ASSESSMENT OF VERTICAL ACCURACY OF OPEN SOURCE DEMs IN PARTS OF GANGETIC PLAIN REGION WITH ICESat DATA

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1 KEY WORDS

Spaceborne LiDAR, GLAS, CartoDEM, ASTER, SRTM

2 ABSTRACT

Open source Digital Elevation Models (DEM) are very useful in providing an elevation reference for various applications. In Geographical Information System (GIS), DEM provides a terrain model to facilitate drainage network analysis, watershed demarcation, soil erosion mapping, contour generation and for other area and volume calculations. In this study Open Source DEMs namely ASTER, SRTM and CartoDEM are analyzed with ICESat footprints. The selection of DEM is very much dependent on geographical features of earth affecting its quality in the area. The accuracy assessment was carried out for the Open source DEMs with the help of ICESat land altimetry data. ICESat carried a single instrument, Geoscience Laser Altimeter System (GLAS), which measured the travel time of laser returns from the earth surface along profiles, with a spatial resolution of approximately 70 m and an along-track sampling of 172 m (Herring, 1997). It is used to measure ice sheet elevations, change in elevation through time, height profiles of clouds and aerosols, land elevation and vegetation cover and can approximate the sea ice thickness. Total 400 footprints of ICESat data are considered for analysis of elevation derived from Geoscience Laser Altimeter System (GLAS) data. The elevation derived using ASTER, SRTM and CartoDEM are compared with these footprints. These footprints are passing through two districts i.e. Kanpur and Unnao of Uttar Pradesh. All 400 footprints of ICESat /GLAS are divided into six classes for statistical analysis. The result shows that the accuracy is highest in CartoDEM followed by SRTM. The elevation profile of CartoDEM has a better linear correlation as compare to other DEMs. The RMSE value of CartoDEM is varying for different classes from 2.40m (fallow land) to 3.71 m (Built-up area).

3 INTRODUCTION

Global and countrywide open source DEMs are available on several web portals, such as United States Geological Survey (USGS) earth explorer, and BHUVAN respectively. Selection of DEM depends upon the accuracy of DEM for particular work and the type of area. The accuracy can be described on the basis of error in the output information. Like any spatial dataset, DEM is subject to different type of errors such as gross error during data collection, deficient orientation of stereo images (systematic error) with photogrammetrically determined elevation values (Mukherjee, 2013) and unknown combinations of errors (random error) which cannot be avoided. These errors vary geographically depending on terrain conditions (Holmes,2013). Errors in DEM are widely recognized to comprise mainly two components, the horizontal, often referred as the positional accuracy of X and Y components, and the vertical component or the accuracy of the attribute. However, positional and attributive accuracy generally cannot be separated (Forkuor,2012); the error may be due to an incorrect elevation value at the correct position or a proper elevation for an incorrect position or any combination of these. Basically three groups are affecting the uncertainties of all available open source DEMs. The first one characterizes the system parameters during data acquisition: baseline length and orientation, phase, slant range and position of the antenna, the second group deals with raw data processing steps, and the last group contains the influences of vegetation and land cover (Liu, 2015). For example, an error of one arc sec in the baseline tilt causes an elevation error of 1.5 m at a ground range of 300 km also, a 1-m error in the baseline length will lead to an elevation error of 0.5 m (Elkhrachy,2017).

The available Open Source DEM's such as ASTER, SRTM covers whole Earth and for INDIAN region Carto-DEM is available with countrywide region. It is important to examine the quality of the dataset before usage carefully. The accuracy and quality of reference data should be at least one order better than the data to be evaluated (Elkhrachy,2017).The present study is to assess the accuracy of DEM in two different ways; First, analyzing the elevation of ASTER GDEM version 2, SRTM and Cartosat-1 V3 DEM with ICESat Geoscience Laser Altimetry System (GLAS) elevation footprints; Second, examining the association of DEMs error with terrain attributes and identifying the variation of error in height with respect to land use/land Cover features.

4 OBJECTIVE

The objective of this study is to perform an accuracy assessment of open source latest release Digital Elevation Models: ASTER, SRTM and cartosat-1 DEMs using ICESat data for the area of Kanpur, Unnao region of Uttar Pradesh, India.

5 STUDY AREA AND DATA SETS

The study area lies between 26°12' and 26°49' North latitude and 80°12' and 80°59' East longitudes with an area of 5382 km² approximately in middle of Uttar Pradesh, India. This area covers District Kanpur, Unnao and some portion of Lucknow. The average altitude of Kanpur is 126 m above mean Sea level and Major Physiographic Unit is Central Ganga Alluvial Plain. The LiDAR track is passing over an area in between Kanpur and Unnao is taken for study. The major area is having LiDAR footprints over river, forest, Dry River sand, agriculture, fallow land and built up area.

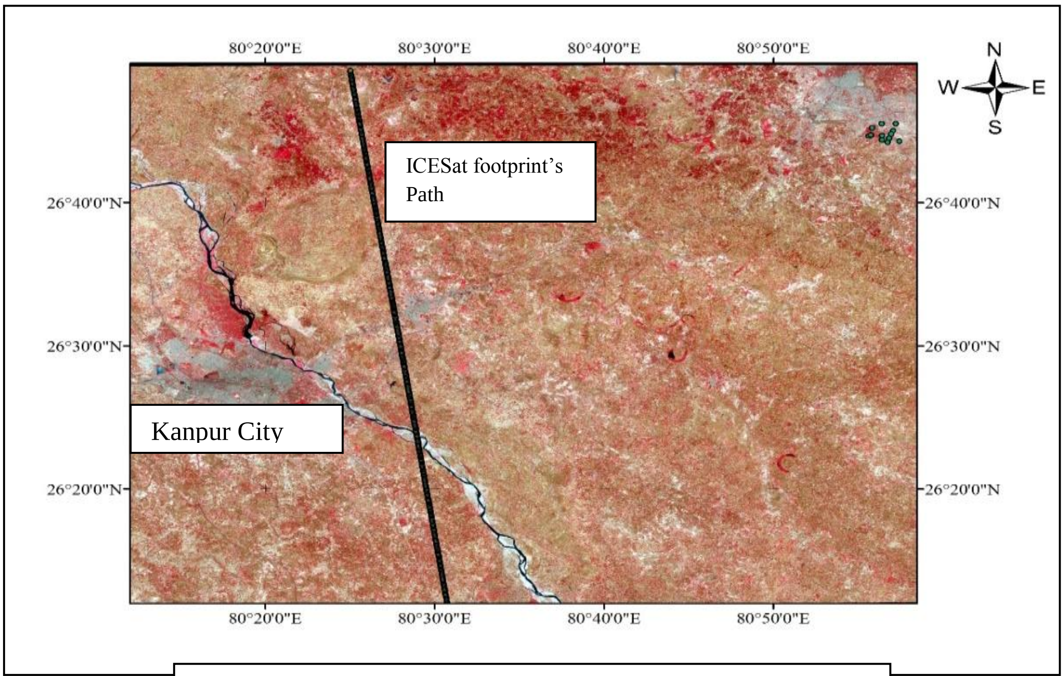


Figure 1: Image of study area containing ICESat footprints

5.1 Dataset Used

All the datasets used in this study are open source. The selection of data is based on two criteria: firstly the availability latest version and second, the selection of satellite images of same season for same LULC properties. The SRTM was a joint project of NASA, National Geospatial-Intelligence Agency (NGA) with German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry (Guth,2006). It was the 11 days mission and executed on February 2000. The data are referenced to WGS-84 ellipsoid in the horizontal direction and EGM-96 GEOID in the vertical direction. The SRTM version 3 has been used instead of the previous version. It has been updated and then released after using sophisticated interpolation and hole filling algorithms which make use of ancillary data sources when they are available (Elkhrachy,2017). It has an over-all accuracy of around ±16 m at 95% confidence level (Bamler,1999). ASTER was a joint project of NASA and Ministry of Economy, Trade and Industry of Japan (METI). ASTER DEM covers 99% of the Earth's Land Mass. In it the near-infrared stereo imagery was collected simultaneously at both nadir and off nadir angles with along-track alignment (Abrams, 2002). This stereo imagery was then used to develop a DEM through stereo pair correlation technique (Oliveira,2009). It is an advanced multispectral imaging system of varying spatial resolution between 15m to 90 m. ASTER relative DEM data has a horizontal accuracy of ±15 m and better and a vertical accuracy of ±15–25 m (Harding,2005), depending on the environmental setting of the region. CartoDEM V3 is the open source DEM available at BHUVAN portal. The primary mission goal of CARTOSAT-1 is to generate a current, accurate and consistent DEM throughout the country to facilitate the user communities of remote sensing and GIS.

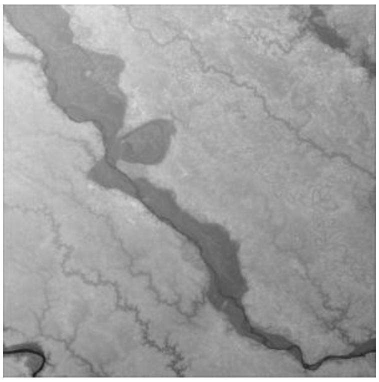


Figure2: SRTM DEM image

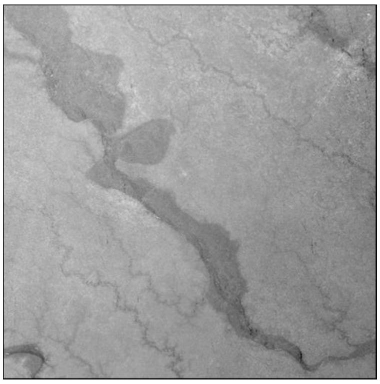


Figure3: ASTER DEM image

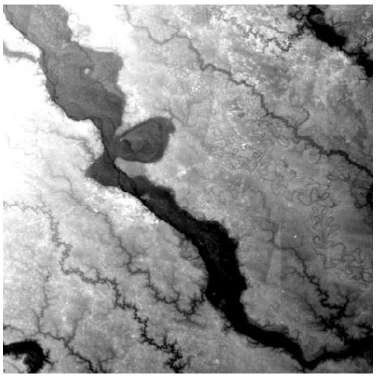


Figure4: CartoDEM V3R1 Image

6 METHODOLOGY

The elevations derived from the GLA14 are compared with ASTER, SRTM and CartoDEM. All the elevation values are transformed into same datum. The reference ICESat data were transform into WGS84 ellipsoid. All 400 footprints of ICESat /GLAS are divided into six described classes for statistical analysis. The maximum number of footprints lies in agricultural area whereas the minimum in water body. For further comparative analysis, the elevation differences of SRTM and GLAS (SRTM-GLAS); the elevation differences of ASTER and GLAS (ASTER-GLAS); the elevation differences of CartoDEM and GLAS (CartoDEM-GLAS) have been calculated respectively. The variation of errors in these classes are compared through statistical analysis of the tabular data (Table 3 to 8) with the help of RMSE (Root Mean Square Error), mean error, standard deviation of errors, maximum error, minimum error, Skewness and Kurtosis. The process has been done using following methodology diagram:

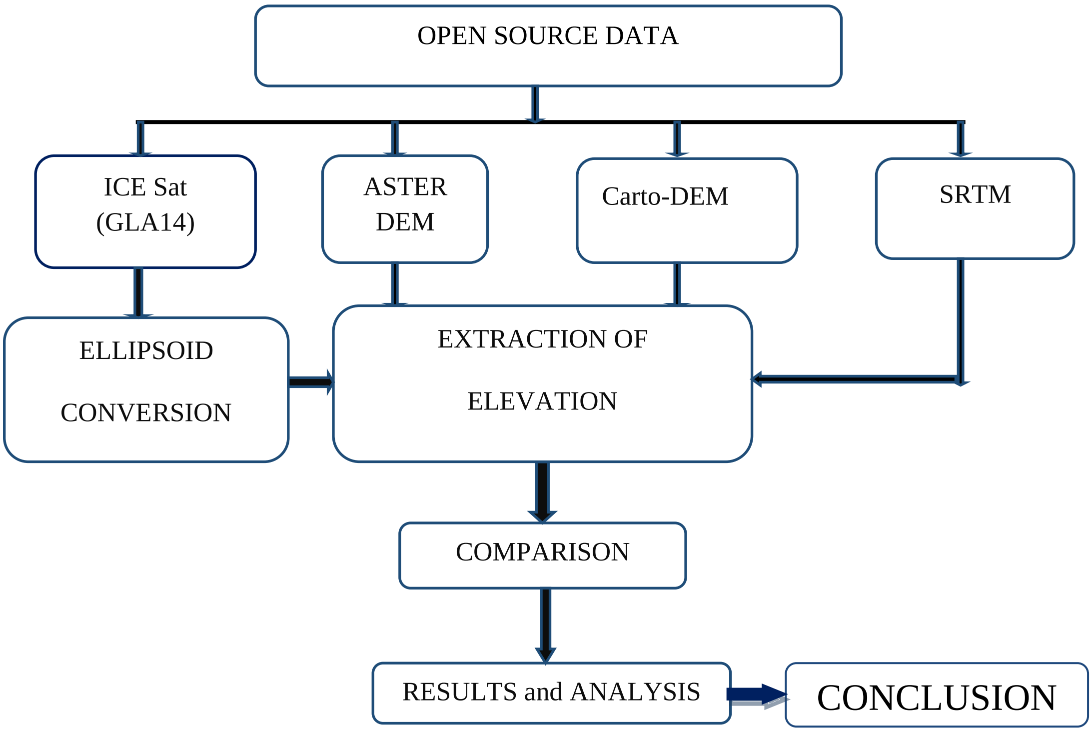


Figure 5: Methodology flowchart for the elevation comparison analysis

6.1 Tools for Visualizing GLAS Data

As an open source tool QGIS or SNAP All tools for the GLAS related data are open source and available in the NSIDC official website. In this study the for land surface altimetry data (GLA 14) NGAT height extraction tool is used. After performing above steps import the excel sheet in ArcGIS and add "X and Y" data after projection change. This coordinate information gave the path of footprints in points. For validation of places one can export this file using export tool as shape file to "kml" which converted this shape file into kml file so that it can run under Google earth and can track the given LiDAR track on Google Earth.

Figure 6: Image of GLAS track on Google earth

6.2 Comparison of DEMs with ICESat data

In DEM, each pixel represents the average value of altitude (elevation) of respective location covered in those pixels that are given in attribute table of DEM. The ICESat GLAS data are discrete vector (point data) in X-Y- Z format and DEM data is in raster grid format (Zwally, 2002) .The total 400 ICESat footprints are covered in the area considered for study. To extract respective pixel values of DEM layer the spatial analyst tool of "extract values to point" in ArcGIS 10.3 has been used which extract elevation of given overlaid pixel based on ICESat/GLAS point features. Then, the elevation between ICESat and given DEM is compared and analyzed in tabular form by converting into EXCEL sheet.

6.2.1 Preprocessing of data

In the pre-processing of multisensory satellite data the conversion of raw data must done into same format so that one can compare the correct data. In this study all GLAS footprints has been converted into WGS 84 geographic coordinate system ellipsoid and then calculate the orthometric height (H) with the help of EGM 96 (earth gravitational model1998) Geoid height calculator. The Geoid surface is an equipotential or constant geopotential surface which corresponds to MSL (Mean Sea Level). The geoid height/geoid undulation (N) is the difference in height between geoid and ellipsoid at a point.

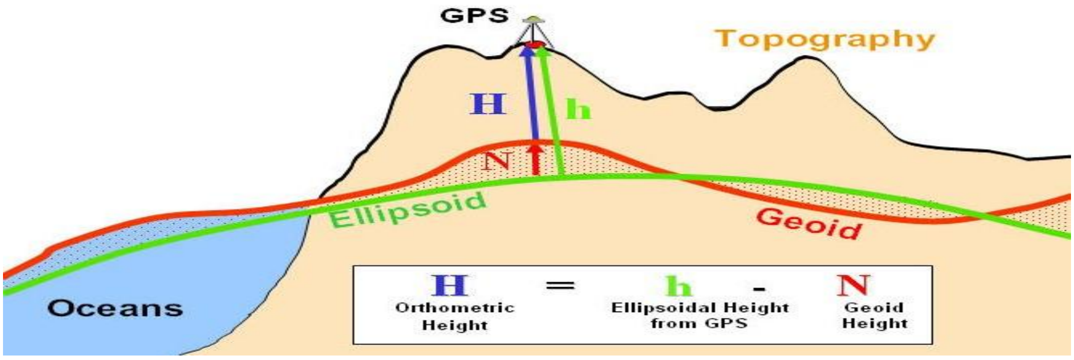


Figure7: Conversion of ellipsoid height into orthometric height (I. Elkhrachy,2017)

The Datum of ICESat GLAS data is Topex/Poseidon ellipsoid and difference between WGS84 ellipsoid elevation and Topex/Poseidon elevations is between 70cm to 71cm (NSIDC; renganathan, 2010) .So in present study we assume that Topex/Poseidon elevations having 70cm higher values than the WGS84 elevations. So the GLA14 elevation of WGS84 can be calculated as: $H_{(WGS84)} = h - N - 0.70$ (1)

Table 2: Example of Conversion of ICESat/GLAS elevation into orthometricheight (H)

(X)LONG	(Y)LAT	(h)TOPEX	(h)wgs84	(N)GEOID	H=h-N
80.511638	26.201	54.158	53.458	-62.171282	115.629282
80.511396	26.204	55.805	55.105	-62.175641	117.280641
80.511155	26.205	55.109	54.409	-62.18	116.589

7 RESULT AND ANALYSIS

7.1 Statistical Analysis of Elevation Differences

The variation of errors in these classes is compare through statistical analysis of the tabular data with the help of RMSE (Root Mean Square Error), mean error, standard deviation of errors, maximum error, minimum error, Skewness and Kurtosis. The main statistical parameter is RMSE which provide the understanding of differences between two types of data. The root mean square error computation formula is

$$\text{RMS Error} = \sqrt{\frac{\sum_{i=1}^{N} \text{Yi}^2}{\text{N}}} \quad (2)$$

$$\text{Where Yi} = (A_D - \text{A}_\text{R}) \quad (3)$$

In above equation 'Yi' represent the elevation difference (error) at a particular sample of DEM "A_D" from reference data elevation "A_R" (ICESat /GLAS data) and 'N' represents the number of samples. RMSE gives the size of error deviation from regression line (Watts, 2008).Apart from RMSE mean error, standard deviation of errors, skewness and kurtosis property error samples are also calculated. Mean is simply the average of the errors that indicate the "central" value of a set of errors (Howell, 2007).

$$\bar{Y} = \sum_{i=1}^{N} \frac{Yi}{N} \quad (4)$$

Standard deviation is a measure of the dispersion of an error from its mean. If the data points are further from the mean error, there is higher deviation within the data set. The formula of calculating the standard deviation is

$$SD = \sqrt{\frac{\sum_{i=1}^{N}(Yi-\bar{Y})^2}{(N-1)}} \quad (5)$$

Where Yi is the sample error value and $\bar{Y}$ is the mean of these entire samples. Standard deviation is a measure of the dispersion of a set of data from its mean. If the magnitudes of error are further from the mean, there is higher deviation within the errors. Skewness can be defined as the measure of symmetry, or more precisely, the lack of symmetry .it shows the errors are symmetrical (skewness =0), positive skewed or negative skewed).

$$\text{Skewness} = \frac{\sum_{i=1}^{N}(Yi-\bar{Y})^3}{(N-1)\times SD^3} \quad (6)$$

$$\text{kurtosis} = \frac{\sum_{i=1}^{N}(Yi-\bar{Y})^4}{(N-1)\times SD^4} \quad (7)$$

All 400 footprints of ICESat /GLAS are divided into six described classes for statistical analysis. The maximum number of footprints lies in agricultural area whereas the minimum in water body. The value of Root Mean Square Error is least of CartoDEM in three classes i.e. dry sand (2.416062706m), fallow land (2.409267939m) and forest area (3.223609778). SRTM have least RMSE in built-up (3.31335177m) and in water (1.926161987 m) and in agricultural land (2.687513721m) ASTER has least value. Apart from RMSE the value of standard deviation ,skewness and kurtosis also indicates that the CartoDEM has the most symmetric and flat variation. The statistical values of SRTM are also satisfactory in the built-up and forest areas.

TABLE 3: Statistical Parameters of Agriculture Area

Parameters	SRTM-GLAS	ASTER-GLAS	Carto-GLAS
FOOTPRINTS	305	305	305
RMSE(meter)	3.33	2.68	3.05
MEAN(meter)	2.80	-0.24	2.59
STAN.DEV. (meter)	1.80	2.68	1.62
MIN(meter)	-3.08	-7.17	-1.43
MAX(meter)	9.31	11.22	6.89
SKEWNESS	0.16	0.63	0.40
KURTOSIS	0.50	1.82	-0.37

TABLE 4: Statistical Parameters of Built-Up Areas

Parameters	SRTM-GLAS	ASTER-GLAS	Carto-GLAS
FOOTPRINTS	25	25	25
RMSE(m)	3.31	3.67	3.70
MEAN(m)	2.76	1.56	3.37
STAN.DEV. (m)	1.87	3.40	1.56
MIN(m)	-1.61	-5.93	0.8
MAX(m)	7.23	8.38	6.86
SKEWNESS	0.22	-0.04	0.59
KUTOSIS	0.69	-0.41	-0.03

TABLE 5: Statistical Parameters of Dry River Bed

Parameters	SRTM-GLAS	ASTER-GLAS	Carto-GLAS
FOOTPRINTS	10	10	10
RMSE(m)	3.10	4.26	2.41
MEAN(m)	1.32	1.02	1.91
STAN.DEV. (m)	2.96	4.36	1.54
MIN(m)	-2.65	-4.84	0.02
MAX(m)	5.02	8.47	4.41
SKEWNESS	-0.38	0.47	0.44
KURTOSIS	-1.59	-0.92	-0.92

TABLE 6: Statistical Parameters of Fallow Land

Parameters	SRTM-GLAS	ASTER-GLAS	Carto-GLAS
FOOTPRINTS	39	39	39
RMSE(m)	3.02	3.13	2.40
MEAN(m)	2.05	-0.40	2.05
STAN.DEV. (m)	2.25	3.14	1.26
MIN(m)	-3.83	-11.21	-1.27
MAX(m)	6.25	4.89	5.00
SKEWNESS	-0.64	-0.95	0.17
KURTOSIS	0.60	2.23	0.61

TABLE 7: Statistical Parameters of Forest Area

Parameters	SRTM-GLAS	ASTER-GLAS	Carto-GLAS
FOOTPRINTS	17	17	17
RMSE(m)	4.63	4.19	3.22
MEAN(m)	4.22	1.64	1.99
STAN.DEV. (m)	1.96	3.97	2.60
MIN(m)	0.11	-6.49	-2.01
MAX(m)	8.86	8.09	7.06
SKEWNESS	0.37	-0.13	0.43
KURTOSIS	1.36	-0.54	-0.004

TABLE 8: Statistical Parameters of Water Body

Parameters	SRTM-GLAS	ASTER-GLAS	Carto-GLAS
FOOTPRINTS	4	4	4
RMSE(m)	1.92	4.62	3.56
MEAN(m)	-0.30	2.94	3.12
STAN.DEV. (m)	2.19	4.11	1.99
MIN(m)	-3.32	-2.11	1.34
MAX(m)	1.88	7.44	5.43
SKEWNESS	-1.04	-0.32	0.33
KURTOSIS	1.72	-0.95	-3.9

From the above tables which depicts the finer accuracy of CartoDEM. The comparison of different statistical parameters for the LULC classes has been represented in Fig. 5 and 6

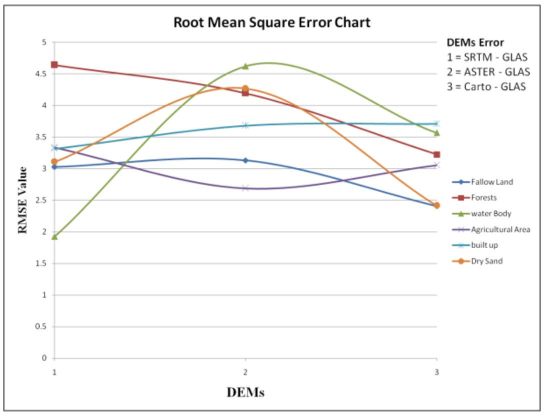


Figure 8: RMSE values of DEMs

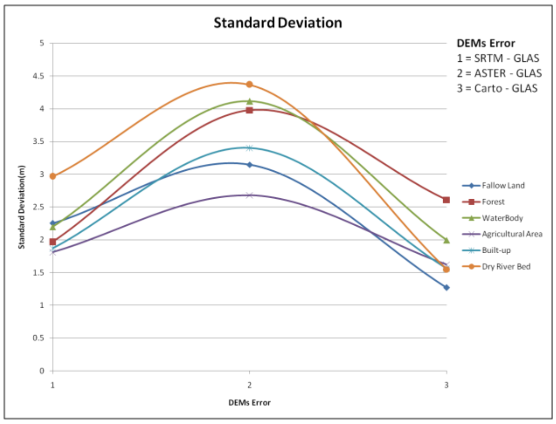


Figure 9: standard dev. Values of DEMs

7.2 Correlation and Regression Analysis of variation in elevation

Whereas R^2 determines the percentage of variation in the values of errors in this study. R^2 is known as coefficient of determination and Its value varies from 0 to 1. It is the measure of how well the regression line. If the regression line passes through every point in scatter plot it would be able to define all variation and as much regression line is away from the points, explanation would be poor (Howell, 2007). Figure 10 to 27 shows the slope and variation in error values for the different LULC with the help of regression line.

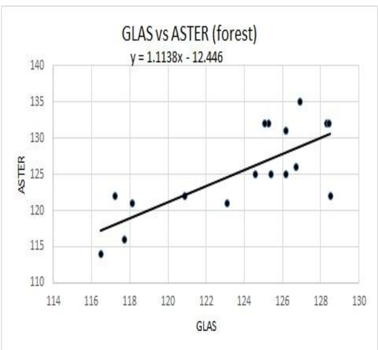


Figure10:G-A forest (R^2= 0.577)

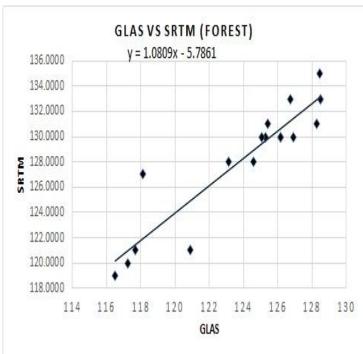


Figure 11:G-S forest (R^2=0.842)

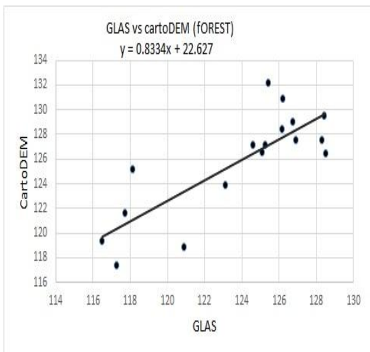


Figure 12 :G-C forest (R^2= 0.653)

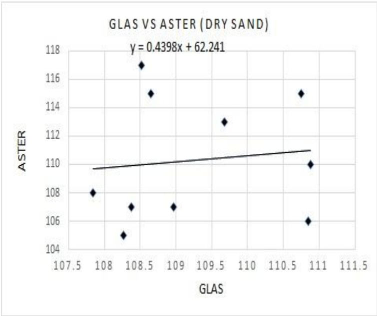


Figure 13:G-A dry sand (R^2=0.014)

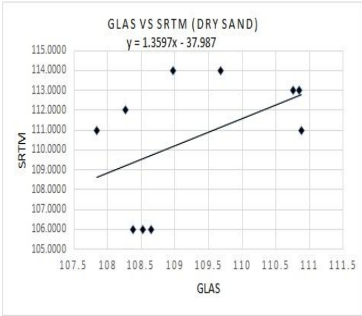


Figure 14:G-S dry sand (R^2=0.226)

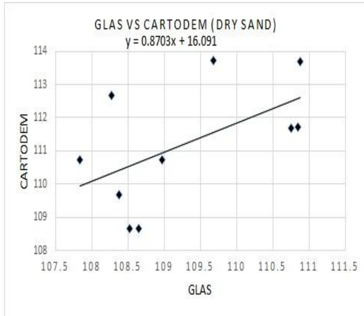


Figure15:G-C dry sand (R^2= 0.303 **)**

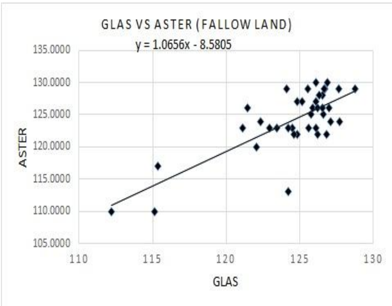


Figure16: G-A fallow (**R^2**=0.585)

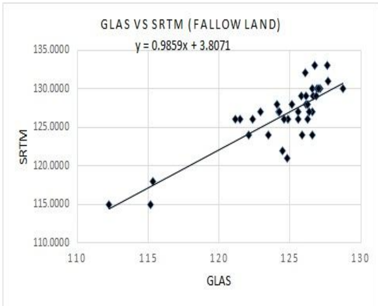


Figure 17 : G-S fallow (**R^2**= 0.701 **)**

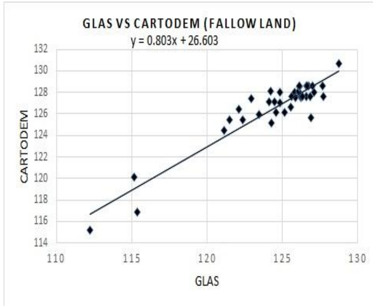


Figure 18:G-C fallow (R^2=0.874)

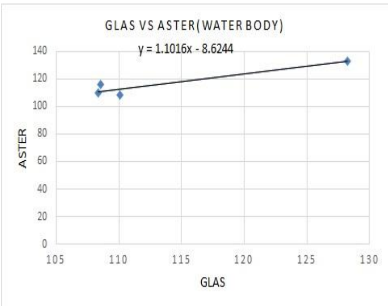


Figure19:G-A water (R^2=0.876)

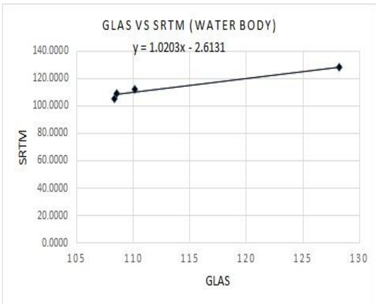


Figure 20:G-S water (R^2= 0.953)

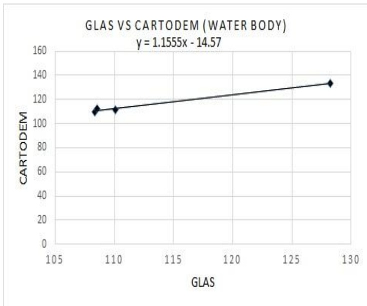


Figure 21:G-C water (R^2=0.986)

Figure 22:G-A builtup (R^2=0.639)

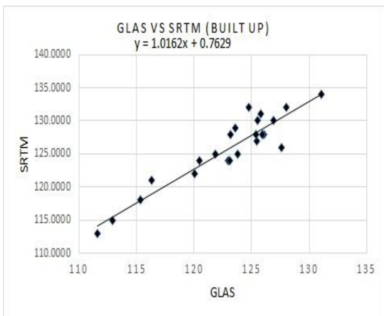


Figure 23:G-S builtup (R^2= 0.868)

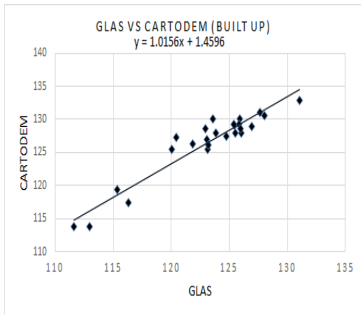
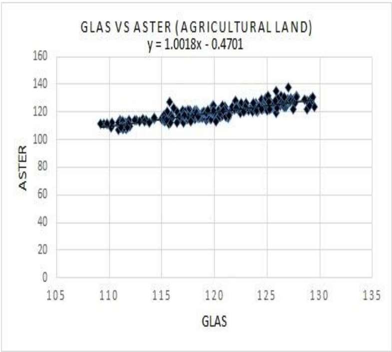
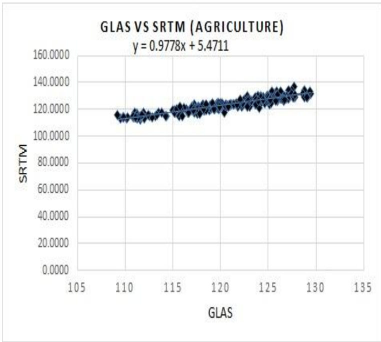


Figure 24:G-C built up (R^2= 0.904)





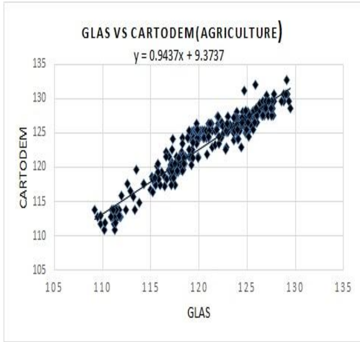


Figure 25: G-A agriculture (R^2= 0.775) **Figure26:**G-S agriculture (R^2=0.896) **Figure 27:**G-C agriculture (R^2=0.878)

In above analysis the value of R^2 is highest in CartoDEM among five classes. Only in forest area SRTM has maximum value which indicates the best correlation of elevation of CartoDEM from the GLAS elevation among all three DEMs. SRTM has better values of R^2 than ASTER.

8 CONCLUSION

Present study shows the utility of open source DEMs and ICESat LiDAR data in analysis of relation between the terrain features and the accuracies of them. The accuracy of ICESat (V34) data was verified with respect to the CartoDEM V3R1, SRTM and ASTER DEMs over Kanpur and Unnao district located at the bank of Ganges at plain region for about 400 points. The RMSE for the forest areas was found to be more as compared to the fallow land and agricultural areas. The statistical parameters indicate that CartoDEM data product is best among studied three DEMs (ASTER, SRTM and CartoDEM) in 5 classes except built-up area when compared with GLAS data products. SRTM elevation data product can be used for classes such as water body, built-up area and forests etc. It is better than ASTER elevation data product. ASTER elevation data product can be satisfactorily used in mapping agricultural areas and has least accuracy in three DEMs.

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