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ASSESSMENT OF CLASSICAL, ASTER AND SRTM DEMs IN NAIROBI REGION, KENYA

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Abstract

A digital elevation model (DEM) is a three-dimensional model of the terrain on Earth. To get the most out of terrain elevation measurements collected by satellite, a global digital elevation model (GDEM) has to have high vertical precision. Typical applications of digital elevation models (DEMs) include reconnaissance surveys, hydrological analysis, biomass calculation, geoid modeling, and others; this research evaluates the vertical accuracy of three DEMs: Classical, ASTER (30 m), and SRTM (90 m). While ASTER and SRTM DEMs are derived from satellite-based remote sensing missions, classical DEMs are derived from regional topographical maps. For this evaluation, we used DEM-derived heights across Nairobi County and the surrounding area to compare with orthometric heights obtained via accurate leveling at 18 sites. The research identified that for conventional DEM, the mean and standard deviation of the direct disparities between precisely leveled heights and DEM heights are 3.97 m and ±7.76 m, for ASTER DEM, they are 16.36 m and ±7.79 m, and for SRTM DEM, they are -0.25 m and ±4.00 m, respectively. According to the findings, the traditional and ASTER DEMs are the next most accurate, after SRTM DEM. After that, we used a second-order surface polynomial at 12 sites to describe the discrepancies in heights between the DEM and orthometric data, and we applied the same polynomial to 6 test points using cross-validation. While the conventional and ASTER DEMs saw a decline in accuracy, the SRTM DEM saw an improvement because to the polynomial findings.

Keywords: ASTER DEM, SRTM DEM, Classical DEM, GPS, orthometric height, secondorder surface polynomial

1.0 Introduction

A numerical depiction of terrain is known as a digital elevation model (DEM). A few examples of its many useful uses include digital surface modeling, three-dimensional terrain visualization, hydrology, run-off analysis, and feasibility assessments for various projects.

Nikolakopoulos et al. (2006), Gorokhovich and Voustianiouk (2006), Sertel (2010), Zhao et al. (2011), Ioannidis et al. (2014), and Kolecka (2015) are among the publications that have evaluated the vertical accuracy of ASTER and SRTM digital elevation models (DEMs).

with Kozak (2014). Because no one knows how accurate ASTER and SRTM DEMs are in terms of vertical accuracy in Kenya, this research is necessary. Typically, their spatial resolution is what determines their use, but that doesn't mean they're always accurate in the vertical dimension. Regional studies using ground truthing data as a control are necessary to assess the accuracy of ASTER and SRTM DEMs data (e.g., Gorokhovic and Voustianiouk, 2006). Data from the ASTER and SRTM satellite missions are used to create classical DEMs, whereas digital contours of regional topographical maps are used to construct ASTER and SRTMDEMs, respectively. These DEMs derived from satellite imagery have spatial resolutions of 30 m × 30 m for ASTER and 90 m × 90 m for SRTM. Countries including Japan, China, Poland, and Turkey have had their global DEMs evaluated for accuracy. According to the ASTER GDEM Validation Team (2009), while comparing ASTER DEM's vertical accuracy in Japan to more than 13,000 benchmarks spread throughout the nation, a continuous negative bias was found on ASTER DEM's heights, leading to an RMSE of ±10.87 m. In the Chinese example study, the ground control points (GCPs) were compared to similar heights from ASTER and SRTMDEMs in two different areas: the hilly Loess plateau and the flat North China plains. Although both DEMs had wider error margins in height approximation over tough terrain, the result was that SRTM DEM was better than ASTER DEM. The root-mean-squared error (RMSE) for SRTM DEM was

According to Zhao et al. (2011), ASTER had an accuracy of ±7.95 meters, whereas ±2.22 meters was observed for them. A highly accurate locally available DEM constructed from aerial photos was compared with the ASTER DEM in the case study of Turkey. The study area, Istanbul, which includes coastal, mountainous, and heavily built-up areas, has a wide range of topographic variations (Sertel, 2010). The Tatra Polish Mountains, a region in Poland with very rough topography, were the focus of the case study. By comparing a DEM with high accuracy to an SRTM DEM, an RMSE value of ±14.74 m was achieved (Kolecka and Kozak, 2014).

Over the Nairobi area, this research aims to compare orthometric height data that has been properly leveled with height data that has been approximated using Classical, ASTER, and SRTM DEMs. To compensate for the heights provided by the DEMs, a second-order surface polynomial is used to represent the discrepancies between the orthometric heights that have been precisely leveled and the orthometric heights that have been generated from them. In its last section, it details several practical uses of the DEMs that were the focus of this investigation.

2.0 Materials and Methods

2.1 Ground Control Points

Eighteen (18) Ground Control Points (GCPs) have been used for the assessment of the three DEMs; their positions are described by ellipsoidal curvilinear coordinates(ϕ , λ) determined using Global Positioning System (GPS) and orthometric heights (H) determined by spirit levelling over Nairobi region. Theoretically, DEMs should precise approximations of orthometric heights; but, in practice, this is seldom the case, leading to inaccuracies in DEMs. Plumb lines are curved trajectories that are orthogonal to the geoid. Orthometric heights, which are displacements along these lines, properly express potential (Torge, 2001; Hofmann-Wellenhof and Moritz, 2005). Because potential is the primary determinant of fluid flow, orthometric heights are ideal for engineering purposes. Odera et al. (2014) and Odera and Fukuda (2015) provide details on orthometric height systems.

Nairobi County and portions of neighboring counties Kiambu, Kajiado, and Machakos make up the research area known as the Nairobi region. With an elevation difference of more than 600 m, the geographical location is situated between the longitudes 36˚ 37′ 30″ E and 37˚ 1′ 30″ E, and the latitudes 1˚ 25′ 30″ S and 1˚ 7′ 30″ S. The research region was selected using data that was readily available, particularly GPS and leveling data. Based on the 1984 World Geodetic System (WGS84), Figure 1 displays both the research region and the distribution of GCPs.

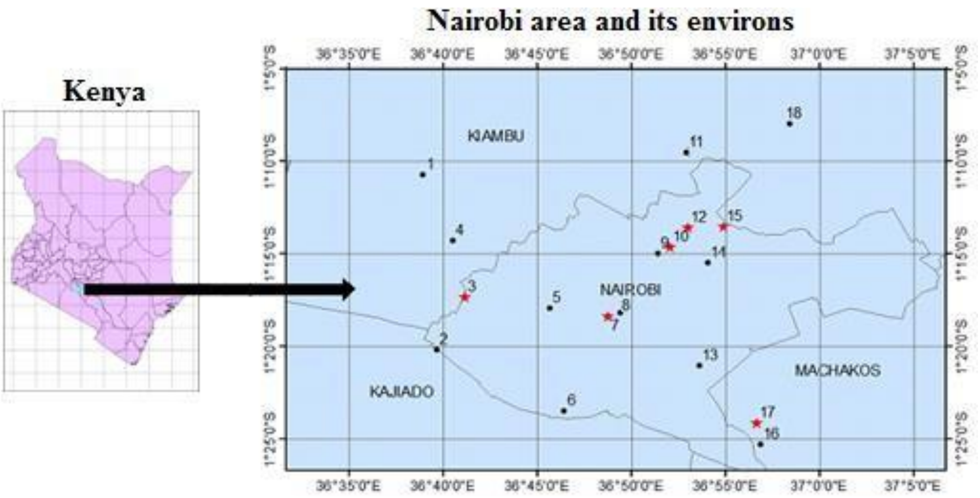

Figure 1: Research region; data points are represented by black dots, while test points are shown by red stars.

2.2 Digital Elevation Models

2.2.1 Classical DEMs

Classical DEMs are generated from digitizing contours from topographical maps. These contours constitute a huge bulk of readily available elevation data in Kenya. Topographical maps are plotted from countrywide aerial photogrammetric data obtained by aerial surveys. Such maps are published by the Survey of Kenya at varying scales.

An ASTER in Space, an Advanced System for Thermal Emission and Reflection Radiometer

As a component of the worldwide earth observation system that incorporates digital elevation models, ASTER is a cooperative space project between the Japanese Ministry of Economy, Trade and Industry (METI) and the United States National Aeronautics and Space Administration (NASA) (Yamaguchi et al., 1998). The Terra Satellite, one of the most precisely orbited spacecraft ever built, is home to ASTER's array of multispectral sensors. The Terra Satellite is a near-polar, sun-synchronous spacecraft that employs a long track scan approach to gather data; its orbital height is 705 km, its inclination is 98.2°, and its repetition cycle is 16 days. ASTER uses Thermal Remote Sensing to gather geographical information. Its multispectral sensors can detect changes in the Earth's surface using either the visible near infrared (VNIR) or thermal infrared (TIR) bands. The satellite has a spatial resolution of 1″ or 30 m by 30 m, and it covers an area between 83° N and 83° S. (Tighe, 2012).

3 The SRTM, or Shuttle Radar Topographic Mission

3.0.1

4 SRTM is a joint venture between the German space agency, the National Imagery and Mapping Agency (NIMA), and the National Aeronautics and Space Administration (NASA) that aims to create digital elevation models as part of its worldwide earth observation program. SRTM collects geographical data using the Interferometric Synthetic Aperture Radar (InSAR) technology. The space shuttle had two radar antenna configurations, one in the cargo bay and one at the top of a 60-meter-long mast, for the C and X bands, respectively. At first, SRTM covers an area that encompasses about 80% of the Earth's landmass, spanning from 60° N to 56° S. Some more sources that go into more detail regarding SRTM are Farr and Kobrick, 2001; Hensley et al., 2000; and Jordan et al., 1996. Based on WGS84, we used a publicly available SRTM 3″ with a spatial resolution of 90 m by 90 m. We have taken note of the newly-delivered SRTM (30 m) for use in our next research.

4.0 Numerical Tests

3.0 Results and Discussion

3.1 Direct Comparison

4 4 The DEM and orthometric heights were directly compared using Equation (1). Orthometric height is denoted by H, and the differential

equation of mass (HDEM) is a symbol for it. For the DEM heights, we use interpolation with the Classical, ASTER, and SRTM DEMs; for the orthometric heights, we employ spirit leveling at eighteen ground control locations (Figure 1). To improve the DEM-predicted orthometric heights, a 2nd-order quadratic surface polynomial must be used to describe the orthometric height disparities in equation (1). We accomplished this by dividing the data points, which included a grand total of eighteen GPS and leveling points, into two groups: the twelve issues to do cross-validation, and six for calculating polynomial coefficients. Here is the second-order surface polynomial that was used in this study:

Table 1: Differences in leveled and DEM orthometric heights (in meters) with statistical breakdown

Point	*Levelled Orthometric Height (* H *)*	H_{DEMC} *(Classical)*	H_{DEMS} *(SRTM)*	H_{DEMA} *(ASTER)*	ΔH_C *Classical*	ΔH_S *SRTM*	ΔH_A *ASTER*
1	2144.19	2139	2153	2130	5.19	-8.81	14.19
2	1934.59	1911	1935	1912	23.59	-0.41	22.59
3	1894.69	1892	1896	1871	2.69	-1.31	23.69
4	1996.13	1989	2000	1970	7.13	-3.87	26.13
5	1794.63	1785	1795	1779	9.63	-0.37	15.63
6	1716.20	1705	1717	1697	11.2	-0.8	19.2
7	1680.10	1684	1685	1663	-3.9	-4.9	17.1
8	1661.84	1668	1666	1644	-6.16	-4.16	17.84
9	1645.27	1633	1640	1617	12.27	5.27	28.27
10	1620.72	1621	1622	1611	-0.28	-1.28	9.72
11	1590.49	1587	1592	1581	3.49	-1.51	9.49
12	1611.34	1620	1615	1607	-8.66	-3.66	4.34
13	1636.67	1630	1636	1609	6.67	0.67	27.67
14	1596.98	1597	1594	1594	-0.02	2.98	2.98

15	1588.51	1593	1585	1576	-4.49	3.51	12.51
16	1549.54	1545	1544	1527	4.54	5.54	22.54
17	1590.20	1590	1585	1577	0.2	5.2	13.2
18	1534.39	1526	1531	1527	8.39	3.39	7.39
Minimum					*-8.66*	*-8.81*	*2.98*
Maximum					*23.59*	*5.54*	*28.27*
Mean					*3.97*	*-0.25*	*16.36*
SD					*±7.76*	*±4.00*	*±7.79*
Range					*32.25*	*14.35*	*25.29*

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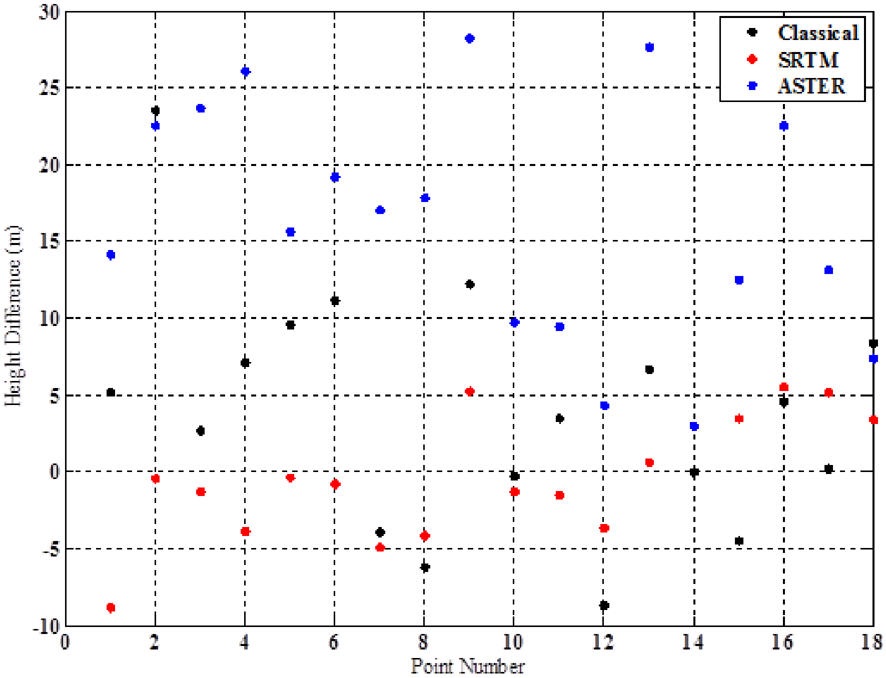

The discrepancies between the leveled and DEM orthometric heights are seen in Figure 1.

Both the good and negative outcomes from the SRTM and Classical DEMs are balanced in Figure 2. The fact that the average height difference between SRTM and Classical DEMs is just -0.25 m and 3.97 m, respectively, demonstrates this. As a whole,

ASTER DEM orthometric heights (Table 1) and leveled orthometric heights (Figure 2) show a height discrepancy of 16.36 m. Orthometric heights in the research region are regularly underestimated by ASTER DEM. Put another way, in the research region, leveled orthometric heights are always higher than orthometric heights calculated from ASTER.

3.2 Optimization with the use of polynomial

Equation (2), employing 12 data points (Figure 1), yields the coefficients of the second-order surface polynomial. Table 2 provides the coefficients. To get better orthometric heights at 6 test locations, these parameters or coefficients are utilized in the equation (3) to calculate adjustments to the predicted orthometric heights using DEMs. Each DEM makes use of a unique set of coefficients, as shown in Table 2. The second-order surface polynomial coefficients are determined without include the six test points in order to make a cross-validation test easier. Table 3 displays the statistical variances at each of the six test locations between the leveled (real) orthometric heights and the enhanced DEMorthometric heights.

The average and standard deviation (SD) of the direct discrepancies in the orthometric heights at the 6 test places for the conventional DEM, SRTM DEM, and ASTER DEM are -3.32 m and ±7.32 m, 0.69 m and ±4.55 m, and 16.52 m and ±8.55 m, respectively, according to Table 3. In contrast, the classical DEM shows a mean of -3.48 m and an SD of ±8.30 m for the differences between the orthometric heights of the leveled and improved DEM at the 6 test points, the SRTM DEM shows a mean of 0.60 m and an SD of ±3.69 m, and the ASTER DEM shows a mean of 1.17 m and an SD of ±8.87 m. Using a second-order surface polynomial will increase the precision of height determination in SRTM DEM from ±4.55 m to ±3.69 m, which is an improvement of 18.9%, according to these data. On the other hand, using the second order polynomial reduces the accuracy of heights from conventional and ASTER DEM measurements.

Table 2: Computed Coefficients (units are in m)

Coefficients	*Classical DEM*	*SRTM DEM*	*ASTER DEM*
k_O	-444480.3084	-219779.6785	-182870.5488
k_1	1412401.1100	694963.5814	562766.3914
k_2	886300.7748	262236.2311	-151834.5926
k_3	-1122065.446	-548846.9402	-432967.0939
k_4	-560514.3904	265427.4083	-191292.3836
k_5	-1413799.7770	-387384.1267	227833.9267

Comparison of enhanced DEM orthometric heights with leveled heights (measured in meters): statistical table 3.

	Direct comparison of heights	*Comparison after improvement on DEM heights*

Point	ΔH_C *Classical*	ΔH_S *SRTM*	ΔH_A *ASTER*	δH_C *Classical*	δH_S *SRTM*	δH_A *ASTER*
3	2.69	-1.31	23.69	-9.66	1.39	3.60
7	-3.9	-4.9	17.1	-6.54	-3.42	0.99
9	12.27	5.27	28.27	12.95	6.47	16.04
12	-8.66	-3.66	4.34	-8.22	-3.27	-6.34
15	-4.49	3.51	12.51	-5.48	1.89	2.00
17	0.2	5.2	13.2	-3.93	0.54	-9.28
Minimum	*-8.66*	*-4.90*	*4.34*	*-9.66*	*-3.42*	*-9.28*
Maximum	*12.27*	*5.27*	*28.27*	*12.95*	*6.47*	*16.04*

Mean	*-0.32*	*0.69*	*16.52*	*-3.48*	*0.60*	*1.17*
SD	*±7.32*	*±4.55*	*±8.55*	*±8.30*	*±3.69*	*±8.87*
Range	*20.93*	*10.17*	*23.93*	*22.61*	*9.89*	*25.32*

We acknowledge that the present study only covers a small region; thus, more research should be conducted to uncover the precise accuracy of the most recent DEMs, ideally spanning a bigger area, such as a nation. Nevertheless, our work has shed light on crucial accuracy characteristics that should be taken into account when choosing a DEM for engineering and related tasks.

4.0 Conclusions

Compared to traditional and ASTER DEMs, SRTM DEM outperforms them in height approximation and error distribution. The SRTM, Classical, and ASTER DEMs have standard deviations of ±4.00 m, ±7.76 m, and ±7.79 m for the disparities between leveled orthometric heights and the calculated orthometric heights from the DEM, respectively.The findings show that SRTMDEM outperforms ASTER DEM, despite having a lower spatial resolution of 30 m, despite having a 90 m spatial resolution. It should be mentioned that ASTER DEM has traditionally been preferred because of its high spatial resolution; nevertheless, this research demonstrates that SRTM DEM offers superior vertical resolution within the study region. This fits well with the vertical accuracy requirements that SRTM and ASTER DEMs have already set. ASTER DEM consistently under-estimated orthometric heights due to its positive bias, indicating that the mistake was not evenly distributed. A second-order surface polynomial enhances the accuracy of height determination in the SRTM DEM, but it reduces the accuracy in the classical and ASTER DEMs, according to the findings of enhanced DEM heights. General reconnaissance surveys may be accomplished using Classical and ASTER DEMs, whereas SRTM DEM is best suited for hydrology, mass flow analysis, 3D visualization, and feasibility evaluations of potential locations for significant engineering projects.