Comparison of Digital Elevation Models for the designing water reservoirs: a case study Pskom water reservoir.

*Khojiakbar Khasanov**, and *Azamat Ahmedov*

Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Tashkent, Uzbekistan

Abstract. This study investigates the accuracy of various DEMs (SRTM DEM, ASTER GDEM, and ALOS PALSAR DEM) for the area of the designing Pskom water reservoir (recommended to construction in Pskom River, in Tashkent region. DEMs are compared for the study area using the Global Mapper application and selection Ground Control Points (GCP). The RMSE we calculate is the most easily interpreted statistic as the square root of the mean square error because it has the same units as the quantity drawn on the vertical axis. Results show that SRTM based measurements of ground control points (GCPs) exhibit RMSE of 15.72 m while ASTER DEM based measurements exhibits and RMSE of 18.47 m, ALOS PALSAR exhibit RMSE of 14.02 m for the Water reservoir located in the plain. There are AOS PALSAR outperforms SRTM and ASTER DEM in detecting vertical accuracy. Based on the capabilities of the Global Mapper program, we can build the longitudinal profile of the approximate location where the dam can be built in each DEM and compare. The results obtained show that the dam height is 187 m at ALOS PALSAR DEM, 168 m at ASTER GDEM, and 175 m at SRTM. The study found that using ALOS PALSAR data in the design of the proposed Pskom Reservoir for construction leads to a more accurate result. Comparing the DEMs data shows that there is more difference between the vertical accuracy; the horizontal accuracy level is almost the same. The results were obtained using ALOS PALSAR data in determining the storage volume ($W=479368568 \text{ m}^3$) and area ($F=8.31 \text{ sq., km}$) of the water reservoir.

1 Introduction

Reservoirs - created by damming rivers throughout their history have played an important role in societies around the world, regulating floods, generating hydroelectricity, and redistributing river runoff for irrigation, usually where natural precipitation is volatile or seasonal as they store water during wet periods to make it available during dry periods[1–3].

Uzbekistan is a mostly arid region, where evaporation exceeds precipitation and annual precipitation is lower. Its climate is mostly arid, and its water resources are unevenly distributed both in space and time. This means that agricultural production is impossible

* Corresponding author: kh.khasanov@mail.ru

without irrigation. So, the irrigation system is primarily one of the main economic development factors, employment, and food security in Uzbekistan. There are 59 reservoirs in Uzbekistan, 29 of which are located in the floodplains of rivers and are a channel, and 30 are bulk reservoirs[4–6].

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 constructing reservoirs and obtaining initial data (the geographical location, storage volume, water surface area, profile of the dam site, and others) imposes a great task on project institutes.

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. Today, geographic information system (GIS) and Remote Sensing (RS) technologies are an integral part of many branches of industry. Using the digital elevation model (DEM) in the GIS, it is possible to determine the potential location for the reservoir construction, to estimate the volume of the reservoir build-up, to simulate groundwater, to determine possible erosion and the mudflow hazard and mudflow-resistant areas[7, 8]. The introduction of GIS and RS technologies into human life has made it possible to accomplish many tasks quickly, cheaply, and accurately, including in the performance of environmental engineering work [1], [9–12].

1.1 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 concerning any coordinate system, the simplest form and digital characteristics of the topographical surface; it 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[13–15]. Nowadays, remote sensing satellites, in addition, to their high temporal and spatial resolutions, low-cost production compared to direct measurements. DEMs produced from these sources vary in cost, accuracy, availability, and sampling density[16].

1.2 Shuttle Radar Topography Mission (SRTM)

SRTM - The first disposable SAR (synthetic aperture radar) interferometer in space was launched after a short delay aboard the Space Shuttle Endeavor (STS-99). On February 11, 2000, two modified antenna synthetic aperture radar systems were operated. It was a joint project of the U.S. Department of Defense's National Aerospace and Space Administration, the National Geographic Intelligence Agency. Equipped with a set of SRTM C-band and X-Band synthetic aperture radars, it allows developing 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. SRTM DEM 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 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. The second, Version 2.1 (~2005), is an edited version of v1; Void Filled elevation data result from 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 (30 meters)[17]–[23].

1.3 Advanced Spaceborne Thermal Emission Reflectometer(ASTER)

ASTER - the freely available Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model Version 2 (ASTER GDEM) is a joint initiative undertaken by the Ministry of Economics, Trade, and Industry (METI) of Japan and the National Aeronautical and Space Administration (NASA) of the United States, was released to the public in mid-October, 2011. The first ASTER GDEM was released in 2009, with Version 2 being released in 2011. The ASTER GDEM Version 3 maintains the GeoTIFF format and the same gridding and tile structure as in previous versions, with 30-meter spatial resolution and $1^{\circ} \times 1^{\circ}$ tiles. ASTER thermal bands measure not just surface temperature but also surface emissivity spectra, and the measurements are subject to atmospheric effects. G-DEM is expected to be a better source of global topographic information for various scientific applications[24]–[27].

1.4 Advanced Land Observation System

The Advanced Land Observing Satellite (ALOS) was launched on January 24, 2006, by the Japan Aerospace and Exploration Agency (JAXA) and was operational until May 12, 2011. ALOS, also referred to as DAICHI, (the Japanese often give two names to each of their space projects; the names are used interchangeably in the JAXA literature), captured 6.5 million scenes during its five years of operation. ALOS is equipped with three Earth observation sensor instruments: 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. The ALOS satellite was successfully launched from the Tanegashima Space Center on January 24, 2006 (Japan Standard Time) using an H-IIA launch vehicle [8], [28–33].

Considering that the total data produced by the ALOS sensors daily (around 700 Gbyte) was beyond the capabilities of any single agency to attempt to manage, but that there was worldwide interest in the use of ALOS data, JAXA has established the concept of the ALOS Data Nodes with local archives, as a mechanism for sharing the processing and distribution load.

1.5 Data Accuracy

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[34], [35]. Moreover, these factors can cause adverse effects for some DEM-based positioning errors for applications due to the altitude data acquisition methodology and the different processing stages of the models. DEMs are prone to errors because they can never be completely eradicated, and they need to be managed effectively and investigate their errors[14, 16], [36–41].

This study investigates the accuracy of various DEMs (SRTM DEM, ASTER GDEM, and ALOS PALSAR DEM) for the area of the designing Pskom water reservoir (recommended to construction in Pskom River, in Tashkent region, 'figure 1'). DEMs are compared for the study area using the Global Mapper application and selection Ground Control Points (GCP).

Fig. 1. Study area. Pskom water reservoir is recommended for construction in Pskom River.
(Tashkent region, Uzbekistan)

2 Material and Methods

The overall purpose of this paper is to compare the accuracy of SRTM DEM, ASTER DEM ALOS PALSAR data downloaded by free open-search websites for the area of the designing Pskom water reservoir. And to determine the water storage volume and area of the reservoir based on high-precision DEM data for that region. The vertical accuracy of each DEM elevation matrix is estimated using data from the Global Positioning System (GPS) at 40 control points obtained from intensive geodetic surveys. These points cover almost the entire area 'figure 2'.

Table 1. Metadata

SRTM DEM	ASTER DEM
FILENAME=SRTM DEM PROJ_DESC=UTM Zone 42 / WGS84 / meters COVERED AREA=158.74 sq km NUM COLUMNS=316 NUM ROWS=346 NUM BANDS=1 PIXEL WIDTH=38.219 meters PIXEL HEIGHT=38.219 meters MIN ELEVATION=985.1 m MAX ELEVATION=1219.1 m ELEVATION UNITS=METERS BIT DEPTH=32 SAMPLE TYPE=32-bit Floating Point	FILENAME=ASTER DEM PROJ_DESC=UTM Zone 42 / WGS84 / meters COVERED AREA=158.74 sq km LOAD TIME=0.02 s NUM COLUMNS=316 NUM ROWS=346 NUM BANDS=1 PIXEL WIDTH=38.219 meters PIXEL HEIGHT=38.219 meters MIN ELEVATION=986.5 m MAX ELEVATION=1232.2 m ELEVATION UNITS=METERS BIT DEPTH=32 SAMPLE TYPE=32-bit Floating Point
ALOS POLSAR DEM	
FILENAME= ALOS POLSAR DEM PROJ_DESC=UTM Zone 42/WGS84/meters COVERED AREA=158.95 sq km LOAD TIME=0.02 s NUM COLUMNS=524 NUM ROWS=429 NUM BANDS=1	PIXEL WIDTH=23.022 meters PIXEL HEIGHT=30.844 meters MIN ELEVATION=977.5 m MAX ELEVATION=1184.9 m ELEVATION UNITS=METERS BIT DEPTH=32 SAMPLE TYPE=32-bit Floating Point

3 Results and Discussion

First, vertical differences between SRTM, ASTER GDEM, and ALOS PALSAR products were computed as the root mean squared error (RMSE) compared to GPS data. The RMSE we calculate is the most easily interpreted statistic as the square root of the mean square error because it has the same units as the quantity drawn on the vertical axis[10], [47]–[51], [18], [39].

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

Results show that SRTM based measurements of ground control points (GCPs) exhibit RMSE of 15.72 m while ASTER DEM based measurements exhibits and RMSE of 18.47 m, ALOS PALSAR exhibit RMSE of 14.02 m for the Water reservoir located in the plain 'figure 3'. There are AOS PALSAR outperforms SRTM and ASTER DEM in detecting vertical accuracy.

Fig. 3. RMSE results

Second, determine the storage volume and area of the reservoir using the Global Mapper program and each DEM data for comparing the DEMs[50]–[52]. The water level in the projected reservoir is approximately 1166.5m relative to the sea level. We generated contours for 1170m relative to the sea level using Generate Contours command. And the surface area is generated from this contour and the dam location section using Create New Area Features command from the Selected Lines option. The storage volume and area are determined on the resulting surface using the Measure Volume (Cut-and-Fill) command. The results showed three different outcomes in the three DEMs. The results are presented in 'table 1' and 'figure 3'

Table 2. The determined storage volume and area for each DEM dates

BASE HEIGHT, m (Sea Level)	SRM		ASTER GDEM		ALOS PALSAR	
	FILL VOLUME, m ³	FILL AREA sq. km	FILL VOLUME, m ³	FILL AREA sq. km	FILL VOLUME, m ³	FILL AREA sq. km
1000	199286.7	0.0451	150741.62	0.0215	664082.86	0.1058
1010	1064510.1	0.1411	872876.63	0.1305	2224332.4	0.2072
1020	3078364.4	0.261	2788219.2	0.249	4777633.1	0.3218
1030	6421532.8	0.429	5872156	0.3694	8974555.8	0.524
1040	11899239	0.662	10627231	0.612	15192802	0.723
1050	19794559	0.923	18153325	0.892	23753540	0.995
1060	30340059	1.191	28281590	1.132	35292828	1.327
1070	43831664	1.53	41027870	1.425	50279019	1.67
1080	60897129	1.899	56992084	1.785	68969691	2.076
1090	82349377	2.392	76967966	2.231	91905550	2.536
1100	108914226	2.932	101803039	2.752	119800728	3.05
1110	140977315	3.485	132096316	3.301	153043997	3.59
1120	178544887	4.064	168124416	3.941	192015296	4.214
1130	222763810	4.802	211437989	4.724	238214673	5.039
1140	275171193	5.673	262507235	5.494	292702295	5.847
1150	335891077	6.494	321822498	6.373	355296954	6.708
1160	405844153	7.529	390608997	7.389	427242085	7.695
1166,5	457140013	8.258	440530965	7.951	479368568	8.31

Fig. 4. Graphics of $F=f(h)$ and $W=f(h)$

Third, based on the capabilities of the Global Mapper program, we can build the longitudinal profile of the approximate location where the dam can be built[53]. And we do this in each DEM and compare 'figure 5'. The results obtained show that the dam height is 187 m at ALOS PALSAR DEM, 168 m at ASTER GDEM, and 175 m at SRTM.

Fig. 5. The longitudinal profiles of both dam

4 Conclusions

The study found that using ALOS PALSAR data in the design of the proposed Pskom Reservoir for construction leads to a more accurate result. Comparing the DEM data shows that there is more difference between the vertical accuracy; the horizontal accuracy level is almost the same. The results obtained using ALOS PALSAR data determine the storage volume ($W=479368568\text{ m}^3$) and area ($F=8,31\text{ sq., km}$) of the proposed Pskom Reservoir are shown in Figure 6.

Fig. 4. Graphics of $F=f(h)$ and $W=f(h)$

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