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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 utilised to define thermal, radiative and roughness properties of urban areas, having significant impact on urban microclimate. The rapidly growing urbanization especially in developing region leads to modification in urban geometry, which calls for characterization of UCPs in the countries of such region to account for high population pressure, heterogeneous urban environment and 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 extraction of building height and footprints, which is further employed for computation of UCPs. However, the study evaluates only the key input parameters due to non- availability of 3D geodatabase. Hence, in this study an attempt has been made to evaluate all UCPs derived from VHR optical stereo along with key input parameters against reference data collected from 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 has high prediction accuracy. Overall bias, overall Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) from satellite derived UCPs was found to be better than 1m for most of the UCPs except for Building Surface Area to Plan Area Ratio, Height-to-width Ratio, and Complete Aspect Ratio which is found to be less than 2.7m. The correlation coefficient value were also observed to be more than 0.7 for most of the UCPs except Plan Area Density, Roughness Length and Frontal Area Density. The study concludes that UCPs derived from VHR Optical Stereo data has high accuracy even in the low-to-medium rise urban environment of study area. The study has high potential to be replicated in countries of developing region, which has similar development characteristics, and face resource and policy constraints with respect to availability of Airborne LiDAR and SAR data.

Keywords: urban canopy parameters; very high resolution optical satellite stereo; 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 thermal, radiative and roughness properties of urban areas and impact urban micro climate significantly. UCPs like street height or type of buildings etc. strongly effect the urban microclimate [1]. The availability of UCPs is very important for urban climate studies as recent Urban Canopy Models (UCMs) ingest detailed UCPs for characterizing the urban heterogeneity in the models to obtain quantified information on urban climate. Numerical weather simulations with UCMs have also indicated that availability of accurate information on UCPs provide improved simulation results for understanding the urban heat island (UHI), air pollution and climate change scenarios [2–8]. The remote sensing datasets of Airborne LiDAR and Aerial

Photography has been widely used in the developed countries for obtaining the information on UCPs [9]. However, due to limited availability of airborne LiDAR and aerial photography especially in developing region, hence [10] has employed Very High Resolution Satellite (VHRS) optical stereo datasets for retrieval of building height and UCPs in complex urban environment of Delhi due to their cost effectiveness and easy availability [10–13]. Although the study evaluated key input parameters such as building height, building surface area, Land Use Land Cover (LULC) and found acceptable accuracies for generation of UCPs, it was felt that UCPs generated from VHRS optical stereo need to be evaluated with field based benchmark data. Hence, this study chooses a representative urban area to evaluate the accuracies of generated UCPs from VHRS optical stereo with reference data collected from ground.

2. Study Area and Datasets

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

Material used for study were obtained from field surveys to collect Building Height, Hemispherical Photographs, Building Footprint, and reference points for Land use and Land cover information. Around 954 building height samples and footprints were collected using Leica Distometer Instrument for creation of three-dimensional (3D) reference geodatabase for validation. The acquired remote sensing data for the study include Stereo pairs of Pleiades. Pleiades is a French satellite and have resolution of 0.5m. Pleiades stereo pairs with both multi-spectral and panchromatic sensors are used for the study.

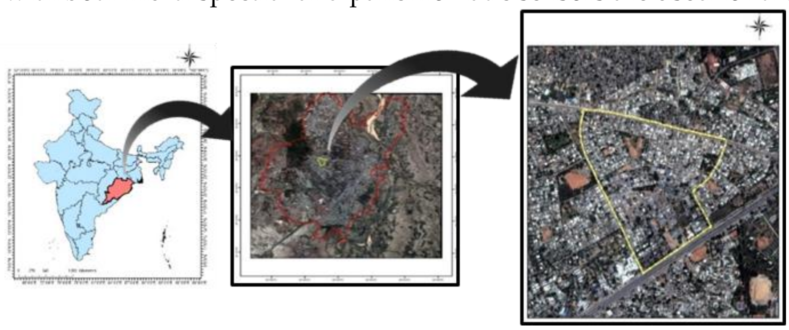

Figure 1. Depicts the study area- Nayapalli, Bhubneswar.

3. Methodology

The study was performed in number of stages to achieve the research aim (Figure 2). The first step involve generation of Digital Surface Model (DSM) from VHRS optical stereo datasets using Ground control points (GCPs), which were obtained from Differential Ground Positioning System (DGPS survey). Digital Terrain Model (DTM) was generated by applying morphological filters on generated DSM. By utilizing DSM and DTM of optical stereo pair, Normalized Digital Surface Model (nDSM) were derived by subtracting DTM from DSM. Accuracy assessment of all generated DSMs, DTMs and nDSMs were performed using GCPs and field data of building height. The second step involved generation of Ortho-rectified images using Multi-spectral Pleiades images.

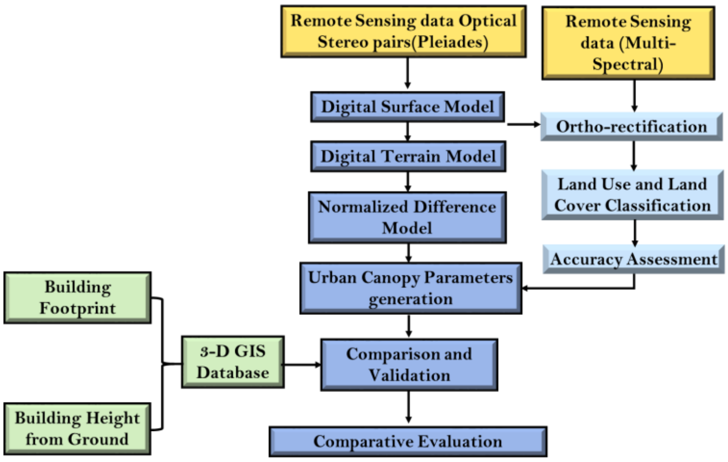

Figure 2. Methodology of the study.

The generated ortho-rectified multispectral image of Pleiades were further classified to get the distribution of LULC which was followed by accuracy assessment for the generated classes. Supervised classification of MX ortho-rectfied image have been carried out for six classes- Built-up, vegetation, agricultural land, water body, bare soil and river bed. The third step of study involved computation of UCPs. The input data required such as Building footprints and Building height, for UCPs generation were derived from nDSM. Most widely used UCPs for climate studies [13], were calculated for the selected study area using VHRS optical stereo data. The forth step involved 3D reference geodatabase creation for study area (ward number 27) which is obtained through extensive field survey. The final step consist of comparative evaluation of computed UCPs from 3D reference geodatabase with UCPs generated from VHRS optical stereo at a grid resolution of 30m. The statistical evaluation of UCPs was carried out by computing Bias, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Correlation Coefficient (r).

4. Results

VHRS DSM generated at 1m Spatial resolution through photogrammetric processing found to have RMSE of 3.08m, while DTM after filtering of DSM has RMSE of 2.8m. nDSM obtained after subtraction of DTM from DSM has displayed RMSE of 0.38 m with respect to height observations collected from ground (**Error! Reference source not found.** (a-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 stratified random sampling method. All the classes were classified with overall accuracy of 91.79% which is more than the recommended accuracy of 85% [14] with an overall kappa index of 0.9042 (Figure 3 (d)).

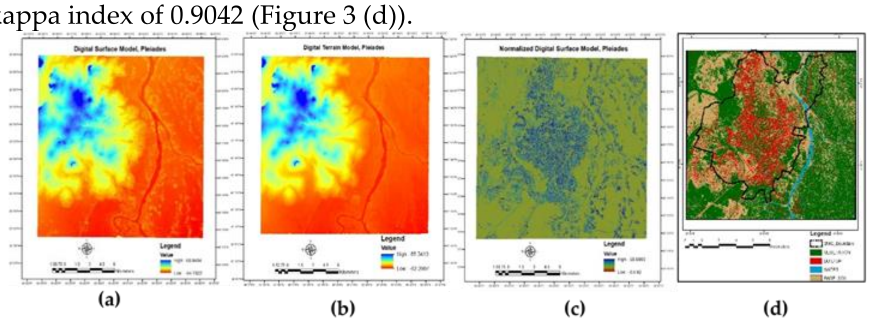

Figure 3. Input layers for UCPs derivation- (**a**)DSM, (**b**) DTM, (**c**) nDSM, (**d**) LULC.

4.1. Building Footprints and Building Height

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

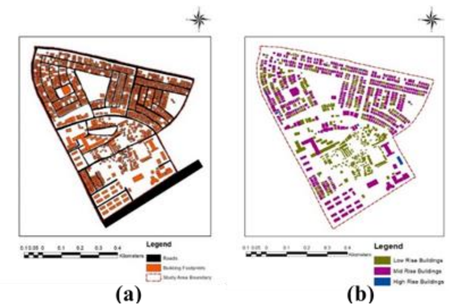

Figure 4. Reference data for UCPs derivation (a) Building footprints, (b) Building Height.

Building footprints and building height were also retrieved from VHRS nDSM (generated in previous section) by following the methodology adopted by [10, 15]. The completeness analysis of retrieved building footprints shows that 82.72% of buildings were correctly extracted from VHRS optical stereo. False Positive Rate of 17.27% shows that very less percentage of buildings has been incorrectly classified as other features. Similarly, buildings height retrieved from satellite data shows positive bias of 0.09m. The MAE is 0.57m, while RMSE is 0.70m. The correlation coefficient of 0.99 has been observed between reference and retrieved building heights.

4.1. Urban Canopy Parameters

By utilizing the extracted input parameters- building footprints, building height, and Land use land cover, a set of UCPs has been derived at spatial resolution of 30m by following the methodology developed by [15]. All fourteen (14) UCPs as shown in **Error! Reference source not found.**(a-n) - Mean Building Height (MBH) and Standard deviation of Building Height (SDBH), Building Surface Fraction (BSF), Sky View Factor (SVF), 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), Plan Area Density (PAD), Roof Area Density(RAD) were derived pixel to pixel.

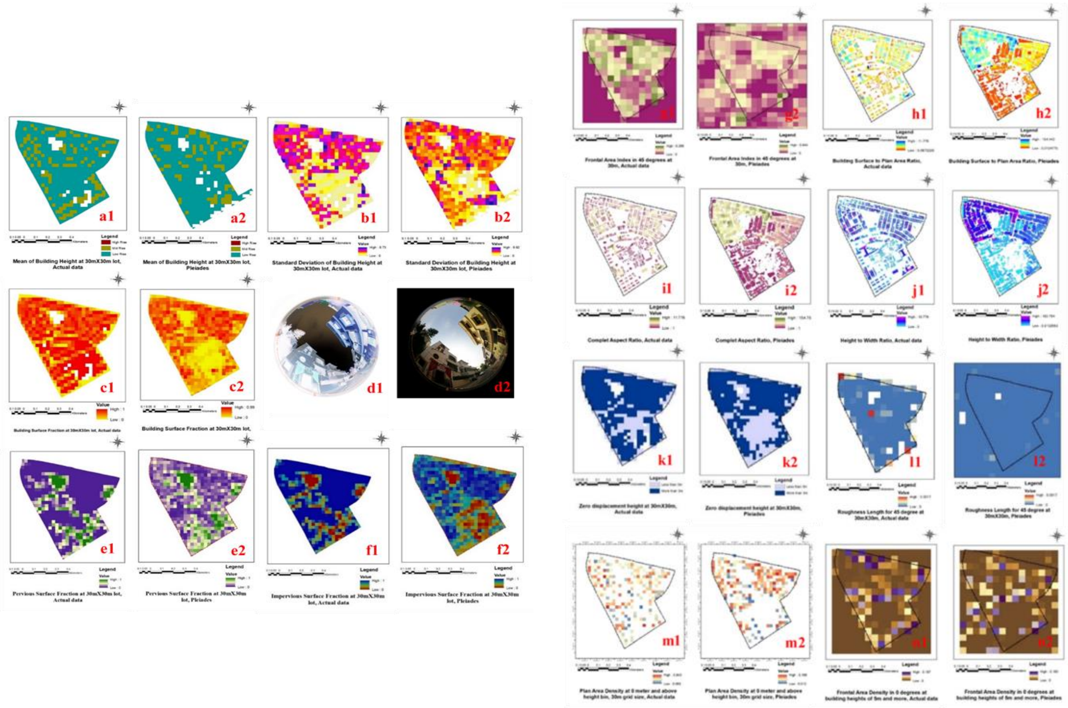

Figure 5. UCPs derived using satellite data (1) and reference data (2), (**a**)MBH, (**b**)SDBH, (**c**)BSF, (**d**)SVF, (**e**)PSF, (**f**)ISF), (**g**)FAI, (**h**)BSPAR, (**i**)CAR, (**j**)H/W Ratio, (**k**)Zd, (**l**)RH, (**m**)PAD, (**n**)FAD.

The computed UCPs from satellite data were compared against reference data derived UCPs using statistical measures such as Bias, MAE, RMSE and Correlation Coefficient as shown in Table 1 and Table 2. It can be seen that most of the satellite data derived UCPs have shown high Correlation coefficient (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. Conclusion

The study has presented the evaluation of retrieved UCPs from VHRS optical stereo data for a part of Bhubaneshwar city, India with ground based field observations and ground based reference 3D geodatabase. The assessment of building footprints and building heights retrieved from VHRS optical stereo has shown high performance of Pleiades dataset for extraction of building footprint with True Positive Rate of 82.7% and building height with RMSE of 0.7 m and correlation coefficient of 0.99. Further, performance evaluation of most widely used UCPs for climate studies shows that at 30 m resolution, all UCPs derived from VHRS optical stereo has shown very high accuracy with RMSE value less than 2 and high correlation coefficient of more than 0.7. The generated UCPs can be utilized for ventilation studies, generating urban climatic map and local climate zonation, climatic modelling, numerical weather prediction over urban areas, shading analysis, urban heat island studies and urban heat island studies and many 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 was 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 includes 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 case to case basis within the purview of data security policy.

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

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