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Vertical Assessment of Public Global Digital Elevation Models Including 1″ SRTM Generally, and in Eight Sample Land Covers and Terrains of Tanzania

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Abstract

Recent public global digital elevation models (GDEMs) include 1″ SRTM , 1″ASTERv2 , 3″ACEv2 and 3″ SRTM CGIAR-CSIv4.1 . GDEMs have many useful applications in many areas. Many developing countries are not in position to determine their own reliable digital elevation models (GDEMs). Often a resort is to search for public GDEM that suits its purpose better. The search for a suitable DEM for Tanzania has been going on for more than a decade. In this paper, a review of search for a better GDEM for Tanzania in the past five years through vertical assessment of public GDEMs is given. The method used is the statistical assessment of the differences of GDEM and GPS control point heights relative to EGM96 geoid model. The assessment used between 127 and 222 GPS control points scattered over Tanzania. Always two GDEMs were compared and validated, often 3″ SRTM CGIAR-CSIv4.1 was one of the GDEMs. In 2012 and 2013, the comparison and assessment was general over the whole country. In 2014, in addition to the general assessment, three representative land covers and terrains were also involved. In 2015, the representative land covers and terrains were increased to six and in 2016 they were eight. The other public GDEMs involved are 1″ASTERv2 , 3″SRTM-JdeFv4.1 and 3″ACEv2 . 1″ASTERv2 and 3″ACEv2 proved in their first assessments to be much inferior to 3″ SRTM CGIAR-CSIv4.1 and 3″ SRTM-JdeFv4.1 . The overall fit of 1″SRTM to the GPS controls is about 7m while for the 3″ SRTM CGIAR-CSIv4.1 and 3″ SRTM-JdeFv4.1 is around 10m. 1″SRTM is close to the two 3-arc seconds GDEMs by about 6m.

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Performance of 1″SRTM is the best in flat and almost bare land where STD is 1.5m and RMS is 2.4m, and is the worst in rough, mountainous and forested terrain where the STD is 10m and RMS is 10.5m. 1″SRTM performance is superior to all the GDEMs validated until 2016 and therefore the best DEM for Tanzania.

Keywords**:** Public GDEMs; vertical validation; 1″ SRTM ; 3″SRTM CGIAR-CSI; Tanzania.

1. Introduction

The Shuttle Radar Topography Mission (SRTM) is a joint research project of the National Aeronautics and Space Administration (NASA), the National Geospatial-Intelligence Agency (NGA) of USA government, and the German and Italian Space Agencies. SRTM consisted of a specially modified radar system that is based on the older Space-borne Imaging Synthetic Aperture Radar (SIR-C/X-SAR) of 1994. The SRTM payload was outfitted with two radar antennas, one located in the Shuttle's payload bay, and the other a critical change from the SIR-C/X-SAR, allowing single-pass interferometry on the end of a 60-meter (200-foot) mast that extended from the payload bay once the Shuttle was in space. The technique employed is known as Interferometric Synthetic Aperture Radar (InSAR), i.e. Figure 1.

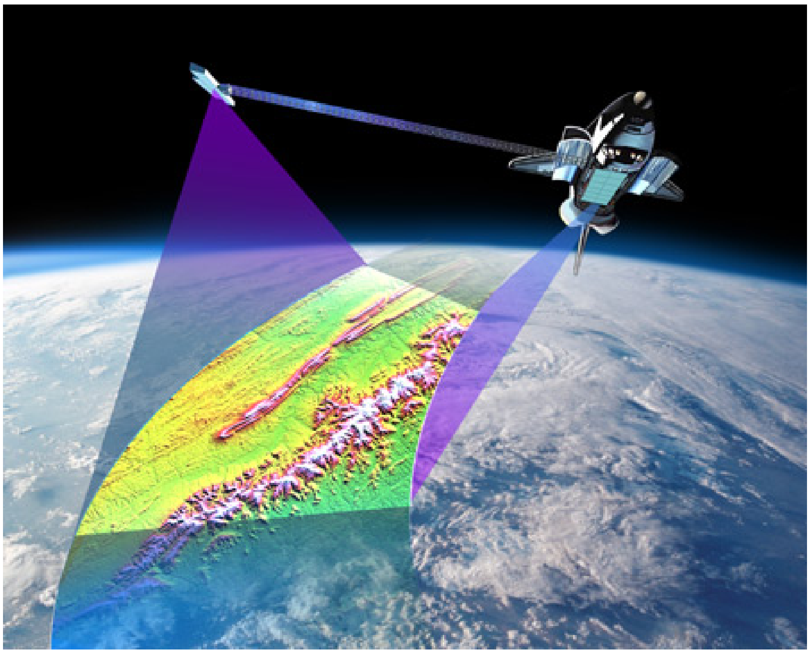

Figure 1: Configuration and principle of Interferometric Synthetic Aperture Radar (InSAR) of SRTM. Source:http://komunitas-atlas.blogspot.com/2011/11/shuttle-radar-topography-mission-srtm.html

On February 11, 2000, SRTM payload on-board Space Shuttle Endeavour was launched into space to acquire elevation data in eleven days. SRTM collected topographic data on a near- global scale, from 60° N to 56° S, i.e. nearly 80 percent of Earth's land surface, creating the first-ever most complete near-global high-resolution database of the Earth's topography; for more insight see http://www2.jpl.nasa.gov/srtm/index.html, also [1]. After processing the data generated by the on-board C-band sensor to global digital elevation model (GDEM), it was available in two resolutions of 1- and 3- arc seconds, i.e. $1''$ and $3''$ respectively. The $1''$SRTM GDEM was available only for the USA government and its allies, but the $3''$SRTM was made public from the beginning. The original $3''$SRTM GDEM is available at the USA Geological Survey's (USGS) EROS Data Centre for download via File Transfer Protocol (ftp); thus ftp://e0srp01u.ecs.nasa.gov. Data are also available through the USGS seamless server at http://seamless.usgs.gov/.

Due to presence of no-data points in the original SRTM GDEM, several new web sites have re-processed the original $3''$SRTM data in different formats than the one available at the USGS sites e.g. the Global Land Cover Facility at (http://glcf.umiacs.umd.edu/data/srtm/index.shtml) or the Consultative Group for International Agricultural Research (CGIAR) of the Consortium for Spatial Information (CGIAR-CSI) (http://srtm.csi.cgiar.org/) and the Jonathan de Ferranti (JdeF) site http://www.viwfinderpanoramas.org/dem3.html#images. Over years, both the $1''$ and $3''$ SRTM GDEM have undergone significant improvements, they include $3''$ SRTM GDEM from the CGIAR-CSI and the JdeF.

$3''$ SRTM *CGIAR-CSI GDEM*

The original USGS $3''$SRTM GDEM had too many no-data points (voids and spikes), thus CGIAR-CSI opted to improve the GDEM tiles. Initially, CGIAR-CSI used statistical and mathematical interpolation procedures which took into account natural trends to eliminate outliers from the USGS $3''$SRTM $1^\circ \times 1^\circ$ tiles. Although the approach improved the situation appreciably, it was still not the best; a better way would be for example to use photogrammetric or GPS methods. In 2008, the $3''$SRTM CGIAR-CSI version 4.1 (v4.1) was released. It used a new spatial interpolation method and more high-resolution auxiliary DEMs such as Canadian Digital Elevation Data Level 1 and the 30-arc second SRTM30 DEM. $3''$SRTM CGIAR-CSI v4.1 is the most current and the highest quality public 3-arc seconds GDEM, see for example http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1.

1.1 Digital Elevation Data and Applications

The digital elevation data (DED) often refers to Digital Surface Model (DSM), Digital Terrain Model (DTM) or Digital Elevation Model (DEM). At times, either is used to mean the rest, but indeed the three have minor and major differences. The DSM is a DED that represents the elevation of surface a remote sensing system encounters first. Thus it consists of elevations of forest canopy, bare land and built up features. The Digital Elevation Model (DEM) is a regularly-spaced bare-earth raster grid referenced to a common vertical datum without the above ground features. In some countries, a DTM means the same as DEM. This means that a DTM is simply an elevation surface representing the bare earth referenced to a common vertical datum. But in some countries like USA, a DTM is a DEM with additional data about natural features such as ridges and break-lines. In this paper, our focus is DEM as defined above. Since the remote sensing raw data provides a DSM at first, and then the DEM and the DTM are derived from it, then the quality of a DEM is also a function of how reliably the above ground features have been estimated and removed from the respective DSM.

DEMs have many useful applications; the wider groups include Geographic Information Systems (GIS), civil engineering, earth sciences, resource planning and management, topographic mapping, military planning and field procedures, hazard mapping & mitigations to list but a few. Within the bigger groups there are many smaller ones, some of which are of great importance, for example within the hazard mapping we find useful applications in favour of flooding and, sea level rise monitoring and mitigation. In earth sciences, applications are such as aerial gravity project planning, gravity smoothing and prediction, mass reductions, fluid transport by gravity and gravimetric geoid determination.

1.2 Search for the Best DEM for Tanzania

Most of the developing countries rely on global public DEMs because the cost of producing a reliable one of their own is usually prohibitive to many. Since 1990's, there have been continuous efforts to validate public GDEMs in search of one that suits Tanzania better. The area of interest (AOI) i.e. Tanzania has been limited to $1^{\circ}\mathrm{N}$ to $12^{\circ}\mathrm{S}$ and $29^{\circ}\mathrm{E}$ to $41^{\circ}\mathrm{E}$. Since all the DEMs under consideration have the EGM96 geoid model as their vertical datum, then all the ellipsoidal heights of the GPS controls used in the various GDEM validations, were converted into EGM96 orthometric heights to establish a uniform vertical platform for assessment. A summary of what has been done and the outcomes during the search for the best DEM for Tanzania is briefly given below.

Reference [2] compared SRTM-CGIARv4.1 and ASTER GDEMv2 as well as validation of the same using 127-2nd order ground GPS controls well distributed over the AOI; Figure 2. Note that SRTM-CGIARv4.1 is a 3-arc second GDEM whereas the ASTERv2 is a 1-arc second GDEM, thus in ASTERv2 GDEM, extraction at the 3-arc second was carried out before the comparison and assessment commenced. Download ASTERv2 GDEM freely at: http://www.gdem.aster.ersdac.or.jp/ and, https://wist.echo.nasa.gov/~wist/api/imswelcome/, but first visit http://gdex.cr.usgs.gov/gdex/ for details.

Comparison of the two GDEMs at the 127 ground control locations in unit of meter using mean, minimum, maximum and standard deviation (STD) statistics of the height differences between the $1''$ ASTERv2 and $3''$ SRTM-CGAIRv4.1 GDEMs are: 2.0, -37.3, 22.3 and 10.4 respectively.

As for the validation against the GPS controls, using mean, minimum, maximum, STD and the root mean square (RMS), the $1''$ ASTERv2 GDEM statistics in unit of meter are 5, -42, 41, 14.6 and 15.4, and for the $3''$ SRTM-CGAIRv4.1 they are 3, -30, 39, 12.5 and 12.8 respectively. Despite the fact that SRTM-CGAIRv4.1 is a 3-arc seconds GDEM, it performs better over TANZANIA than the $1''$ ASTERv2 GDEM.

Reference [3] compared $3''$ SRTM-CGAIRv4.1 with the Jonathan de Ferranti (JdeF) $3''$ SRTM GDEM version 4.1; hereafter to be referred to as $3''$ SRTM-JdeFv4.1, also both GDEMs were validated using ground GPS controls. Jonathan de Ferranti site (http://www.viewfinderpanoramas.org/dem3.html#images) improves the original USGS $3''$ SRTM by replacing the no-data points with photogrammetric and or cartographic data; thus the quality of filling in is likely to be better than the CGIAR-CSI interpolation scheme.

Table 1: Statistics of the differences of the two GDEMs with the 127 GPS controls scattered throughout the AOI as seen in Figure 2.

Statistic	H^{GPS}_{EGM96} -H^{SRTM}_{JdeF} (m)	H^{GPS}_{EGM96} -H^{SRTM}_{CGIAR} (m)
Minimum	-29.7	-29.5
Maximum	38.1	36.5
Mean	0.9	1.4
STD	9.7	10.2
RMS	9.7	10.2

Jonathan de Ferranti's SRTM-3arc second ver4.1 (3″ SRTM-JdeFv4.1) has a better performance in Tanzania than the CGIAR CSI SRTM-3-arc seconds ver4.1 as witnessed in Table 1 above.

Validation of 3″ SRTM-CGAIRv4.1 and 1″ ASTERv2 GDEMs was continued by [4] in three distinct areas, namely flat and bare in central Tanzania (Dodoma), forested and flat in Tanga and mountainous & forested (within Kilimanjaro and Meru mountains) as seen in Figure 3. The results are summarized in Table-2.

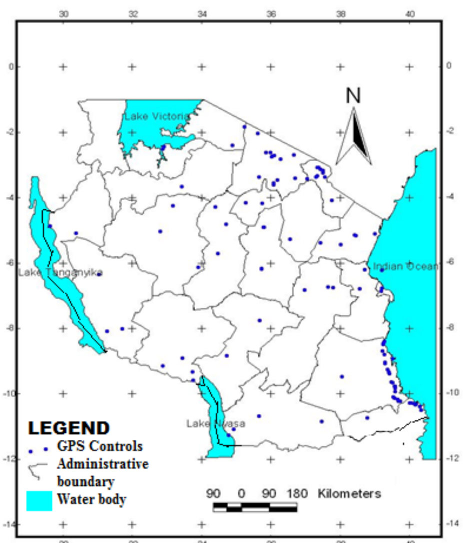

Figure 2: Distribution of 127-GPS Control points; source [1].

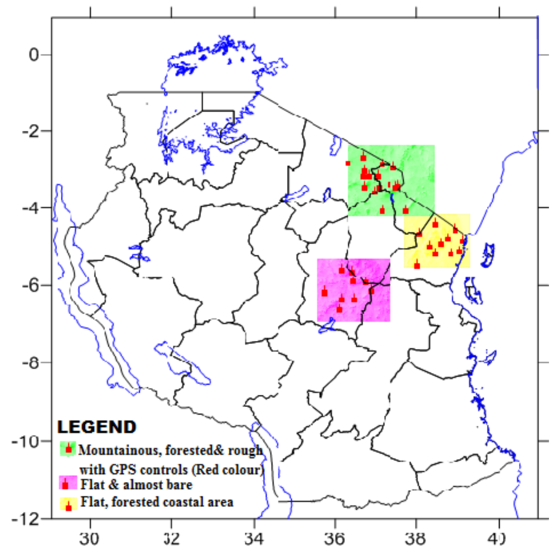

Figure 3: The three distinct boundaries of different land covers and terrains and their respective GPS controls; source [4].

Once again 3″ SRTM-CGAIRv4.1 GDEM has proved to perform better than 1″ ASTERv2 GDEM in all the three land covers and terrain categories when compared to geodetic GPS controls referenced to the same vertical datum as the DEMs, i.e. EGM96 global geoid model. Performance of 3″ SRTM-CGAIRv4.1 is exceptionally good in the flat and bare terrain found in Dodoma and is the worst in mountainous and forested relief found between Kilimanjaro and Arusha, but still much better than the 16m standard deviation from the global overall assessment of USGS 3″ SRTM GDEM [5], [6]. This is a reflection of the quality of the algorithm used by the CGIAR-CSI version 4.1 to fill the no-data areas [7, 8] also http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1

Table 2: Assessment of 3″ SRTM-CGAIRv4.1 and 1″ ASTERv2 GDEMs in Dodoma, Tanga and Kilimanjaro/Arusha selected areas in Tanzania.

Land Cover & Terrain Type	GDEM	STATISTICS		
		Mean (m)	STD (m)	RMS (m)
Flat and Bare (Purple colour Dodoma)	1″ ASTERv2	9.8	6.4	11.5
	3″ SRTM-CGAIRv4.1	1.5	1.5	2.1
Forested and Flat (Orange colour, Tanga)	1″ ASTERv2	8.1	7.8	11.0
	3″ SRTM-CGAIRv4.1	-1.5	2.0	2.5
Mountainous and Forested (Kilimanjaro to Arusha)	1″ ASTERv2	11.8	10.2	15.3
	3″ SRTM-CGAIRv4.1	5.1	8.5	9.7

Reference [9] continued the validation of 3″ SRTM-CGAIRv4.1 using denser GPS controls and more representative sample areas of the AOI, also its comparison to 3″ ACEv2. For further information regarding ACEv2, visit https://www.aces.gov.in. The results are given in Table 4. Table 3 is a key to the numbered letters used for the sample areas and AOI. The 222 GPS controls and the six sample areas are given in Figures 4 & 5 respectively.

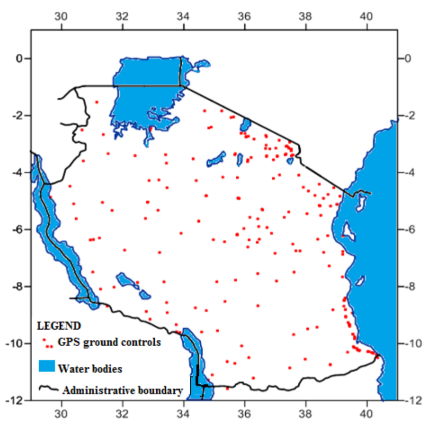

Figure 4: The density and distribution of 222 GPS ground controls for general assessment; source [9].

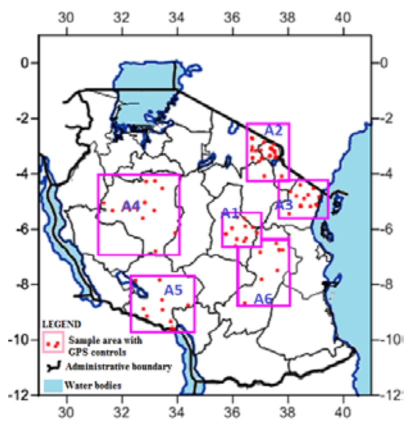

Figure 5: The six sample land covers & terrains within the AOI and the respective GPS controls; source [9].

Table 3: Key to selected areas of different land covers and terrains, also the AOI

A1	A2	A3	A4	A5	A6	C
Dodoma: Flat & bare	Kilimanjaro and Arusha: Mountainous and forested	Tanga: Forested and fairly flat	Tabora: Flat and bare	Mbeya: Highlands and forested	Morogoro: Slightly mountainous and forested	Countrywide (AOI)

Table 4: Statistics of validation of $3''$ ACEv2 and $3''$ SRTM-CGAIRv4.1 using GPS ground controls in six (6) different land covers and terrains found in Tanzania, also AIO in unit of meter.

	A1	A3	A4	A4	A1	A6	A3	C	A6	A5	C	A5	A2	A2
	SRTM 3	SRTM 3	SRTM 3	ACE 2	ACE 2	SRTM 3	ACE 2	SRTM 3	ACE 2	SRTM 3	ACE 2	ACE 2	SRTM 3	ACE 2
Max	-7.5	-12	-6.9	-9.9	-14.2	-6.9	-17.9	-30.8	-5.8	-5.4	-38.3	-5.8	-7.2	-11.8
Min	4.1	9	10.9	17.7	3.8	7.2	24.2	39.2	29.7	28.1	73.8	29.7	36.2	69.9
Mean	-2.7	0.2	0	2.2	-5.3	5	2.5	0.6	7.2	3.8	2.7	6.1	9.8	10.2
STD	2.8	5.3	5.9	6.8	5.6	7.8	9.2	10.2	12.3	12.7	14.1	13.7	12.1	18.8
RMS	3.8	5.1	5.7	7.2	7.5	7.9	9.2	10.2	12.2	13.2	14.3	15.1	15.6	21.4

The above results show that until 2015 $3''$SRTM CGIARv4.1 was the best public GDEM for Tanzania, its performance exceeds that of $3''$ACEv2 substantially generally and in all the six selected land covers and terrains. The general fit of $3''$SRTM CGIARv4.1 to the GPS controls in terms of mean, STD and the RMS are 0.6m, 10.2m, 10.2m while for the $3''$ACEv2 they are 2.7m, 14.1m and 14.3m respectively. In addition, the $3''$SRTM CGIARv4.1 performs exceptionally well in flat and bare area also in forested and fairly flat area. Performance of the two GDEMs particularly $3''$ACEv2 is the worst in area within Kilimanjaro and Arusha which is mountainous and forested, also in Mbeya which is highland and forested. Thus until 2015, $3''$ SRTM CGIARv4.1 had demonstrated to be the best public GDEM in Tanzania in all respects after proving to be much better than $3''$ACEv2 and $1''$ASTERv2 generally over the AOI and in all the six sample land covers and terrains. Moreover, the results obtained are better than those of [4] and [2] because of the significant increase in the number and distribution of GPS controls in the AOI as witnessed in Figures 2 and 4.

1.3 Release of $1''$**SRTM** *to Public*

On 23rd September 2014, during the United Nations Climate Summit in New York, President Obama of the

United States of America (USA) unveiled the release of the restricted $1''$SRTM GDEM to the public to improve the quality of elevation information worldwide.

He explained that the move intended to empower local authorities to better plan for the impacts of severe environmental changes such as drought, glacial retreat, flooding, landslides, coastal storm surges, agricultural stresses, and challenges concerning public health, also to help vulnerable populations around the world strengthen their climate resilience (http://www.ee.co.za/article/srtm-30-m-elevation-data-available.html; accessed in January 2016).

The new $1''$SRTM has a resolution of 30m, whereas the $3''$ SRTM CGIAR-CSIv4.1 resolution is 90m. It is understood that the new $1''$SRTM GDEM has undergone substantial improvements since its first release in 2003. In view of the above, the search for a better DEM for Tanzania had to continue.

1 Assessment of $1''$SRTM GDEM using GPS Ground Controls Generally and in Eight (8) Selected Land Covers and Terrains in the AOI

In addition to validation $1''$SRTM using 222 GPS ground controls given in Figure 4, it was also compared to two DEMs already passed for Tanzania namely $3''$SRTM-JdeFv4.1 and $3''$SRTM CGIAR-CSIv4.1. First generally over the AOI and then in eight representative samples of reliefs and land covers found in Tanzania [10, 11]. The six samples are the same as those in Figure 5.

The two added are from Mtwara and Lindi along the South Eastern Coast of Tanzania. From Table 5, the general assessment of closeness of the two GDEMs is around 6m, The STD and RMS of $3''$SRTM CGIAR-CSIv4.1 in Tanzania is about 10m and for the new and high resolution $1''$SRTM is about 7m.

The performances of $3''$SRTM CGIAR-CSIv4.1 and $3''$SRTM-JdeFv4.1 in the eight sample areas against the GPS controls within the respective sample areas are given in Tables 6 and 7 respectively.

Table 5: Statistics of differences of ($1''$SRTM and $3''$SRTM CGIAR-CSIv4.1), (GPS controls and $3''$SRTM CGIAR-CSIv4.1) and (GPS controls and $1''$SRTM) at the 222 GPS control positions

	values	Min	Max	Mean	STD	RMS
$H^{SRTM1} - H^{SRTM3}$ (m)	222	-12.5	25.2	2.1	6.1	6.5
$H^{GPS} - H^{SRTM3}$ (m)	222	-30.8	39.2	0.6	10.2	10.2
$H^{GPS} - H^{SRTM1}$ (m)	222	-31.3	28.3	-1.5	7.1	7.2

Table 6: Summary of statistical assessment of 1″SRTM and 3″SRTM CGIAR-CSIv4.1 against 222 GPS controls in eight representative land covers and terrains all over Tanzania

Land Cover & Terrain Type	GDEM	STATISTICS		
		Mean (m)	STD (m)	RMS (m)
Dodoma: Flat and Bare	1″SRTM	-1.9	1.5	2.4
	3″SRTM CGIAR-CSIv4.1	-2.7	2.8	3.8
Tanga: Forested and Fairly Flat	1″SRTM	-1.6	2.4	2.8
	3″SRTM CGIAR-CSIv4.1	0.2	5.3	5.1
Kilimanjaro to Arusha: Mountainous and Forested	1″SRTM	4.0	9.9	10.5
	3″SRTM CGIAR-CSIv4.1	9.8	12.1	15.5
Tabora: Flat and Bare	1″SRTM	0.5	4.9	4.7
	3″SRTM CGIAR-CSIv4.1	0.0	5.9	5.6
Mbeya: Highlands and Forested	1″SRTM	-1.9	7.0	6.9
	3″SRTM CGIAR-CSIv4.1	3.8	12.7	12.6
Morogoro: Slightly Mountainous & Forested	1″SRTM	-1.2	7.3	7.0
	3″SRTM CGIAR-CSIv4.1	1.4	15.8	14.8
Mtwara: Forested and Fairly Flat Coastal Area	1″SRTM	-4.2	4.6	6.1
	3″SRTM CGIAR-CSIv4.1	-5.3	6.9	8.5
Lindi: Forested and Fairly Flat Coastal Area	1″SRTM	-6.6	3.4	7.4
	3″SRTM CGIAR-CSIv4.1	-6.7	4.7	8.2

Table 8 provides statistics of the closeness of 1″SRTM and 3″SRTM-JdeFv4.1 , GPS controls and the 3″SRTM-JdeFv4.1 and GPS controls and 3″SRTM CGIAR-CSIv4.1 respectively. From Table 8, the general assessment of closeness of 1″SRTM and 3″SRTM-JdeFv4.1 is the same as that of 1″SRTM and 3″SRTM CGIAR-CSIv4.1 i.e. around 6m.

Table 7: Summary of statistical assessment of 1″SRTM and 3″SRTM-JdeFv4.1 against 222 GPS controls in eight representative land covers and terrains all over Tanzania

Land Cover & Terrain Type	GDEM	STATISTICS		
		Mean (m)	STD (m)	RMS (m)
Dodoma: Flat and Bare	1″SRTM	-1.9	1.5	2.4
	3″SRTM CGIAR-CSIv4.1	-2.4	2.5	3.4

Tanga: Forested and Fairly Flat	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	-1.6 -0.1	2.4 3.3	2.8 3.2
Kilimanjaro to Arusha: Mountainous and Forested	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	4.0 6.3	10.0 14.6	10.5 15.7
Tabora: Flat and Bare	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	0.5 0.8	4.9 5.3	4.7 5.2
Mbeya: Highlands and Forested	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	-1.9 2.6	7.0 12.0	6.9 11.7
Morogoro: Slightly Mountainous & Forested	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	-1.2 2.0	7.3 16.9	7.0 15.9
Mtwara: Forested and Fairly Flat Coastal Area	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	-4.2 -3.9	4.6 6.2	6.1 7.1
Lindi: Forested and Fairly Flat Coastal Area	$1''$SRTM $3''$SRTM CGIAR-CSIv4.1	-6.6 -6.8	3.4 5.9	7.4 9.0

Table 8: Statistics of differences of ($1''$SRTM and $3''$SRTM-JdeFv4.1), (GPS controls and $3''$SRTM-JdeFv4.1) and (GPS controls and $1''$SRTM) at the 222 GPS control locations as in Figure 4

	No. GPS Points	Min. (m)	Max. (m)	Mean (m)	STD (m)	RMS (m)
$H^{SRTM1} - H^{JdeF}$	222	-18.3	27.4	1.6	5.9	6.1
$H^{GPS} - H^{JdeF}$	222	-32.7	43.3	0.1	10.9	10.8
$H^{GPS} - H^{SRTM1}$	222	-31.3	28.3	-1.5	7.1	7.2

The standard deviation and RMS of $3''$SRTM-JdeFv4.1 in Tanzania is about 11m, which is a unit less precise compared to $3''$SRTM CGIAR-CSIv4.1. The new and high resolution $1''$SRTM GDEM general agreement with geodetic GPS controls over the whole country is about 7m.

2. Constraints and Limitations

1. GPS ground controls (GGCs) in rough and/or mountainous areas are few or absent due to the difficult of provision, consequently reliable assessment often is not achieved,
2. In forested areas, location of GGCs should be under forest canopy; this is often not the case due to the

GGCs field observation requirement for an open sky. Thus the particular point assessed is often on an open and bare ground,

3. The distribution and density of GGCs in the whole of the study area and in the selected eight representative areas is not uniform, and sometimes they are very different; this is likely to result into biased assessments and conclusion,
4. There are other important areas where assessment of the performance of the GDEMs in this paper would result into useful information, such are areas like the rims of the two arms of the East African Rift Valley System (EARVS) within Tanzania, but there are very few GGCs or absent all together.

3. Conclusion

The statistical outcomes from all the Tables reveal that 1″SRTM is superior to both the already passed GDEMs 3″SRTM CGIAR-CSIv4.1 and 3″SRTM-JdeFv4.1 by far in all respects. The overall fit of 1″SRTM to the GPS ground controls is about 7m while for the other two GDEMs is around 10m. 1″SRTM is close to the two 3-arc seconds GDEMs by about 6m. Performance of 1″SRTM is the best in flat and almost bare land found in central Tanzania, where STD is 1.5m and RMS is 2.4m relative to GPS controls. Its performance is the worst in rough, mountainous and forested terrain found between Kilimanjaro and Meru Mountains where the STD and RMS are both around 10m. The performances of the two 3-arc seconds GDEMs are very close to one another, they show the same trend of doing better in flat and almost bare land and have the worst performance in rough, mountainous and forested terrain where the STD is around 12m, and the RMS is about 16m. Therefore it can be said that, in general, irrespective of the resolution, SRTM GDEM performs better in low and flat land and its performance deteriorates as the terrain becomes rougher and higher. The above ground vegetation affects SRTM but not as much as the increase of terrain roughness and altitude. Since the worst performance of 1″SRTM in Tanzania is about 10m, there are many useful applications to which 1″SRTM can be subjected to.

Therefore, from the validations of the public GDEMs conducted at Ardhi University in the past five years, the best public GDEM for Tanzania is the 1-arc second SRTM released by President Obama of the USA in 2014.

4. Recommendations

1. To extend the GGCs to important areas mentioned in the constraints and limitations to a distribution and density that will result into reliable assessment of the performance of the GDEMs in the sample areas as well as in the study area,
2. In forested areas, other surveying (geomatics) methods e.g. traversing, should be used to extend the GGCs to under forest canopy where the sky is not open,
3. Further vertical assessment and comparison of 1″SRTM should be continued using new public GDEMs like ALOS version 2, the coming NASADEM and if possible using the commercial TanDEM-X (WorldDEM) which are of 1-arc second or less resolutions.

References

[1] T. G. Farr, P. A. Rosen, E. Caro, R. Crippen, R. Duren, S. Hensley, et al. “The Shuttle Radar Topography Mission".” Reviews of Geophysics. 2007.

[2] R. P. Valerian. “Validation of recent public DEMs in Tanzania (SRTM-CGIARv4.1 and ASTERv2 GDEM).” B.Sc. Dissertation, Department of Geomatics, Ardhi University, Dar es Salaam, Tanzania 2012.

[3] A. M. Nkamba. “Assessment of the SRTM3 - CGIAR CSI v4.1 and Jonathan de Ferranti archives using GPS controls in Tanzania.” B.Sc. Dissertation, Department of Geomatics, Ardhi University, Dar es Salaam, Tanzania 2013.

[4] S. H. Mohamed. “Assessment of SRTM3-CGIAR v4.1 and ASTER v2 GDEMs in three distinct terrains using GPS controls in Tanzania.” B.Sc. Dissertation, Department of Geomatics, Ardhi University, Dar es Salaam, Tanzania, 2014.

[5] K. Jacobsen. “Analysis of SRTM Elevation Models.” in EARSeL Conference Proceedings, Porto, 2005. http://www.ipi.uni-hannover. de/uploads/tx_tkpublikationen/ASEjac.pdf (Jul. 28, 2009).

[6] P. A. M. Berry, J. D. Garlick and R. G. Smith. “Near-global validation of the SRTM DEM using satellite radar altimetry.” Earth and Planetary Remote Sensing Laboratory, De Montfort University, The Gateway, Leicester, LE19BH, UK. 2006.

[7] H. I. Reuter, A. Nelson and A. Jarvis. “An evaluation of void filling interpolation methods for SRTM data”. International Journal of Geographic Information Science, 21 (9), pp. 983-1008, 2007.

[8] A. Jarvis, H. I. Reuter, A. Nelson and E. Guevara. “Hole-filled SRTM for the globe version 4. 2008” http://srtm.csi.cgiar.org (Jan. 2012).

[9] A. K. Omary. “Validation of ACE2 Using 2nd order GPS Geodetic Control Network and its Comparison to SRTM-CGIARv4.1.” B.Sc. Dissertation, Department of Geomatics, Ardhi University, Dar es Salaam, Tanzania 2015.

[10] G. Sowani. “Validation of SRTM-1 using Tanzania 2nd order Geodetic Control Network and its Comparison to Jonathan de Ferranti SRTM-3 GDEM.” B.Sc. Dissertation, Department of Geomatics, Ardhi University, Dar es Salaam, Tanzania 2016.

[11] G. M. Mwansasu. “Validation of SRTM1 using 2nd oder Geodetic Control Network and its Comparison to SRTM3 - CGIAR CSI v4.1”. B.Sc. Dissertation, Department of Geomatics, Ardhi University, Dar es Salaam, Tanzania, 2016.