar panels and effect of temperature.

Thank you!

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