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Analyzing Sky View Factor Calculation Methods for Urban Climate Studies: Case Study Kolkata

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Abstract: ***Many studies confirm that urban morphology cannot simply be described by the common indicators like urban canyon ration, ground coverage, density, building height, etc. It varies according to location and functions. The Sky View Factor (SVF) is an important parameter to describe the geometric shape of an urban canyon. This study introduces a new python-based approach to calculate SVF and assess the accuracy with existing SVF calculation methods for defining SVF in urban areas. Photographic Method, which analyses the Sky View Factor from Fish Eye lens images, and Remote Sensing and GIS method, which uses an urban 3D building dataset or DSM and proposed python-based method is chosen for the research. For Remote Sensing and GIS analysis, the existing buildings were considered and trees and street furniture were discarded. The building's footprints are digitized in ArcGIS and building heights measured by laser distance meter. The vector and raster database were created and processed. We used same input dataset to analysis SVF using the python script. The results show that lower values of SVF were obtained with the fish-eye lens analysis compared with the GIS methods and Python script. The mean variation between the SVF values obtained from python script and GIS method is 0.014, and with Fish-eye lens image is 0.079. The photographic method and vector-based GIS method was systematic enough for studying smaller areas having more details. For continuous SVF analysis over raster-based GIS method and python script is preferable. Raster-based python method is time consuming in respect with python script. The study of viewing each method of sky view has been made objective for specific research. Further investigation of the subject is recommended.***

Keywords: Sky View Factor, Urban Canyon, Fish Eye Lens, Building Footprints, Python

1. Introduction

Urban development leads to radical land cover change (Stewart, 2011). Urban expansion accelerates development but reduces natural environments, as results higher temperatures rather than natural surroundings. A compound urban geometry formed and dilutes open space. Sky visibility gradually declined from the surface. The sky view factor indicates the percentage of the visualizing sky or a definite viewer or rather observing a specific area (Holmer et al., 2000). SVF values are dimensionless and range from 0 to 1, respectively, signifying blocked and open areas (Oke, 1988). Changes in climate process in urban areas are challenging. This result has alarmed the location surface temperature, and also radiation fluxes which impacts the thermal comfort. Different methods for determining SVF have been investigated during the last few decades. These initiatives started with the development of mathematical techniques that calculated SVF using geometric equations based on the height and width of the urban canyon. The measure of the degree to which the sky is screened by the surrounding for a given point is termed as sky view factor. In this research Photographic and Geographical Information System (GIS) tools was used to calculate the SVF and analyze the accuracy and relation between selected methods.

2. Study Area

Kolkata is a high-density city located at 22°30’ and 88°30’ in the lower Ganga basin at an altitude of 6 meters. The city belongs to the climatic type Aw of Koppen’s climatic classification, which means tropical wet-and-dry climate. The SVF was calculated and analyzed in the selected 4^2 km (2 km X 2 km) area in Kolkata. The area is highly congested and has mixed occupations with commercial and residential built-up.

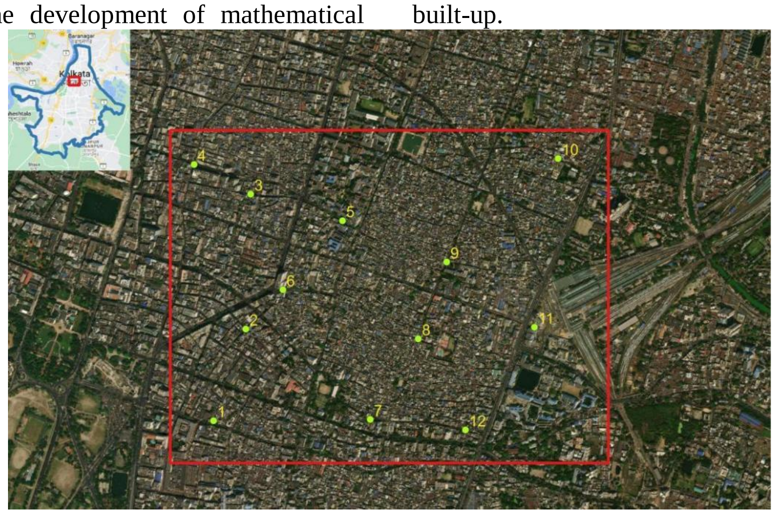

Figure 1: Location Map of Study Area. The green dots are used to measure SVF using fish eye lens and SVF mapping tools and validate to check accuracy with the observed SVF values of UMEP QGIS and proposed python script

3. Methods to estimate Sky View Factor

There have been various approaches created to calculate sky view factor, each with their own benefits and drawbacks, but ultimately no one strategy can be said to be robust. In urban climate research measurement and calculation of SVF has a history (Johnson & Watson, 1984; Watson & Johnson, 1987), though it is still considered intensive research in the field of urban studies.

The methods can be categorized into four different categories: analytical models, photographic method, GPS methods, and Software methods.

3.1 Analytical methods

Analytical methods are also known as geometrical methods. Geometrical and radiation exchange model of urban canyons is used to calculate SVF. Johnson & Watson (1984) estimated the SVF for a generic scenario by examining the portion of the radiation flux leaving an investigated surface element that reaches the visible sky and provided.

$$\text{SVF} = \frac{1}{\pi R^2} \int S_v \cos\theta \, dS$$

Where,

S is the section representing the visible sky

Φ is the angle from S to the zenith

R is the radius of the hemispheric radiating environment

The analytical techniques provide a conceptual foundation for calculating SVF for a specific point in various urban structures. They are easily suitable for the depiction of algorithm testing and parametric analysis.

3.2 Photographic methods

The photographic methods take site photographs with the help of a fish-eye lens to project the hemispheric environment onto a circular plane. To define the skyline, additional processing is applied to the images. The relationship between the blocked and unblocked portions of the sky is then determined using the proper transformations. Steyn et al. (1986) uses video images to analyze SVF. The video image is first digitalized and then examined to differentiate between "sky" and "non-sky" pixels. A composite sky view factor for the image is produced by summing the individual view factors for all "sky" pixels. Anderson (1964) was first person, who considered the view factor issue through a photographic computation to estimate sunlight distribution methods received its true value in 1980s by determining SVF in urban research.

The photographic method is especially well suited for estimating SVF in actual cases since it can handle buildings of varying sizes and unusual shapes. The images also contain information on the vegetation, making it possible to acquire precise SVF without risk of error from other approaches in this case (Grimmond et al., 2001; T. GÁL, M. RZEPA, 2007). However, because this method calls for the creation and processing of images, it is frequently time-consuming. Additionally, there aren't many opportunities for surveys using this method because it requires a uniformly cloudy sky; issues with picture processing result from direct sunshine or other cloud types (CHAPMAN & THORNES, 2003). Additionally, the examined points' spatial information is either missing entirely or needs to be managed in distinct databases. The photographic methods are not suitable for big area examination due to these drawbacks.

The most popular method to calculate SVF is to take a 180° fisheye photograph. Digital models of the environment can be used to measure SVF (Bruse & Fleer, 1998; Teller & Azar, 2001). Each angle component of the hemispheric environment, as well as the accompanying azimuth angle α and elevation angle β (in relation to the created shadow), are used in this calculation.

$$\text{SVF}=1-i\sum sin2\square i(ai360°)$$

$$\text{SVF}=1-\text{i}\sum\text{sin}2\beta\text{i}(\text{ai}360°)\square s=1-i\sum sin2\square iai360°$$

3.3 GPS Methods

In contrast to the methods that have been discussed on photographic methods are mostly based on direct calculation of SVF, the GPS method (Chapman et al., 2002) was deployed to focus on measuring SVF having real-time data input. The bare minimum of satellite visibility data was collected using a GPS receiver. To create a regression equation for the prediction of SVF, the number of visible satellites, precision dilution, and satellite signal intensity were all taken into consideration (Hong et al., 2012). The study showed that the method was effective in urban areas, but it was less explanatory in suburban areas. The rural environments can produce a lot of noise when trying to detect signals. This is likely due to the variation in tree coverage in these areas. The prototypical method was further developed by Chapman & Thornes (2004) to produce instant SVF calculation. The GPS have been segregated with the fish-eye lens which captures and processes on a common mobile platform to give simultaneous yet approximate SVF in real-time. Based on the number of monitored satellites, the number of visible satellites, and the total of signal-to-noise ratios, an artificial neural network was trained to forecast SVF. With a processing rate of one second, the programme could account for almost 69% of SVF variations in metropolitan settings.

The GPS techniques have a number of advantages over the conventional techniques, including the following: (i) they are quick and reasonably priced., (ii) Unlike photographic techniques, the survey is not reliant on atmospheric conditions, and (iii) with the geographic information system (GIS) platform, they may be simply connected.

However, the techniques still have drawbacks that limit the applications they can be used for. First, as the approaches are inherently imprecise, they are unsuitable for situations when accuracy is crucial. Second, since the prediction equation depends on the GPS device being used, it is impossible to develop a universal equation. Third, the method only works well in urban areas.

3.4 Software methods

New opportunities to represent urban geometry from a "virtual" perspective are made possible by the advancement of land surveying and digital mapping techniques as well as the fast-rising computer power. Creating databases, typically GIS-based 3-D models, and rebuilding the urban environment in the computer's memory are all examples of software methods. Software is created to emulate SVF in the rebuilt environment. There are two basic software method approaches: the vector method and the raster method, depending on the kinds of databases employed.

Buildings are condensed in the vector database into flat-roofed blocks that are represented by polygons. Slices of the hemispheric radiating environment are evenly separated by a rotation angle. The approach then looks for a single building with the largest elevation angle along a specific rotation angle. The sky segment obstructed by this building is considered a slice of the basin as examined in Oke's (1987) discussion. SVF can then be determined by adding the view factors for each basin slice in each direction (Gál & Unger, 2014). The rotation angle and searching radius have an impact on this method's accuracy; a smaller rotation angle and a bigger radius produce more accurate SVF estimates.

Another widely used technique for determining SVF is the raster-based approach. Surface topography and terrain data are frequently saved in raster format in a digital elevation model (DEM) database. Building shadow patterns are calculated using a "shadow casting" algorithm created by Ratti & Richens (1999) using high-resolution DEM data. This approach is further improved to compute SVF, and Lindberg (2007) has verified that it produces results that are satisfactory. The raster-based approach is significantly quicker than the vector approach (Hämmerle et al., 2011a). The length of the process is dependent on the database's resolution; a greater resolution produces a more accurate output. The ability to create databases is a key component of the software methods. On the other hand, they provide quick methods for calculating continuous SVF for sizable areas, which could serve as the foundation for further investigation. In recent surveys, they are being noticed by more and more people.

Later on, some models were developed to calculate SVF. Some models even allow for the calculation of continuous sky view factor, which is nothing but a special distribution of sky view factors that represent the area or whole of a city (Gál et al., 2009). Most models are mainly representations of buildings (Souza et al., 2003) or digital elevation models (DEM), which allow simple-shaped buildings and flat roofs. There are a few prototypes that are based on the idea of obstacles, which allow modeling on non-flat roofs and trees as well. A few prototypes are based on the idea of obstacles, allowing for modeling non-flat roofs and trees as well (Hämmerle et al., 2011b).

4. Proposed Python based approach for calculation Sky View Factor

To overcome the disadvantages of existing SVF calculation methods, a python-based script was developed in order to evaluate from digital surface model (DSM) on any Integrated Development Environment platform. The script requires a DSM as input and the output is continuous sky view factor map on raster format preferably tiff in order to preserve as much quality of output image.

The SVF map is created by summarizing the pixel wise SVF values and resulted in a continuous SVF map. The script is effective and capable to produce SVF values for larger area. Python 3.0 with rasterio, numpy, math, and scipy modules are used to derive SVF values. SVFpy module developed by Fernando Gomes of Centro de Estudos da Metrópole, Brazil is used to extract SVF values. DSM is considered as prerequisite and can be derived by processing vector 3D building data or from Lidar data set. Observer height, Kernel size and Radius are defined to processed the scripts. DSM check pixel wise values and iterate until the process end.

Python script is used to extract SVF values from DEM. EPSG 32645 (UTM Zone 45N) projection system is used during GIS processing and the DEM used during Python processing. All buildings are considered as flat roof, and all walls of a building are of the same height. SRTM DEM was downloaded and modified with 3D building database to generate input of Python script.

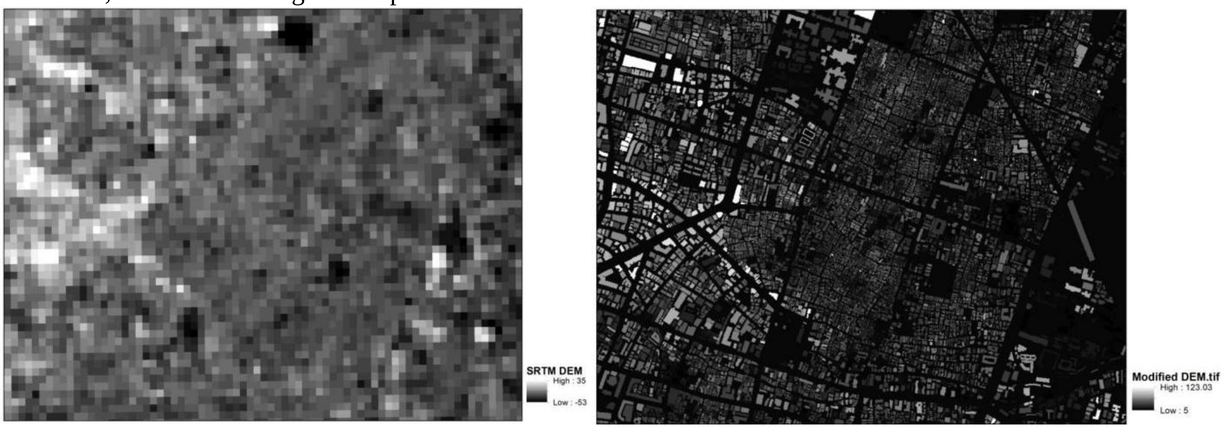

Figure 2: Unprocessed SRTM DEM with spatial resolution is 90 meters and Processed DEM with Spatial resolution is 10 meters

Figure 3: Sky View Factor map prepared using Python script. Spatial resolution is 10 meters

5. Comparison and validation of proposed method with existing method

A new python-based approach is introduced to calculate SVF using Digital Elevation Model. Two conventional methods (Photographic method - Analysis of Fish-eye lens images and other preferred method is from Software methods - by using Remote Sensing and GIS) is used to validate the accuracy with python based SVF calculation approach.

5.1. SVF calculation using Fish-eye lens images

The fish-eye lens is a wide-angle lens, near 180° rather than a regular lens. The methods used to take onsite photographs of the place that project the hemispheric environment onto a circular plane. The photographs are then processed by different software to define the skyline and the relation between obstructed and unobstructed portions of the image or sky is calculated. The most common methods are equiangular projection methods developed by Steyn in 1980. He divided the projected image into several concentric annuli, and the annular sections represent the sky, he estimated SVF by

$$SVF=\frac{1}{2n}\sum_{i=1}^{n}\sin\left[\frac{\pi(i-1/2)}{2n}\right]\cos\left[\frac{\pi(i-1/2)}{2n}\right]\alpha_{i\,sky}$$

Where n is donated as the number of annuli, I is referred as annulus index and αi is termed as angular width of the sky in the ith annulus. Later on, a modified version of Steyn's method was developed by Johnson & Watson in 1984.

$$SVF=\frac{1}{2\pi}\sin\frac{\pi}{2n}\sum_{i=1}^{n}\sin\left[\frac{\pi(2i-1)}{2n}\right]\alpha_{i\,sky}$$

Signifying that Steyn had approximated sin [$\pi/(2n)$] by $\pi/(2n)$ when n is large enough. By expanding the projection to equiangular situations on the basis of their theoretical foundation, the photography technique was further enhanced by Blennow in 1995, and by employing more powerful hardware and software (Brown et al., 2001; Chapman et al., 2001; Hämmerle et al., 2011b).

SVF can be obtained easily from buildings of different sizes and irregular shapes. Vegetation and other obstacles can be identified by this method. However, this approach frequently takes a lot of time. Additionally, there aren't many opportunities for surveys using this method because it requires a uniformly cloudy sky; issues with picture processing result from direct sunshine or other cloud types (CHAPMAN & THORNES, 2003). Besides, spatial information is missing. These limitations the method is unsuitable for large area analysis.

As stated above the sky view factor is retrieved from Fish-eye lens, GIS software and python script on selected area in Kolkata. We selected 12 points in study area to extract SVF values from fish-eye lens and point vector data. Continuous SVF values is extracted in raster method as well as by using Python script. Fish-eye photos (Figure 4) were taken by using Nikon 610D camera with Nikon 16 mm f/2.8D Lens. All photographs are processed by using Sky View Factor Calculator software developed by Johnson and Watson (1984).

Figure 4: Fish-eye lens photographs

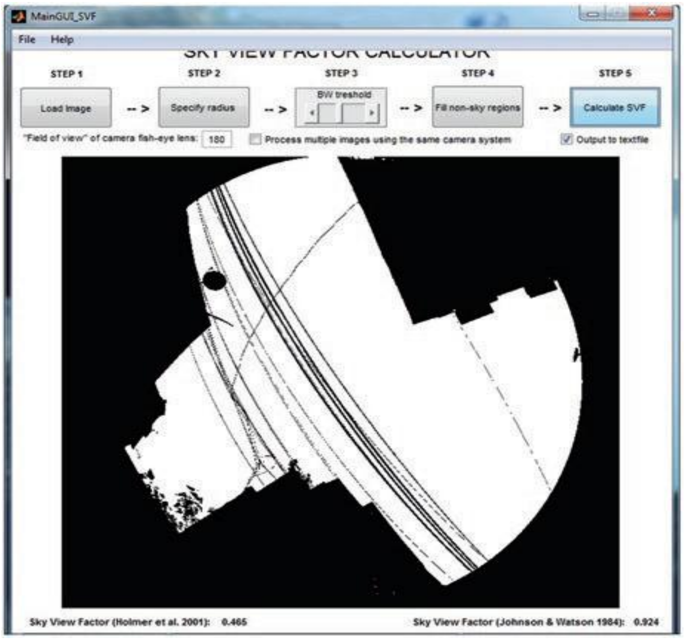

Figure 5: Layout of the sky view factor calculator

5.2. SVF calculation using Remote Sensing and GIS data

To understand and analyze Sky View Factor (SVF), the Remote Sensing and Geographical Information Systems (GIS) became very popular. The technology allows spatial and non-spatial analysis. Geographical Information System helps to optimize calculations as well as reduce research time. The digital elevation model (DEM), in particular, is a raster format that displays 3-D data on a 2-D digital substrate. DEM is a simplified way to represent urban morphologies (Ratti & Richens, 2004). It is considered "not just as a repository of information, but as a tool to support many forms of analysis" (Falcidieno, 1994). Geographical studies are where DEM has really found its most widespread uses due of its close relationship with GIS systems (Lin & Oguchi, 2006; Ruiz-Arias et al., 2009; Tarekegn et al., 2010). Some GIS software including ArcGIS, ArcView, MapInfo, ENVI, QGIS, Saga, etc. can be used to analyze the SVF values.

In the very first step, GIS tools were applied to create the database. Landsat and Google earth images are used to develop the building map so that the location of each building could be carefully determined. Two vital instruments have been implemented to do this research. The first one was the 'Urban Multi-scale Environmental Predictor' (UMEP) Modules of *QGIS* developed by Lindberg et al. (2018). Its algorithm is based on raster input, so the building footprints are rasterized from vector to SVF analysis. The second one, SVF Mapping Tool V1.1, was developed by Gál & Unger (2014), based on vector input and has been developed in the shapefile (.shp) format.

SVF mapping tool V1.1 is developed by Urban Climate Research Group, University of Szeged, is used to calculate SVF values from vector building database. For this analysis we calibrated the radius as 200m and 180° angle. Building polygons in the shape (.shp) file format with a height field and a point layer for the location where the SVF value is calculated are required for the study. The output is shown in point shape.

SVF values can also be calculated from QGIS software using UMEP plugins by using QGIS software. Pixel wise sky view factor map is generated using ground and building digital surface model. The SVF values are in range between 1 and 0.0245. High rise building roofs are showing SVF values as 1 as there is no obstruction. SVF 0.0245 is showing within an obstructed area surrounded by the building.

Figure 6: Sky View Factor Map prepared in QGIS using UMEP plugins. Spatial resolution is 10 meters

5.3. Comparison analysis of proposed method with existing method

12 locations are selected to calculate SVF (Table 1) for each assorted method. The SVF values of these four methods are very similar (Figure 7). Low building density area and building roofs showing respectively higher SVF values and it gradually decreases towards buildings and narrow lanes. Vegetation and other obstacles are invalidated during SVF calculation except fish-eye lens methods. Due to presence of vegetation and other obstacles (wires, poles, flex, banner, etc.) SVF values differ by almost 0.069 from other methods. There is strong correlation (R^2 = 0.8734, 0.8677, and 0.8490) between SVF Mapping tools V1.1, QGIS, Fish-eye lens and Python Script methods.

Table 1: Sky View Factor Analysis comparison

Point of Analysis	Python Script	SVF Mapping Tool V1.1 (radius 200m, direction 180°)	QGIS	Fish Eye Lens
1	0.812	0.903	0.892	0.821
2	0.621	0.581	0.57	0.501
3	0.721	0.703	0.714	0.583
4	0.786	0.843	0.795	0.651
5	0.923	0.882	0.853	0.855
6	0.972	0.932	0.927	0.869
7	0.824	0.878	0.731	0.697
8	0.623	0.625	0.598	0.61
9	0.618	0.561	0.546	0.527
10	0.746	0.765	0.704	0.683
11	0.834	0.815	0.798	0.787
12	0.678	0.692	0.665	0.631

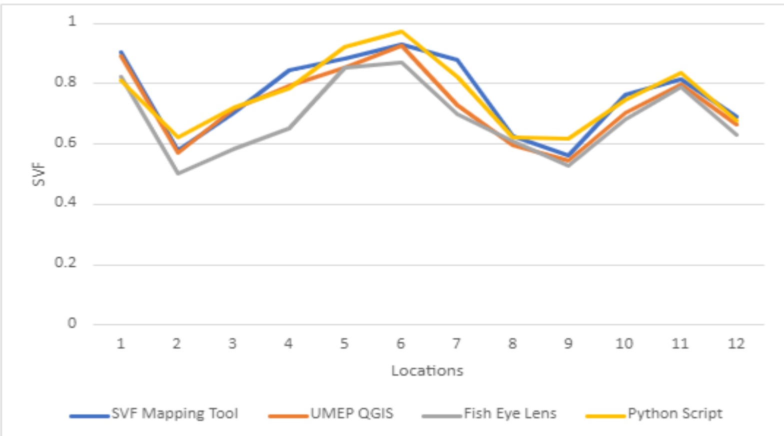

Figure 7: Variance of SVF between the SVF calculation methods

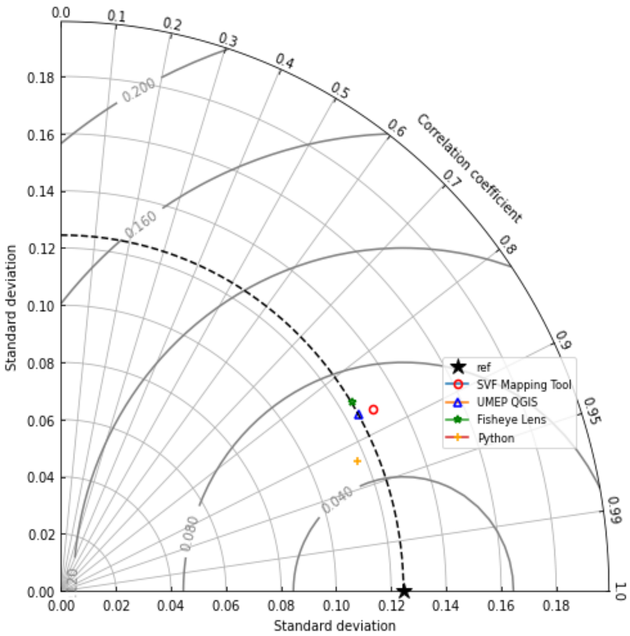

Figure 8: The validation results between the SVFs calculated by the SVF mapping tool V1.1, QGIS, fish-eye images and Python script

SVF Mapping Tool V1.1 considered more visible sky than the Fish-eye lens analyses, QGIS and Python script, whereas fish-eye lens analysis indicates more obstacles. To get maximum accuracy on results the data set should contain all the sky obstacles like buildings, trees, signboards on the city like Kolkata. On the contrary, trees may have a major influence on SVF and the influence may vary with time because Kolkata is situated on tropical deciduous climatic region, where trees shed their leaves in winter. So, the SVF value may vary in summer and winter. Though we are analyzing computational performance on selected SVF calculation methods, only buildings were considered as sky obstacles parameter for GIS and Python script methods.

In order to compare results, a DEM was developed from building footprints, the SVF values in UMEP method and python method were calculated 1 m above ground level, SVF mapping tool V1.1 and fish-eye lens at pedestrian level photography has also been done from 1m ground, to maintain the same height. As a limitation, in Remote Sensing and GIS method, it was not possible to reproduce trees and other street furniture which are required to accurately represent the area. As a limitation of Remote Sensing and GIS model, which did not consider the obstruction caused by trees and other parameters, it was expected to present higher SVF than the ones from the fish-eye lens images. (Table 1).
Processing times for Remote Sensing and GIS methods were faster than photographic methods. Python script is maximum effective to calculate SVF and cost-effective as it uses open-source frameworks. Figure 8 showing the relationship between SVF Mapping Tool (Red circle), UMEP QGIS (Blue triangle), Fish-eye lens (Green star) and Python Script (Orange plus). The reference SVF is shown by black dotted line, with SD value normalized to 0.1245. It can be seen that python model is best with observations. Fish-eye lens and UMEP QGIS are on same standard as observed and SVF Mapping Tool model is larger than observed.

6. Conclusions

The whole process had been done to calculate the sky view factor in an urban environment of Kolkata, a flat landscape region. This research has resulted in analysing the existing morphologies in the selected area, thus the average sky view factors is 0.7364. Some issued have being occurred during fish-eye lens photos were captured when covering the glass facades, which reflect solar radiations, may cause some varies in SVF values.

It can be stated that mainly in models as well as in virtual data, there are always some errors but the real situation gets overcome through python scripts. Python script for SVF calculation is still in progress stage. A small flat area is selected for the analysis and it is possible to run script on similar size and morphological regions. The script is not validated on hilly terrain region or vast areas. The method described can be used in research and applications related to urban climate modelling, and climate planning.

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