Vertical Accuracy of Freely Available Global Digital Elevation Models: A Case Study in Karaman Water Reservoir Territory

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Abstract
Nowadays, Uzbekistan pays great attention to the construction of reservoirs for irrigation and energy purposes. Identification of potential sites for the construction of reservoirs and obtaining initial data (the geographical location, storage volume and water surface area, profile of the dam site and others) imposes a great task on project institutes that develop design and survey and pilot work on water engineering. The use of GIS and RS technologies in human life has made it possible to accomplish many tasks quickly, cheaply and accurately. In this research, the main scope of the work is to assess the accuracy of the tested ALOS World 3D - 30m (AW3D30), ASTER GDEM v3, SRTM Plus, COP-30 and NASADEM products for the Karaman water reservoir (recommended for construction in Jizzakh region, Uzbekistan) territory by comparison with 36 Ground elevation points taken from topographic maps (1:25000). Results of statistics values calculated over the geodetic ground elevation points and the DEM data show that NASADEM and AWED30 DEM data are more accurate than other DEMs. The study found that the use of AWED30 and NASADEM data in the design of the proposed Karaman water reservoir for construction leads to a more accurate result. The results obtained using AWED30 data in determining the storage volume (W=780 mln.m^3) and area (F=41.4 sq.km) of the water reservoir.

1. Introduction

Water reservoirs created by dam construction along rivers have played an important role in societies around the globe throughout their history. The purpose of building reservoirs is to regulate floods, generate hydropower and redistribute river water for irrigation, and store water for use during periods of drought if natural rainfall is irregular or seasonal. (Rodrigues and Fidélis, 2019, Pali and Vadhera, 2018 and Frankowski et al., 2019). A large part of Uzbekistan is an arid region, where evaporation exceeds rainfall and annual precipitation is below and water resources were unevenly distributed both in space and time. Therefore, agricultural production is impossible without irrigation and the irrigation systems are primarily one of the major factors for sustained economic development, employment and food security of Uzbekistan (Mitchell et al., 2017, Aleksandrova et al., 2014 and Lioubimtseva and Henebry, 2009).

Nowadays, there are 59 reservoirs with a total capacity of more than 20.0 billion m^3 in Uzbekistan. By managing these facilities, Uzbekistan provides irrigation of agricultural land, public utilities, industry, fisheries, power generation, etc. (Oybek, 2020, Wegerich, 2008, Jalilov et al., 2018). But, in recent years, water security issues have become increasingly relevant due to global climate change. Most of the water bodies and rivers are located in mountainous areas. The rivers are supplied from seasonal snow cover, glacier melt, and rainwater (Turgunov et al., 2020 and Gerlitz et al., 2019). An acute shortage of water resources in the region will demand the construction of new and reconstruction of the operated water storage facilities. Nowadays, Uzbekistan pays great attention to the construction of reservoirs for irrigation and energy purposes. Identification of potential sites for the construction of reservoirs and obtaining initial data (the geographical location, storage volume and water surface area, profile of the dam site and others) imposes a great task on project institutes (Khasanov and Ahmedov, 2021).

In the water reservoir design, methods such as field surveying or using topographic maps can yield high accuracy terrain data, but they are time-consuming and labor-intensive. The introduction of GIS and RS technologies into human life has made it possible to accomplish many tasks quickly, cheaply and accurately (Ramroop and Ph, 2012).

2. Study area and Materials

2.1 Study Area

This study aims to study the accuracy of various DEMs (SRTM Plus DEM, ASTER GDEM, COP30, AW3D30 and NASADEM) in the development of the Karaman water reservoir project. The DEMs and altitude points were compared in the Global Mapper app. To do this, a total of 36 ground elevation points around the water reservoir area were selected from the topographic map (1:25000) (Figure 1). Karaman water reservoir recommended for construction in the Jizzakh region, located on the Central side of Uzbekistan, extends between the latitude of N40^{0}18' and 40^{0}30' and the longitude 67^{0}15' and 67^{0}45' E. The water reservoir area is approximately 25 km long by 10 km wide, characterized by moderate and high relief, with a height of 300 m to 560 m above sea level. The study area consists of small hills, plains, and sandy areas. The initial design assumed that the dam would be 48 m high and 8 km long, and the storage volume W=750 mln.m^3, and area F=40.4 sq.km of the water reservoir.

After the construction of the reservoir, 264.5 thousand hectares of land (Navai and Jizzakh regions) can be used for irrigated agriculture. The Karaman Reservoir is being built to collect excess water from the South Mirzachul Canal beyond the growing season.

2.2 Digital Elevation Model

The application of Remote Sensing methods to extract DEM from satellite images instead of direct measurement techniques has become a trend. DEM is the digital image of Earth elevation with respect to any coordinate system, the simplest form and digital characteristics of the topographical surface. DEM data can be used in determining detentions and uplands at any point of earth, creating 3D models of the earth surface, obtaining hydrological and geological analysis, surveying natural resources, managing agriculture (Colgan and Ludwig, 2016, Maune, 2010, Zhou et al., 2017 and Moore et al.,1991).

2.3 Shuttle Radar Topography Mission

The Shuttle Radar Topography Mission (SRTM) was launched on February 11-22, 2000 aboard the Endeavor spacecraft that two modified antenna synthetic aperture radar systems were operated in the process. In this, an international project the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA) participated, and acquired radar data which were used to create the first near-global set of land elevations. Equipped with a set of SRTM C-band and X-Band synthetic aperture radars, it allows the development of a consistent and accurate global digital Ground model and topographic maps of all land surfaces from + 60 ° to -56 ° latitude, and this has been successful achieved. RTM data has a horizontal resolution of 1 arc per second and a vertical resolution of 10 m. The level and resolution of data processing will be of three types across the SRTM Data Products: The first, Version 1 (2003-2004) is almost the raw data, processed from raw C-band radar signals spaced at intervals of 1 arc-second non-void filled elevation data.

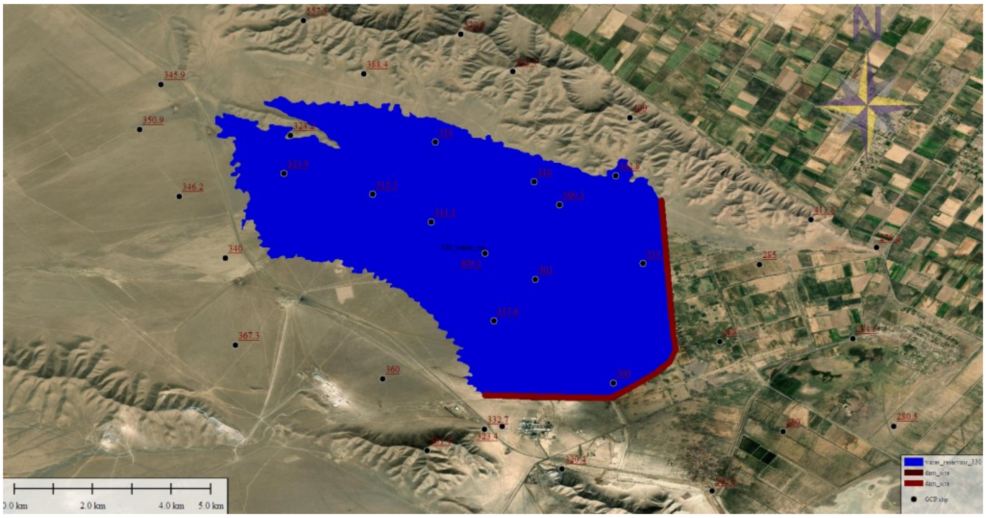

Figure 1: An approximate view of the proposed Karaman Reservoir for construction

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The second, Version 2.1 (~2005) is an edited version of v1, Void Filled elevation data are the result of additional processing to address areas of missing data or voids in the SRTM Non-Void Filled collection. The third, Version 3 (2013), also known as SRTM Plus, 1 Arc-Second Global elevation data offer worldwide coverage of void-filled data at a resolution of 1 arc-second (Zyl, 2001, Rabus et al., 2003, Farr and Kobrick 2000 and Werner, 2001).

2.4 Advanced Spaceborne Thermal Emission Reflectometer

Version 3 of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) covers land surfaces between 83°N and 83°S, and was produced through automated processing of 2.3 million scenes from the ASTER archive. Version 3 also features a new global product that identifies all water bodies as ocean, river, or lake, and each GDEM tile has a corresponding Water Body tile. The ASTER GDEM v3 data was created from the automated processing of the entire ASTER Level 1A archive of scenes acquired between March 1, 2000, and November 30, 2013. Stereo correlation has been used to create more than one million ASTER DEMs scenes, which have been used in cloud masking, and all DEM construction leads to a more accurate result s with cloud screens and DEMs without clouds have been assembled.

The ASTER GDEM Version 3 maintains the GeoTIFF format and the same gridding and tile structure as in previous versions, 1 arc-second spatial resolution and 1°x1° tiles. ASTER thermal bands measure not just surface temperature, but also surface emissivity spectra, and the measurements are subject to atmospheric effects. ASTER GDEM is expected to be a better source of global topographic information for various scientific applications (Tachikawa et al., 2011, Hewson et al., 2020, and Abrams, 2016).

2.5 ALOS World 3D – 30m (AW3D30)

ALOS Global Digital Surface Model (AW3D30) - A global data set from images collected on board the Advanced Earth Observation Satellite from 2006-2011 using a panchromatic remote sensing device (PRISM), which was an optical sensor on board the Advanced Land Observing Satellite "ALOS". ALOS captured 6.5 million scenes during its five years of operation and it is equipped with the Panchromatic Remote-sensing Instrument Stereo Mapping (PRISM) to measure precise land elevation, the Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) to observe what covers land surfaces, and the Phased Array type L-band Synthetic Aperture Radar (PALSAR) to enable day-and-night and all-weather land observations. ALOS is thus expected to show high-resolution capability inland observations. (JAXA, 2008 and Truong et al., 2019). The first version of the AW3D30, with the stereoscopic images were acquired along-track at nadir, backward and forward views and with 2.5 m of spatial resolution, published in 2016 and since then the dataset has been updated to improve the absolute/relative height accuracies with additional calibrations and void filling (Courty et al., 2019, González-Moradas and Viveen, 2020 and Mahesh et al., 2021).

2.6 NASADEM

The NASADEM (released in February 2020) was created by reprocessing the SRTMGL1V003 radar data and modernization of the Digital Elevation Model with improved accuracy by incorporating auxiliary data from ASTER GDEM, ICESat GLAS, and PRISM datasets. The main objective was to eliminate voids and other limitations that were present in the SRTMGL1V003 dataset. The data rely on multiple radar images creating interferograms with 2-dimensional phase arrays that result in greater elevation accuracy. Because of the inherent characteristics of interferometric data, it needs to be wrapped and unwrapped so the data are quantifiable. Vertical and tilt adjustments were applied based on ground control points and laser profiles from the Ice, Cloud and Land Elevation Satellite (ICESat) mission. This application improved the vertical accuracy, swath consistency, and uniformity within the swath mosaic(Crippen et al., 2016, Uuemaa et al., 2020 and Gesch, 2018).

2.7 COP30 (or GLO-30)

Copernicus DEM is based locally on WorldDEM that infilled with local basis with following ASTER, SRTMGL1V00330, GMTED2010, TerraSAR-X Radargrammetric DEM, ALOS World 3D-30m DEMs. Copernicus DEM is a digital surface model (DSM) that reflects the Earth, including buildings, infrastructure and plants. This DSM is derived from an edited WorldDEM, where flattening of water bodies has been included. Originally released in 2019, the high-resolution version of Copernicus DEM has been released for public use. Editing of shore and coastlines, and implausible terrain structures has also been applied. OpenTopography website is providing access to the global 30m (COP30) DSM through the public AWS S3 bucket established by Sinergise. The Copernicus DEM GLO-30, provides more detailed topographic data with a 30 meter resolution (Gascon et al., 2014 and European Environment Agency, 2011, 2017)

3. Methodology

3.1 Vertical Accuracy

Vertical accuracy is an important characteristic of DEM and depends on various factors: the interpolation methods of data, the density of data, data quality and topographic features of the surface and or technical reasons: improper instrument operation, physical limitations of sensors and others (González-Moradas and Viveen, 2020, Pu et al., 2020, Khasanov, 2020 and Jalal et al., 2020). These factors can cause adverse effects for some DEM-based positioning errors for applications. Moreover, errors can occur due to the altitude data acquisition methodology and the different processing stages of the models (Bhagwat et al., 2019 and Bakiev and Khasanov, 2021 a). DEMs are prone to errors, because they can never be completely eradicated, and they need to be managed effectively and investigate their errors (Jalal et al., 2020, Wessel et al., 2018, Maune 2010 and Farr et al., 2007).

3.2 Statistical Methods

The accuracy of the AWED30 DEM, ASTER GDEM, SRTM Plus, COP-30, and NASADEM products tested for the Karaman Reservoir area was compared with 36 ground elevation points obtained from topographic map (1:25000). The following statistical methods were used to estimate the vertical accuracy of DEMs.

RMSE-root mean squared is a measure of precision for comparing the prediction errors of different models for a specific dataset, not between datasets as it is scale dependent. RMSE is the square root of the second sampling time of the difference between predicted and observed values, and RMSD is used to aggregate the magnitudes of prediction errors for different data points into a single measure of predictive power (Nikolakopoulos et al., 2006, Coveney and Roberts, 2017, Dong et al., 2018 and Nadi et al., 2020).

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(y' - y)^2}{n}}$$

Equation 1

MAE - mean absolute error is a general measure of the forecast error in the analysis of the time sequence and is sometimes confused with the standard definition of the average absolute deviation. MAE is an error measurement between pairs of observations representing a single event. Examples of Y and X include predicted and observed, subsequent time and start time, and comparison of a single measurement method with an alternative measurement method. The MAE is a general measure of the forecast error in the analysis of the time sequence and is sometimes confused with the standard definition of the average absolute deviation (Rawat et al., 2019, Vanthof and Kelly, 2019 and Guan et al., 2020).

$$MAE = \frac{\sum_{i=1}^{n} |y_i - x_i|}{n} = \frac{\sum_{i=1}^{n} |e_i|}{n}$$

Equation 2

MBE - Mean bias error is not usually used as a measure of model error because there are high individual errors in forecasting, but MBE is mainly used to estimate the mean bias in the model and to decide whether to take any steps to correct the model. bias and fixes the average forecast deviation. Smaller error values and a significantly larger correlation coefficient for the variable and direction are more important (Rawat et al., 2019, Pham et al., 2018; and Vanthof and Kelly, 2019).

$$MBE = \frac{1}{n} \sum_{i=1}^{n} \frac{x_i - x_{true}}{x_{true}}$$

Equation 3

SD - Standard deviation is a statistic that measures the distribution of a dataset in relation to its mean. The standard deviation is calculated as the square root of the variance by determining the deviation of each data point from the mean, and if the data points farther from the mean, the higher the deviation in the dataset (Vanthof and Kelly, 2019, Abdallah, 2013, Amatulli et al., 2020 and Pham et al., 2018).

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_1 - \bar{x})^2}{n - 1}}$$

Equation 4

MAD - Mean Absolute Deviation of a data set is the average distance between each data point and the mean. It is used to calculate the average value of an absolute value or the difference between actual values and their average values, as well as the demand variability, which gives us an idea of the variability of the data set (Elkhrachy, 2018, Rawat et al., 2019, Vanthof and Kelly, 2019 and Sharma and Tiwari, 2014).

$$MAD = \frac{\sum |x_1 - \bar{x}|}{n}$$

Eqаution 5

3.3 Global Mapper

The Global Mapper program is a program of the Blue Marble Geographics innovative mapping software company, is one of the geoinformation system programs, it is now widespread and differs from other geoinformation systems by the ability to enter the global database, the simplicity and convenience of the software interface, the existence of the Global Mapper program Mobile and the ability to download GPS data to the program (Bakiev and Khasanov, 2021b).

4. Results and Discussion

The results of statistical calculations calculated on the ground elevation points and DEM data show that NASADEM and AW3D30 data are more accurate than other DEMs. The RMSE performance is better in both DEMs (NASADEM 10.15, AW3D30 10.37) than the others. MAE, MBE, SD, MAD performance is also better in both DEMs than the others. The study showed that the use of AW3D30 and NASADEM data in the design of the proposed Karaman Reservoir for construction leads to a more accurate result (Table 1). At the suggestion of the Project Institute, taking into account the surrounding infrastructure, the maximum water level was taken to be 330 m (above sea level) and the dam crest level to be 332 m. The results obtained using AW3D30 data in determining the storage capacity volume (W=780 mln.m^3) and water cover area (F=41.4 sq.km) of the water reservoir (Figure 2).

Table 1: Statistics values calculated over the geodetic ground elevation points and the AWED30 DEM, ASTER GDEM, SRTMGL1V003 DEM, COP-30, and NASADEM compared data

Global DEMs	Root Mean Square Error	Mean Absolute Error	Mean Bias Error	Standart Deviation	Mean Absolute Deviation
AW3D30	10.37	6.408	-5.308	75.22	52.6
SRTM Plus	13.16	7.547	-5.197	70.4	49.67
ASTER GDEM v3	14.8	9.175	-4.78	70.14	48.61
COP30	14.81	8.436	-6.336	71.25	49.31
NASADEM	10.15	6.031	-5.308	72.77	50.96

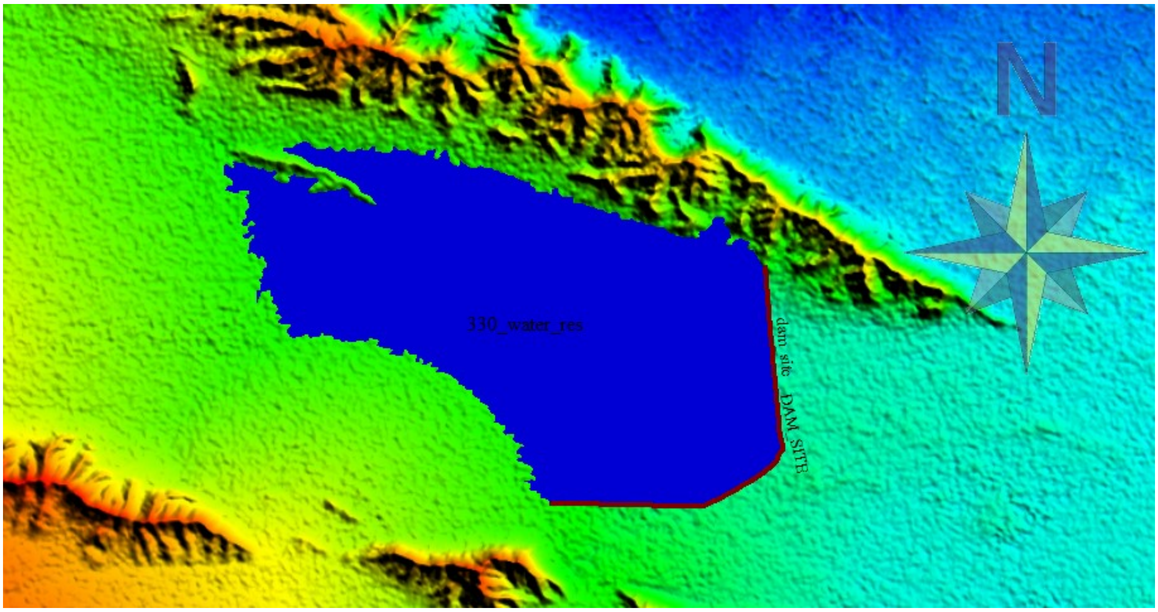

Figure 2: Dam crest level (332 m above sea level) and water surface area (330 m above sea level)

5. Conclusion

Uzbekistan pays great attention to the construction of reservoirs for irrigation and energy purposes. The main goal of our research is to identify potential sites for the construction of reservoirs using GIS and RS and to obtain and obtain initial data (geographical location, storage capacity and water surface area, the profile of dam location, etc.) and put it into practice. Field research or topographic maps are used in the design of reservoirs in the country. These methods can provide high-precision ground data, but they are time-consuming and labour-intensive. In this study, we compared the vertical accuracy of different DEMs (SRTM Plus, ASTER GDEM, COP30, AW3D30, and NASADEM) for the research area in the initial design of the Karaman Reservoir using GIS and RS technologies. Based on data from NASADEM and AW3D30 in the Global Mapper program, we analysed reservoir storage capacity and many water surface area options, taking into account the infrastructure around the reservoir. What does this research work give us? It gives us additional opportunities to identify potential locations for the construction of a new reservoir to meet the water needs of consumers in the context of climate change and the acute shortage of water resources in the region. In obtaining, analysing and drawing the necessary conclusions in determining the geographical location of reservoirs, storage capacity and water surface area, profile of the location of the dam and other parameters.

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