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Accuracy of digital elevation models; under canopy vs. open field

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ABSTRACT

Digital Elevation Models have been known as the representations of terrain elevation data captured, processed and released by remote sensing capabilities. They could either be called Digital Surface Models, which include elevation data of the Earth along with the objects later placed by the humans, or Digital Terrain Models, which only reflect the real z values of the bare ground. This is a conundrum for the latter definition since a considerable amount of earth surface is covered with natural and artificial objects, forests being the most noteworthy. Furthermore, the usage of them on areas covered by forests is a popular phenomenon deserving an in depth questioning. For this reason, the measurement of how accurate they are, is necessary on terrains covered by forests vs. on terrains which barely involves vegetation or no vegetation at all. In this study, the elevation data of Shuttle Radar Topography Mission C-band SAR 30 m Global DEM, Shuttle Radar Topography Mission X- band SAR 25 m partial Global DEM, ALOS Phased Array type L-band SAR 12.5 m Global DEM, ALOS World 3D Precise 30 m Global Digital maps and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER v3) 30 m Global DEM were compared to a high density sample of z values generated by Real Time Kinetic Global Positioning System. Results showed that under the forest canopy, the margin of error increased across the elevation data.

1. INTRODUCTION

Digital Elevation Models (DEMs) are 3 dimensional images which are composed of grids that have elevation values in. They are important datasets used in many fields (Aronoff, 2005) such as management perspectives in natural resources, engineering and infrastructure, disaster and risk analysis, archaeology, security, aviation, forestry, energy, topographic mapping, landslide and flood analysis (Makineci & Karabörk 2016), with ease. They can be manipulated and various new geographical information like elevation, gradient, aspect, topographical roughness, etc. (Ravibabu & Jain, 2008) can be derived from them through Remote Sensing (RS) and Geographical Information System (GIS) capabilities. The first ever Global DEMs were produced by NASA and European Space Agency (ESA) after an 11-day shuttle program equipped with C-band and X-band Synthetic Aperture Radar (SAR) sensors in 2000. However, for remote sensing capabilities, acquiring the elevation information of the ground is difficult to achieve when the ground is covered by natural and artificial objects. Forest vegetation is one of the most encountered obstacle in the way among them. Accuracy in spatial information is a must for forestry, natural resource management, landscape planning, decision making and many other areas, (Murphy et al. 2008). For this purpose, investigating how much accuracy DEMs have under the forest canopy compared to those from the open fields is necessary. In this paper, the acknowledged open source DEMs which are Shuttle Radar Topography Mission C-band SAR 30 m Global DEM (SRTM C-band), Shuttle Radar Topography Mission X- band SAR 25 m partial Global DEM (SRTM X-band), ALOS Phased Array type L-band SAR 12.5 m Global DEM (ALOS PALSAR), ALOS World 3D Precise 30 m Global Digital maps (AW3D30) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER v3) 30 m Global DEM are compared to Real Time Kinetic Global Positioning System (RTK-GPS) elevation values taken in the province of Kastamonu, Turkey. The result values of Root Mean Square Error (RMSE), which were

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indication of the value of difference between the model and an observed value, showed that the absolute error of elevation values extracted from DEMs under forest canopy were greater than the ones on the open lands.

2. METARIAL AND METHODOLOGY

Turkey has been undertaken watershed rehabilitation projects to fight the effects of global warming. Water deposition projects were devised throughout the country. The study area which had previously been surveyed using high precision RTK-GPS in order to get a better view of the topography in this context, was chosen because it also expanded over forest canopy. The location of the study area was situated between 41°12'49'' - 41°14'20'' Northern Latitudes and 33°22'12'' - 33°28'11'' Eastern Longitudes in Kastamonu, Turkey (Figure 1).

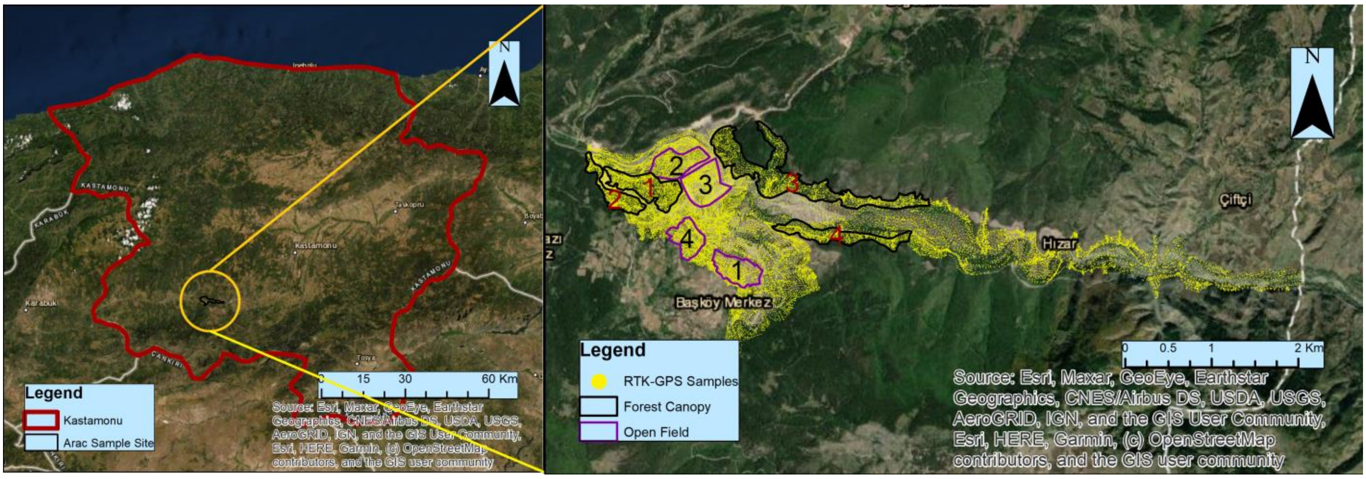

Figure 1. Study Area

Table 1. Land cover type information

Forest Canopy	Area(ha)	Number Of RTK-GPS Points	RTK-GPS Points/Hectare
1	20.57	2714	131.95
2	11.95	1596	133.52
3	57.86	3430	59.28
4	19.19	2343	122.12
Open Field			
1	14.34	2378	165.81
2	15.17	2421	159.61
3	18.21	2794	153.44
4	12.10	2380	196.73

Land cover types for the study were classified as forest canopy and open field. Four locations with enough location readings were selected for each class. Sample sites of forest canopy 1, 2, 3 and 4 had the areas of 20.57, 11.95, 57.86 and 19.19 hectares, respectively. The areas of open field 1, 2, 3 and 4 were 14.34, 15.17, 18.21 and 12.1 hectares, respectively. Google Earth Pro was used for the selection process. The fields of forest canopy were picked from highly dense forest vegetation. Although site number 3 was not as much dense as the others, it still had significant amount of canopy in it. The land use in three of the open fields was agriculture. Site number 3 of open field was a construction site which was predominantly bare ground. GPS point density was ranging from 59,28/ha to 196,73/ha for sampling sites (Table 1).

Data from the mentioned open source DEMs and GPS survey points were processed using ArcMap 10.5. GPS point location z values within the specified class sites were compared to those of the open source DEM extracted z values and root mean square errors (RMSE) were calculated for each class site.

In ArcMap, first, a raster DEM model was generated, using the random GPS points. The procedure allowed us to produce a spatial resolution of 22.7 meter through points to raster conversion (Figure 2). Second, utilizing this newly generated DEM, four sets of systematic points were produced for each land cover type by assigning a point to the center of each raster cell in the model (Figure 3). Third, new systematic points were placed on each open source DEM, and new elevations were extracted for each point from the them (Altunel 2020). Finally, RMSEs were calculated for each land cover class from each DEM.

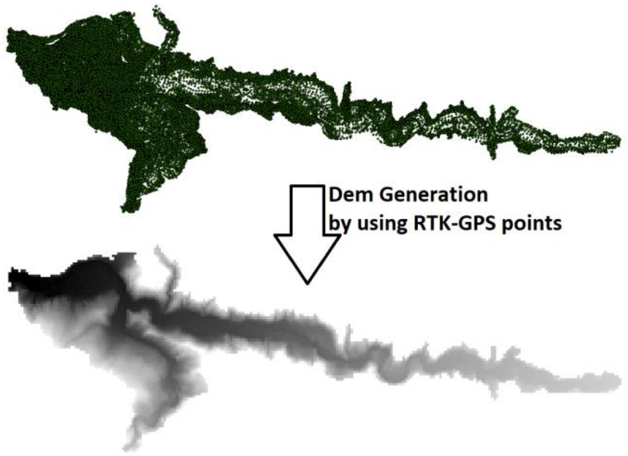

Figure 2. High resolution DEM generated from random GPS points

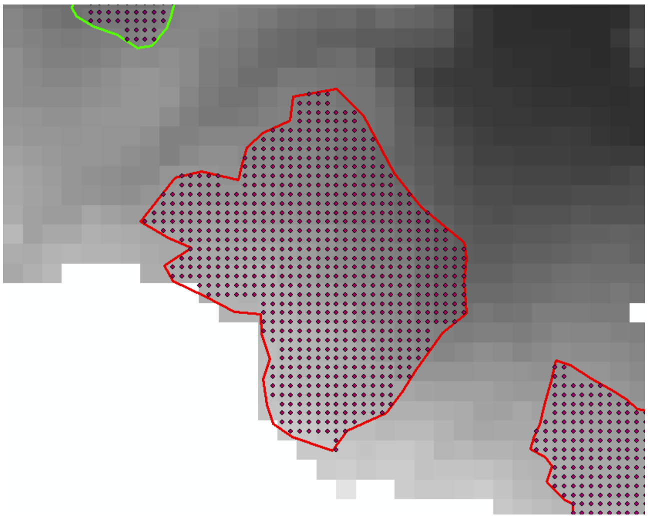

Figure 3. Systematical points, produced from high resolution DEM

RMSE, which has been a frequently used formula for measuring the difference between the measured and model elaborated values, was utilized to evaluate the difference between the GPS measured and open source DEM extracted values.

3. RESULTS

RMSEs between the elevations of GPS, as field measured values, and the elevations of SRTM, SRTM X-band, ALOS PALSAR, AW3D30 and ASTER, as model extracted values, were calculated (Table 2).

It was expected that RMSE values in forest canopy sites would be greater than RMSE values in open field sites for each test of DEMs, individually. The results of all sites in SRTM, SRTM X-band and AW3D30 indicated that this was the case because the difference in RMSE value between forest canopy and open field were considerable. However, site 4 in open field in ASTER had a RMSE value of 12.78 which exceeded the RMSE value of site 2, 3 and 4 in forest canopy. Moreover, site 3 in forest canopy in ALOS PALSAR had a RMSE value of 37.68 which was less than site 3 and 4 in open field.

Regardless of these two sites in ASTER and ALOS PALSAR, as shown in Table 2, RMSE values of all forest canopy sites were greater than RMSE values of all open field sites.

Table 2. RMSE values distributed with respect to open field and forest canopy sites

Sample Sites	RMSE Values of The DEMs (m)				
Forest Canopy	SRTM C-band	SRTM X-band	ASTER v3	ALOS PALSAR	AW3D30
1	10.05	41.64	12.85	45.69	9.45
2	10.66	42.02	10.51	45.66	8.09
3	8.53	38.27	12.51	37.68	9.22
4	10.33	38.77	12.14	48.02	7.92
Open Field					
1	2.69	34.08	9.27	36.42	3.12
2	2.66	33.72	7.58	36.63	3.3
3	6.13	36.68	7.69	39.4	5.21
4	4.76	34.88	12.78	38.51	3.39

4. DISCUSSION and CONCLUSION

This paper set out to evaluate the accuracy of the most acknowledged open source DEMs under forest canopy against open field. It was expected to find out that under canopy accuracy level would decrease. When the DEMs were compared to the GPS sample points, the results of RMSE values indicated that this was indeed the case with the exception of two sites.

SRTM C-band, SRTM X-band and ALOS PALSAR were the synthetic aperture radar (SAR) signal based DEMs which used the microwaves of the electromagnetic spectrum to predict the elevation of target areas. It was shown that longer wavelengths of microwaves penetrate vegetation to a far greater extent (Churchill et al. 1985). While C-band wavelengths were ranging from 3.75cm to 7.5cm, in the case of X-band on the other hand, they were ranging from 2.5cm to 3.75cm. So this can explain why SRTM C-band was better than SRTM X-band under canopy, although in open field, accuracy difference was approximately the same between them.

ALOS PALSAR used L-band whose wavelengths are ranging from 15cm to 30cm and longer than SRTM C-band and SRTM X-band. However, the results of RMSE values from it were counterintuitive to the fact that longer wavelengths of microwaves penetrated the canopy more. Alaska Satellite Facility which is the open source data provider for ALOS PALSAR used in this paper made the project of Radiometric Terrain Correction (RTC) so that the SAR data and the derivatives produced from them were more reliable to a broader community of users. In the validation trials, SRTM and National Elevation Datasets (NED) were used as comparison source data. However, the vast range topographical differences all across the world were probably much more than what it could efficiently represent. In this particular study, the results indicated that it failed to deliver more desirable outcome than one of the other comparison data, SRTM C-band, used in this paper.

ASTER v3 and AW3D30 utilized stereo correlation to produce DEM by using the stereo pairs. Their results of RMSE values in line with the argument that accuracy level of DEMs would decrease under forest canopy except the result of ASTER v3 for site 4 in open field. Both give better results than SRTM X-band and ALOS PALSAR. However, AW3D30 performed better than ASTER v3 and its results were very similar to the SRTM C-band as the recent study suggests (González-Moradas & Viveen 2020).

Overall, all of the DEMs put to the test in this study performed better in open field sites than forest canopy sites which is in the line with the expectancy of this research. In future, this kind of study should be done bigger areas and more remote sample sites to each other should be selected than the sample sites in this paper.

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