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Performance Evaluation of Urban Canopy Parameters Derived from VHR Optical Stereo Data †

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Abstract: Urban canopy parameters (UCPs) are parameters which are utilized to define the thermal, radiative, and roughness properties of urban areas, which have a significant impact on the urban microclimate. The rapidly growing urbanization, especially in developing regions, leads to the modification of urban geometry, which calls for the characterization of UCPs in the countries of such regions to account for high population pressure, heterogeneous urban environments, and the subsequent impacts on global climate change. A research study conducted in Delhi, India, found that very-high-resolution (VHR) optical satellite stereo datasets provide reasonable accuracy with respect to the extraction of building heights and footprints, which are further employed for the computation of UCPs. However, the study evaluates only the key input parameters due to the non-availability of the 3D geodatabase. Hence, in this study, an attempt has been made to evaluate all UCPs derived from VHR optical stereo data, along with the key input parameters, against reference data collected from the field in the city of Bhubaneshwar, India. Performance evaluation with reference-data-derived UCPs shows that all the UCPs retrieved from VHR optical stereo data have a high prediction accuracy. Overall bias, overall mean absolute error (MAE), and root mean square error (RMSE) from satellite-derived UCPs were found to be better than 1 m for most of the UCPs, except for building-surface-area-to-plan-area ratio, height-to-width ratio, and complete aspect ratio, which were found to be less than 2.7 m. The correlation coefficient values were also observed to be more than 0.7 for most of the UCPs, except plan area density, roughness length, and frontal area density. This study concludes that UCPs derived from VHR optical stereo data have high accuracy, even in the low-to-medium-rise urban environments of the study area. The study has a high potential to be replicated in countries in developing regions which have similar development characteristics and face resource and policy constraints with respect to the availability of airborne LiDAR and SAR data.

Keywords: urban canopy parameters; very-high-resolution optical satellite stereo data; mean building height; sky view factor; frontal area index; height-to-width ratio; roughness length

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1. Introduction

Urban canopy parameters (UCPs) define the thermal, radiative, and roughness properties of urban areas and impact the urban microclimate significantly. UCPs, like street height or type of buildings, etc., strongly affect the urban microclimate [1]. The availability of UCPs is very important for urban climate studies, as recent urban canopy models (UCMs) ingest detailed UCPs characterizing urban heterogeneity to obtain quantified information on the urban climate. Numerical weather simulations with UCMs have also indicated that the availability of accurate information on UCPs provide improved simulation results for understanding urban heat island (UHI), air pollution, and climate change scenarios [2–8]. The remote sensing datasets of airborne LiDAR and aerial photography have been widely used in developed countries to obtain information on UCPs [9]. However, due to the limited availability of airborne LiDAR and aerial photography in developing regions, ref. [10] has employed very-high-resolution satellite (VHRS) optical stereo datasets for the retrieval of building heights and UCPs in the complex urban environment of Delhi due to their cost effectiveness and easy availability [10–12]. Although the study evaluated key input parameters, such as building height, building surface area, and land use and land cover (LULC), and found acceptable accuracies for the generated UCPs, it was felt that UCPs generated from VHRS optical stereo data needed to be evaluated against field-based benchmark data. Hence, this study chooses a representative urban area to evaluate the accuracies of generated UCPs derived from VHRS optical stereo data against reference data collected from the ground.

2. Study Area and Datasets

Bhubaneswar has been selected for this study because of the geographic location of the city (Figure 1). It is located near the Bay of Bengal, making it vulnerable to intense cyclones, precipitation, and flood events. The city has a warm and humid climate. The city is a planned urban climate; evaluation of the study area involves fewer constraints than other cities with very complex urban structures. Ward number 27 (also known as Nayapalli) of the Bhubaneswar Municipal Corporation has been selected for ground data collection to validate UCPs derived from satellite images. The criteria for selecting the area were based on heterogeneity in building heights and variation in LULC categories.

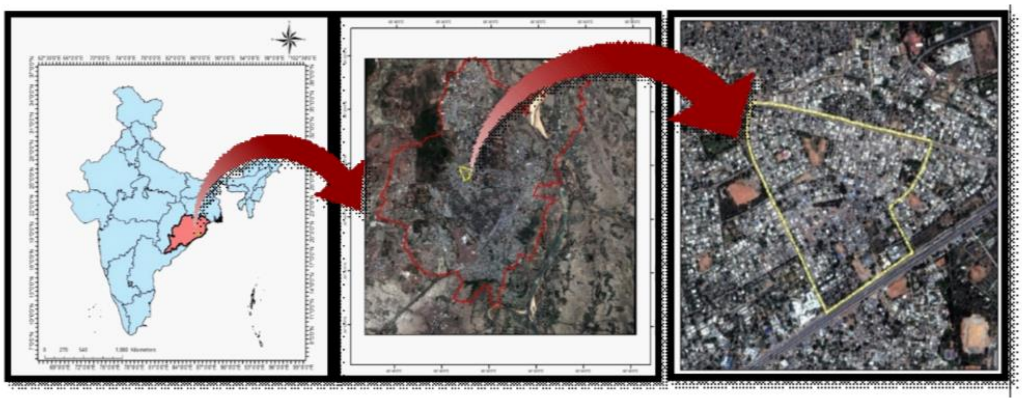

Figure 1. Depicts the study area—Nayapalli, Bhubneswar.

Material used for the study were obtained from field surveys undertaken to collect building heights, hemispherical photographs, building footprints, and reference points for land use and land cover information. Around 954 building height samples and footprints were collected using the Leica Distometer Instrument for the creation of a three-dimensional (3D) reference geodatabases for validation. The acquired remote sensing data for the study include stereo pairs from Pleiades. Pleiades is a French satellite and has a resolution of 0.5 m. Pleiades stereo pairs with both multi-spectral and panchromatic sensors are used for this study.

3. Methodology

This study was performed in a number of stages to achieve the research aim (Figure 2). The first step involved the generation of a digital surface model (DSM) from VHRS optical stereo datasets using ground control points (GCPs), which were obtained from the differential ground positioning system (DGPS survey). A digital terrain model (DTM) was generated by applying morphological filters on the generated DSM. By utilizing a DSM and a DTM of the optical stereo pair, a normalized digital surface model (nDSM) was derived by subtracting the DTM from the DSM. Accuracy assessments of all generated DSMs, DTMs, and nDSMs were performed using GCPs and field data of building heights. The second step involved the generation of orthorectified images using multi-spectral Pleiades images.

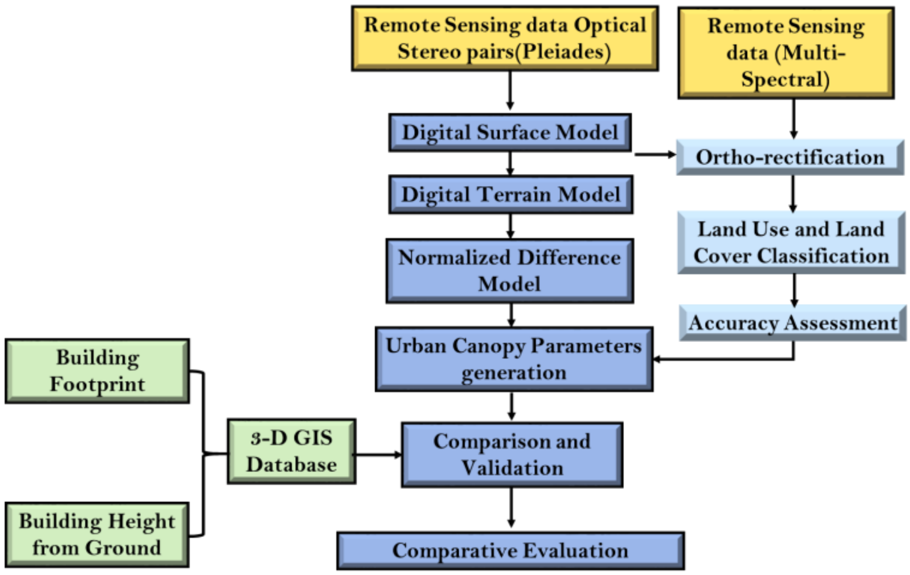

Figure 2. Methodology of the study.

The generated orthorectified multi-spectral Pleiades images were further classified to obtain the distribution of LULC, which was followed by an accuracy assessment of the generated classes. Supervised classifications of MX orthorectified images have been carried out for six classes: built-up, vegetation, agricultural land, water body, bare soil, and river bed. The third step of the study involved the computation of UCPs. The input data required for the generation of UCPs, such as building footprints and building heights, were derived from the nDSM. The most widely used UCPs for climate studies [13] were calculated for the selected study area using VHRS optical stereo data. The fourth step involved a 3D reference geodatabase creation for the study area (ward number 27), which was obtained through an extensive field survey. The final step consisted of the comparative evaluation of computed UCPs from a 3D reference geodatabase, with UCPs generated from VHRS optical stereo data at a grid resolution of 30 m. The statistical evaluation of UCPs was carried out by computing the bias, mean absolute error (MAE), root mean square error (RMSE), and correlation coefficient (r).

4. Results

The VHRS DSM, generated at 1 m spatial resolution through photogrammetric processing, was found to have an RMSE of 3.08 m, while the DTM, after the filtering of the DSM, had an RMSE of 2.8 m. The nDSM obtained after the subtraction of the DTM from the DSM displayed an RMSE of 0.38 m with respect to height observations collected from the ground (Figure 3a–c). Land use and land cover characteristics are very important for urban climate studies. Accuracy assessment has been performed on classified images by selecting sample points using a stratified random sampling method. All the classes were classified with an overall accuracy of 91.79%, which is more than the recommended accuracy of 85% [13], and with an overall kappa index of 0.9042 (Figure 3d).

4.1. Building Footprints and Building Height

Since no authentic 2D and 3D GIS databases were available for study the area, a 3D geodatabase (consisting of 954 buildings) for the study area was prepared after the collection of building footprints digitized from VHRS orthoimages from Pleiades (0.5 m spatial resolution) and the collection of building height data using the Leica Distometer Instrument, as explained in earlier sections (Figure 4a,b). Further, this dataset was utilized to assess the accuracy of the building footprints and building heights obtained from VHRS optical stereo data.

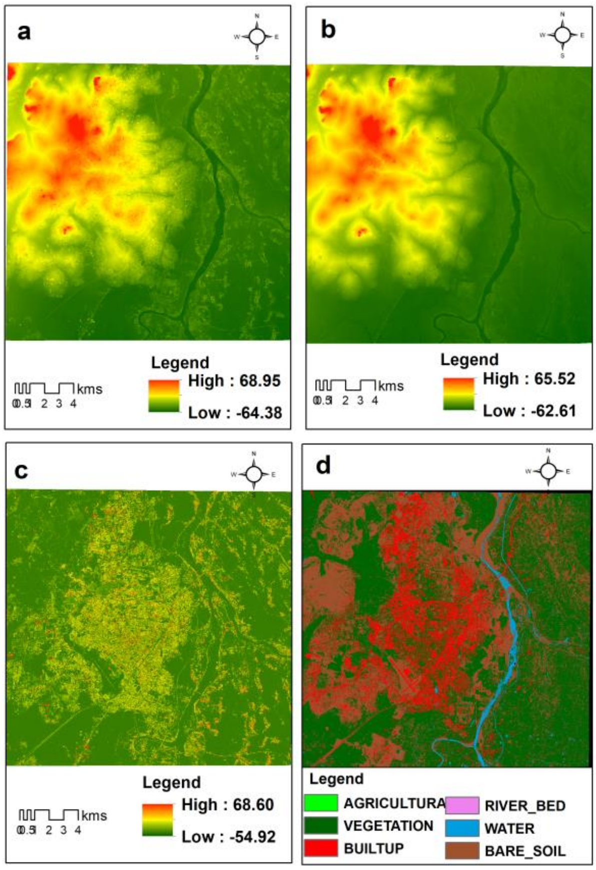

Figure 3. Input layers for UCPs derivation: (**a**) DSM; (**b**) DTM; (**c**) nDSM; (**d**) LULC.

(**a**) (**b**)

Figure 4. Reference data for UCPs derivation: (**a**) building footprints; (**b**) building height.

Building footprints and building height were also retrieved from the VHRS nDSM (generated in the previous section) by following the methodology adopted by [10]. The completeness analysis of the retrieved building footprints shows that 82.72% of buildings were correctly extracted from VHRS optical stereo data. A false positive rate of 17.27% shows that a much smaller percentage of buildings had been incorrectly classified as other features. Similarly, building heights retrieved from satellite data show a positive bias of

0.09 m. The MAE is 0.57 m, while the RMSE is 0.70 m. A correlation coefficient of 0.99 has been observed between the reference and retrieved building heights.

4.2. Urban Canopy Parameters

By utilizing the extracted input parameters—building footprints, building heights, and land use land cover—a set of UCPs has been derived at a spatial resolution of 30 m by following the methodology developed by [10]. All twelve (12) UCPs, as shown in Figure 5a–l—mean building height (MBH) and standard deviation of building height (SDBH), building surface fraction (BSF), pervious surface fraction (PSF), impervious surface fraction (ISF), frontal area index (FAI), building-surface-to-plan-area ratio (BSPAR), height-to-width ratio (H/W ratio), complete aspect ratio (CAR), zero-plane displacement height (Z_d), roughness length (RL), and plan area density (PAD—were derived pixel by pixel.

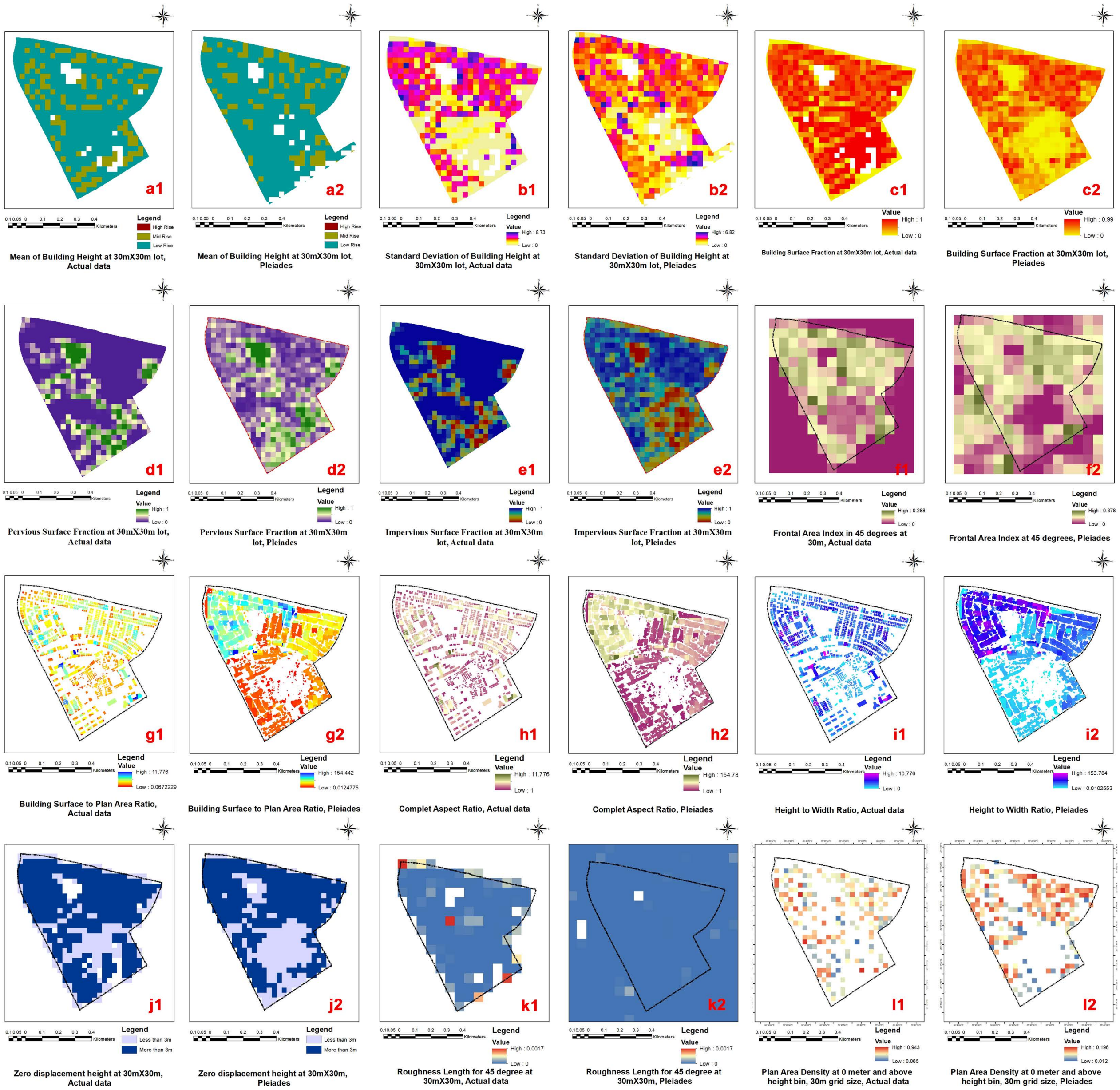

Figure 5. UCPs derived using satellite data (**1**) and reference data (**2**): (**a**) MBH; (**b**) SDBH; (**c**) BSF; (**d**) PSF; (**e**) ISF; (**f**) FAI;(**g**) BSPAR;(**h**) CAR;(**i**) H/W Ratio; (**j**) Zd; (**k**) RL;(**l**) PAD.

The computed UCPs from satellite data were compared against reference-data-derived UCPs using statistical measures such as bias, MAE, RMSE, and correlation coefficients, as shown in Tables 1 and 2. It can be seen that most of the satellite-data-derived UCPs have shown high correlation coefficients (above 0.7) with reference-data-derived UCPs.

Table 1. Accuracy evaluation of satellite-derived UCPs with reference UCPs.

	MBH	SDBH	BSF	SVF	PSF	ISF	FAI
Bias	−0.06	−0.32	0.23	−0.06	0.54	−0.12	0.005
MAE	1.08	0.98	0.26	0.14	0.64	0.19	0.027
RMSE	1.37	1.14	0.39	0.17	0.72	0.28	0.033
(r)	0.83	0.78	0.74	0.77			0.82

Table 2. Accuracy evaluation of satellite-derived UCPs with reference UCPs.

	BSPAR	H/W RATIO	CAR	PAD	Z_d	RH	FAD
Bias	0.13	0.45	−0.14	−0.09	0.04	0.00	−0.02
MAE	1.95	2.76	1.61	0.16	0.76	0.00	0.03
RMSE	3.44	4.77	2.15	0.25	0.95	0.00	0.05
(r)				0.26	0.92	0.30	0.54

5. Conclusions

The study has presented the evaluation of retrieved UCPs from VHRS optical stereo data for a part of Bhubaneshwar city, India, against ground-based field observations and a ground-based reference 3D geodatabase. The assessment of building footprints and building heights retrieved from VHRS optical stereo data has revealed the high performance of the Pleiades dataset in the extraction of building footprints, with a true positive rate of 82.7%, and building heights with an RMSE of 0.7 m and a correlation coefficient of 0.99. Further, performance evaluation of the most widely used UCPs for climate studies shows that at 30 m resolution, all UCPs derived from VHRS optical stereo data have demonstrated very high accuracy, with RMSE values beneath 2 and a high correlation coefficient of more than 0.7. The generated UCPs can be utilized for ventilation studies, generating urban climatic maps and local climate zonation, climatic modeling, numerical weather prediction over urban areas, shading analysis, urban heat island studies, and much more.

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Data Availability Statement: The results and conclusion of the study were derived from the following data sources: 1. VHRS optical satellite stereo raw data: Pleiades data of the study region were used from the archive of the institute (Indian Institute of Remote Sensing, Dehradun) and cannot be shared openly. 2. Ground Survey data: a. field survey data that include ground truthing data for LULC and fish-eye photographs for the study region can be shared upon reasonable request; b. Ground survey data pertaining to ground control points and building heights are highly restricted and cannot be shared with any agencies. 3. Urban canopy parameters generated in the study can be shared upon reasonable request on a case-to-case basis within the purview of data security policy.

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Conflicts of Interest: The authors declare no conflicts of interest.

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