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VERTICAL ACCURACY ASSESSMENT OF VARIOUS OPEN-SOURCE DEM DATA: DEMNAS, SRTM-1, AND ASTER GDEM

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Abstract. DEM can be used optimally when it has good accuracy. Thus, assessing DEM data quality is mandatory before use it for specific thematic applications. Recently, there are open-source DEM data that can be downloaded and used freely by users, such as SRTM and ASTER GDEM. However, Indonesia tried to develop their own national seamless DEM, called DEMNAS. This study aims to evaluate the open-source DEMs that are popular in Indonesia: DEMNAS, SRTM-1, and ASTER GDEM. Accuracy assessment was conducted by comparing the DEMs to GPS measurements. The results showed that SRTM-1 had the best accuracy with 5.529 meters, followed by DEMNAS and ASTER GDEM with 8.172 meters and 13.632 meters, respectively. We also analyzed the linear relation between DEMs and GPS elevation data using the coefficient of determination, and all DEMs showed good R^2 values. Lastly, the correlation between the error and the height of DEMs was also examined. The results were SRTM-1 had correlation between the height and accuracy, as well as ASTER GDEM. In contrast, the errors in DEMNAS were relatively uniform in all range of elevation.

Keywords: digital elevation model (DEM), DEMNAS, SRTM, ASTER GDEM, accuracy assessment.

Introduction

As a representation model of the Earth surface, Digital Elevation Model (DEM) can be utilized for many applications, i.e., 3D spatial analysis, multi-criteria decision support systems, deformation monitoring, or an input data for orthorectification (Alganci et al., 2018). Due to its importance, producing high quality DEM will support any policies of a country. However, like a spatial data in general, DEM can be used optimally when it has good accuracy. Thus, assessing DEM data quality is mandatory before use it for specific thematic applications.

The development of geospatial data acquisition creates opportunities for producing high quality DEM data globally. Recently, there are open-source DEM data that can be downloaded and used freely by users, such as SRTM (Shuttle Radar Topography Mission) and ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer). Several studies tried to analyze the accuracy of SRTM and ASTER data. For instance, Hirt et al. (2010) investigated SRTM ver4.1 and ASTER GDEM ver1 over Western Australia, and the vertical accuracy of SRTM was ~6 meters and ASTER was ~15 meters. Mukherjee et al. (2013) evaluated ASTER and SRTM compared to Cartosat DEM and found that the RMS error of both data were 12.62 meters and 17.76 meters, respectively. Patel et al. (2016) assessed Cartosat-1, SRTM, and ASTER using differential global positioning system (DGPS) and the RMSE of those data ranged from 2–5 meters. Elkhrachy (2018) used the topographic map as a reference elevation, and obtained the accuracy was ±6.87 m for SRTM and ±7.97 m for ASTER. Alganci et al. (2018) also conducted similar research, and the accuracy of SRTM and ASTER ranged from 6–13 meters.

Despite global DEMs like SRTM and ASTER are available, Indonesia tried to develop their own national seamless DEM. Thus, in 2018, Indonesian Geospatial Information Agency (or officially abbreviated as BIG) has launched national DEM by combining multi-resources data such as IFSAR, TerraSAR-X, ALOS PALSAR, and mass points (Julzarika & Harintaka, 2019). The data is called DEMNAS, stands for *DEM Nasional* or National DEM in English. It is similar to previous studies that aims to generating a seamless DEM and producing better data by blending several data. For example, Cook et al. (2012) created 100-m DEM of the Antarctic Peninsula based on ASTER GDEM because there was no DEM that meets desired specifications at the moment. Julzarika (2015)

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integrated various height models such as ALOS PALSAR, X-SAR, SRTM C, and ICESat/GLAS to get better accuracy than global height models. Yue et al. (2017) generated a seamless DEM by integrating SRTM-1, ASTER GDEM v2, and ICESat laser altimetry data.

The purpose of DEMNAS program is to integrate different data sources to create seamless DEM data that can be accessed easily by users. In addition, this data is expected to be better than SRTM and ASTER as global DEM that available right now. Before the product was launched, Susetyo et al. (2018) examined the accuracy of DEMNAS prototype compared to Ground Control Points (GCPs) and got the vertical accuracy of 3.679 meters. Sulistiana et al. (2019) also conducted similar study and found that the accuracy of DEMNAS was 1.818 meters. Ihsan and Sahid (2021) used different approach by considering the slope angle classification to measure the vertical accuracy of DEMNAS, ALOS PALSAR, and Sentinel-1 data, and the result showed DEMNAS was the best among those data.

This study aims to evaluate the open-source DEMs that are popular in Indonesia: DEMNAS, SRTM-1, and ASTER GDEM. Understanding the vertical accuracy of those data is important as a consideration before use them for analysis. The accuracy was obtained by comparing the height in each DEM and the height from field measurement. Our research also portray the performance of national DEM of Indonesia, so it can be an answer whether the main purpose to create better DEM than global DEM was achieved or not.

1. Data and method

1.1. Study area

This study was conducted in Bogor, Indonesia (Figure 1). Bogor is part of Jabodetabek (Jakarta-Bogor-Depok-Tangerang-Bekasi), an area that covers Jakarta as a megapolitan city as well as the capital of Indonesia and its surrounding cities. Located in West Java Province, Bogor has distance to Jakarta about 60 kilometers. Bogor is relatively hilly, so the altitude of our study area ranges from about 30 to 2000 meters. An area of 26.5×40.5 km was taken to be observed in our study.

1.2. Data

First, we used DEMNAS that provided by BIG. As an institution that has responsibility for providing national geospatial data, BIG collects DEM data from various data sources (Figure 2), including TerraSAR-X, IFSAR, and Radarsat. However, they were not seamless. In addition, due to the specification difference of each data, it was not easy to integrate them as one DEM dataset. Then, DEMNAS project was set by the institution to create a national seamless DEM. Based on the information that available on the DEMNAS portal, those source DEMs were assimilated with mass points from topographic data using GMT-surface with tension of 0.32. The assimilation process followed a method proposed by Hell and Jakobsson (2011) by gridding heterogeneous bathymetric datasets for generating digital bathymetric models (DBMs). This approach was selected because it also aims to solved similar problem: utilization of multidata sources that have extreme variations in data density. DEMNAS now available at https://tanahair.indonesia.go.id/demnas/#/ and can be downloaded freely in Geotiff 32-bit float format with a resolution of 0.27 arc-second (about 8 meters).

The next data is SRTM-1, or SRTM with a resolution of 1 arc-second (about 30 meters). SRTM is a global DEM that covers almost the whole of the world, ranges from 60°N to 57°S. It is a cooperation program that involved NASA, the German Aerospace Center (DLR), and Italian Space Agency (ASI). SRTM was acquired using synthetic aperture radar (SAR) interferometry between February 11 and 22, 2000, utilizing C- and X-bands to produced data that has resolution of 1 and 3 arc-seconds. The DEM

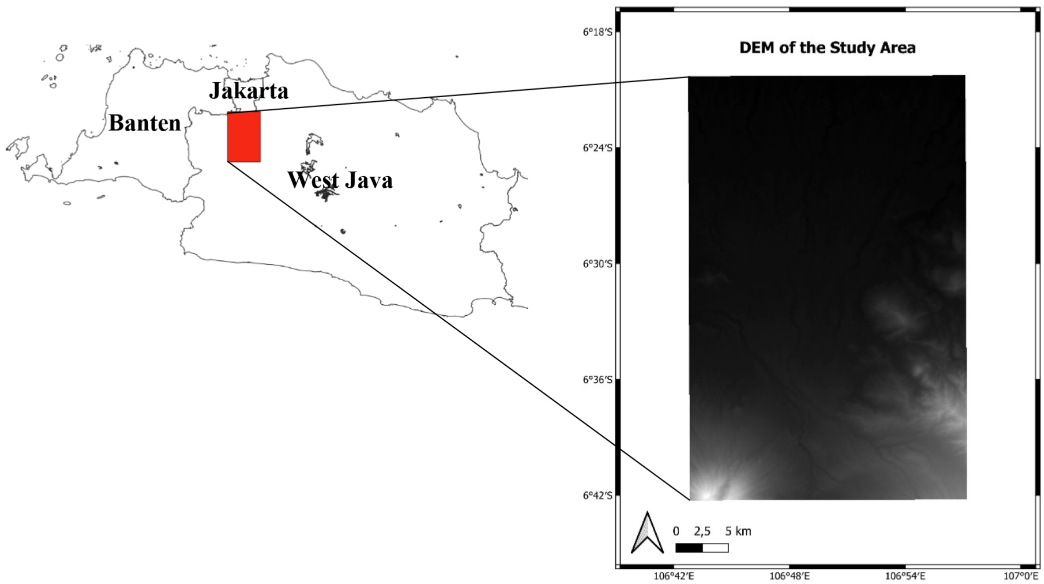


Figure 1. Study area

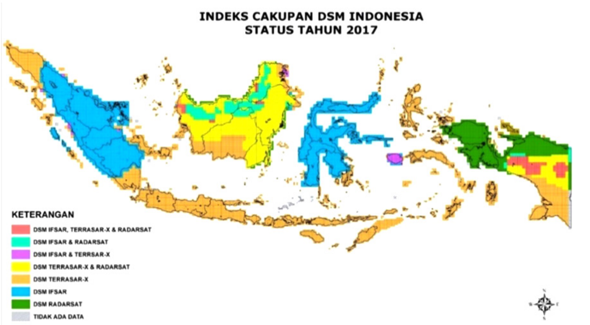
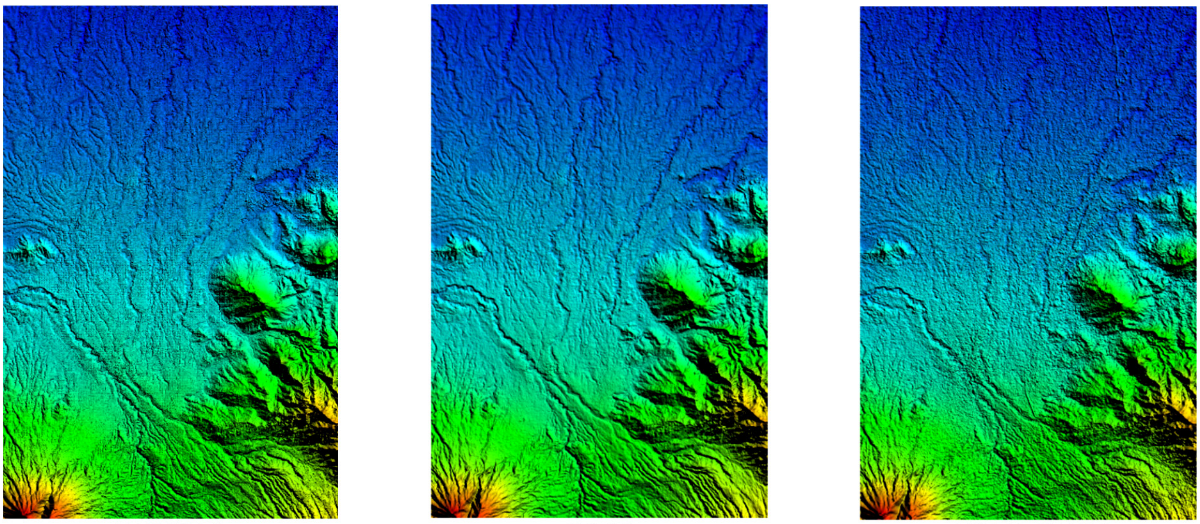


Figure 2. The coverage of DSM from multi-source data in 2017 (source: documentation of BIG)

accuracy are ±16 meters for absolute accuracy and ±6 meters for relative accuracy, which the absolute accuracy is the error throughout the entire mission, while the relative accuracy is the error in a local 200-km scale (Rabus et al., 2003). In the beginning of its launch, SRTM showed a significant improvement in resolution compared to the other DEMs that available in that period, such as GTOPO and altimetric DEMs (Cowan & Cooper, 2004).

We also observed ASTER GDEM version 2 in our study. ASTER GDEM was released for the first time on June 29, 2009, by cooperation between NASA and the Ministry of Economy, Trade, and Industry (METI) of Japan. Previously, in 2007, NASA and METI offered ASTER GDEM to the Group on Earth Observations (GEO) at the Summit of Ministers in Capetown, South Africa, before it was accepted as a contribution to the Global Earth Observing System of Systems (GEOSS) (Abrams et al., 2015). The data covers 83°N to 83°S and has a resolution of 1 arc-second (about 30 meters). The second version of ASTER GDEM was released on October 2011. Several improvements were made in the ASTER GDEM version 2, such as reduce artifacts, higher horizontal resolution using a smaller correlation kernel, improved water mask, and higher accuracy at 17 meters compared to 20 meters in version 1 (ASTER et al., 2011). A study by Tachikawa et al. (2011) also found that ASTER GDEM version 2 reduce the standard deviation of elevation and geolocation error. The visualization of DEMs that used in this study can be seen in Figure 3.

For elevation reference data, we used field measurements using Geodetic GPS. It was sourced from the GCPs that used for airborne aerial photo acquisition. Because of that purpose, the GPS points were measured in the pre-mark, as commonly used in the aerial photo acquisition. The visualization of GPS points can be seen in Figure 4.



DEMNAS SRTM ASTER GDEM

Figure 3. The visualization of DEMNAS, SRTM-1, and ASTER GDEM in the study area

Figure 4. GPS elevation points (source: documentation of BIG)

1.3. Method

The flowchart of our research is presented in Figure 5. All those three data were examined using GPS measurements. However, all data have different vertical datums, which SRTM-1 and ASTER GDEM refer to EGM96, DEMNAS refers to EGM08, and GPS elevation refers to Mean Sea Level (MSL). Accuracy assessment will not possible if the compared data do not have same height reference. Thus, datum conversion was required, where SRTM-1, ASTER GDEM, and GPS elevation were shifted to EGM08.

To obtained SRTM-1 and ASTER GDEM in EGM08 datum, the height difference between EGM96 and EGM08 in the study area was necessary. Then, we subtracted both data and the result is presented in Figure 6. This subtraction output then was used to convert SRTM-1 and ASTER GDEM to refer EGM08 as their vertical datum.

Meanwhile, the conversion of GPS elevation from MSL to EGM08 referred to the mean dynamic topography (MDT) obtained from subtraction of EGM08 and MSL height (Figure 7). This subtraction process used Indonesia bathymetric data (*Batimetri Nasional* or shortened as BATNAS) which provides elevation data both in EGM08 and MSL datum. BATNAS is a national data that created and launched together with DEMNAS. Because BATNAS covers not only the sea, but also the land, it can be used to calculate the MDT to convert the GPS elevation from MSL to EGM08.

Then, accuracy assessment was conducted by comparing the DEMs to GPS measurements that already have orthometric height. Hence, 60 points were used to test the elevation data. The DEMs quality was performed using root mean square error (RMSE) and linear error 90% (LE90), referring to the Indonesia National Standard about Base Map Accuracy. RMSE reflects the average of difference between observed values and assumed true values (Mukherjee et al., 2013). Then, the final accuracy was represented by LE90, which describes that 90% of errors are no more than that distance (Badan Standardisasi Nasional, 2019). The equation of RMSE can be found as follows.

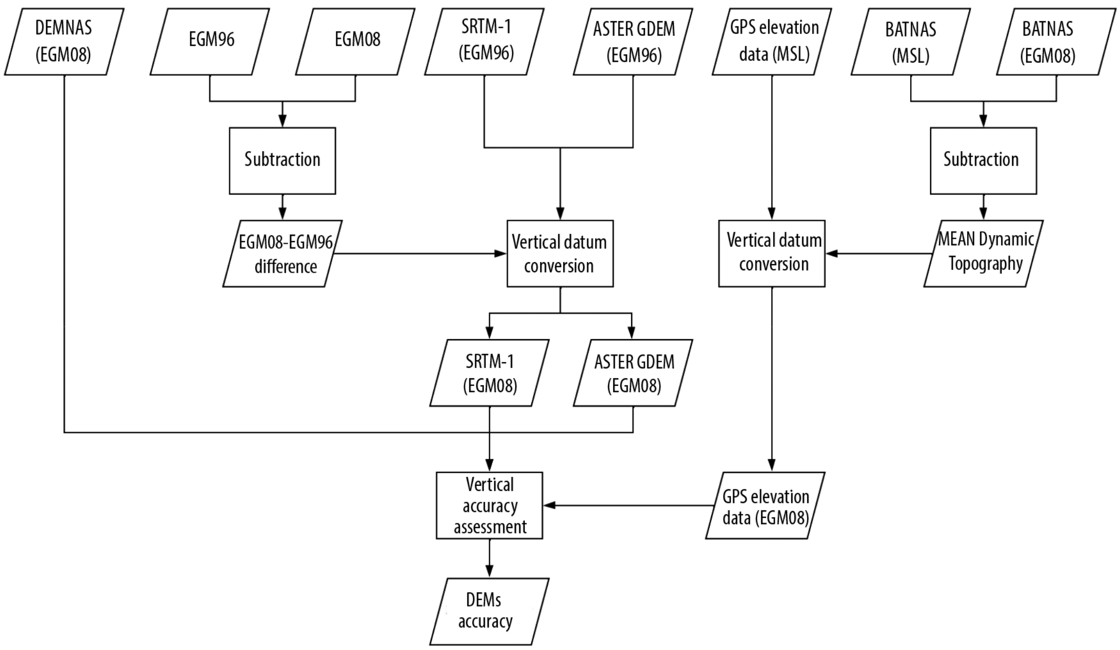


Figure 5. Research flowchart

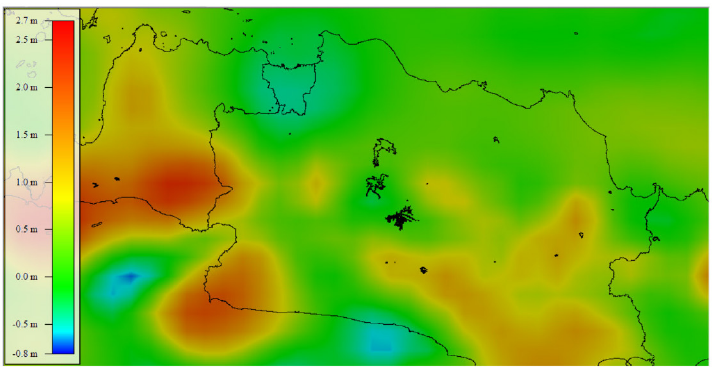


Figure 6. The difference of EGM96 and EGM08

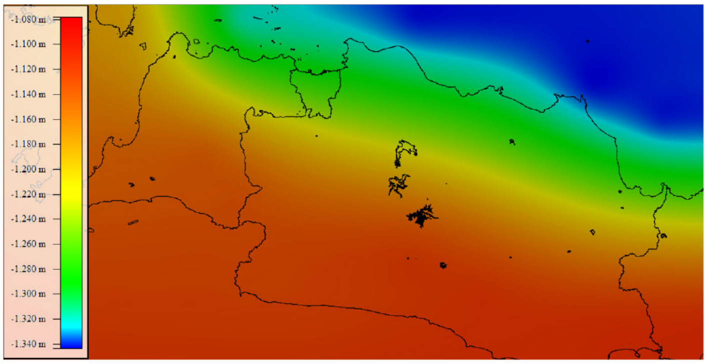


Figure 7. The mean dynamic topography (MDT) in the research area

$$\text{RMSE} = \sqrt{\frac{\Sigma\left(Z_{DEM} - Z_{GPS}\right)^2}{n_{points}}}, \tag{1}$$

where: Z_{DEM} = the elevation of the observed points from DEM data; Z_{GPS} = the elevation of the observed points from GPS measurement; n_{points} = the number of observation points.

Then, from the RMSE, we can obtain LE90 with this equation.

$$\text{LE90} = 1.6449 \times \text{RMSE}. \tag{2}$$

2. Results and discussion

The RMSE and LE90 results are shown in Table 1. Based on RMSE and LE90 that calculated using the Equation (1) and (2), SRTM-1 performed the best accuracy, followed by DEMNAS and ASTER GDEM. SRTM-1 had the RMSE value of 3.361 meters and LE90 value of 5.529 meters. It was close to the relative accuracy of SRTM (Rabus et al., 2003) as well as the results from Hirt et al. (2010) and Elkhrachy (2018), namely ±6 meters. Meanwhile, DEMNAS had 4.968 meters and 8.172 meters for RMSE and LE90, respectively. BIG stated in the DEMNAS portal that based on validation in Sumatera area, the RMSE of DEMNAS is 2.79 meters with the bias error of 0.13 meters. Thus, our results were worse than that official statement, as well as the other findings by Susetyo et al. (2018) and Sulistiana et al. (2019). Last, ASTER had the lowest accuracy with RMSE of 8.288 meters and LE90 of 13.632 meters, which was relatively close to results by Hirt et al. (2010) and Mukherjee et al. (2013). Based on those results, DEMNAS was better than ASTER GDEM, but still had

Table 1. Error in DEMs compared to GPS elevation points

DEM data	RMSE (meters)	LE90 (meters)
DEMNAS	4.968	8.172
SRTM-1	3.361	5.529
ASTER GDEM	8.288	13.632

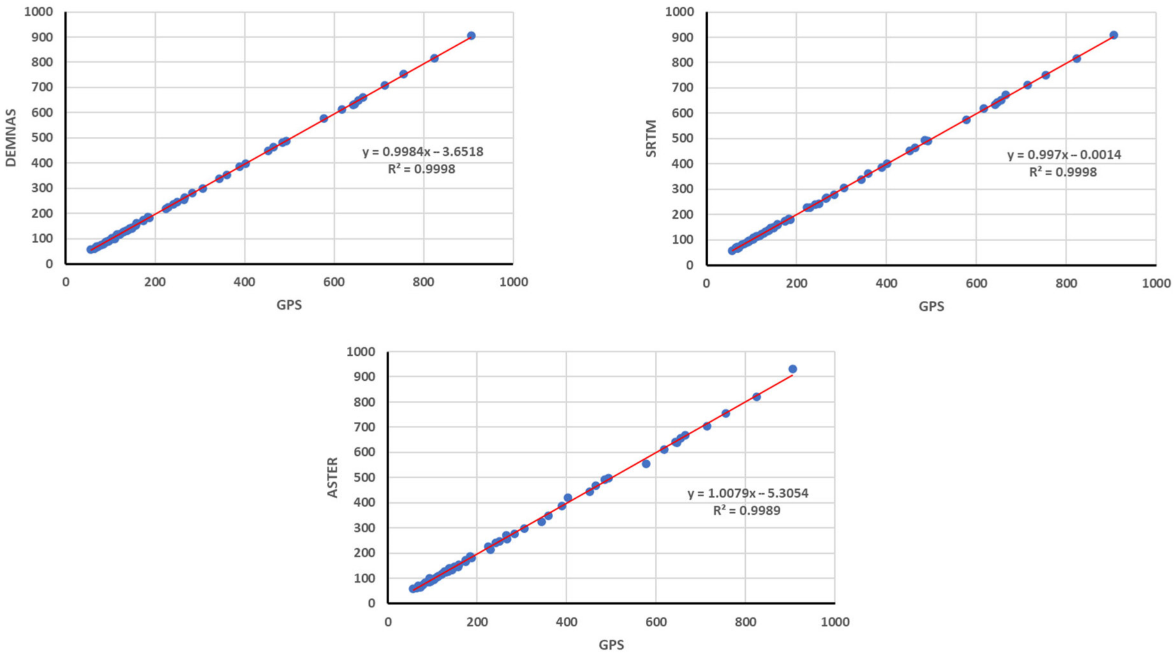


Figure 8. Linear relation between DEMs and GPS elevation data

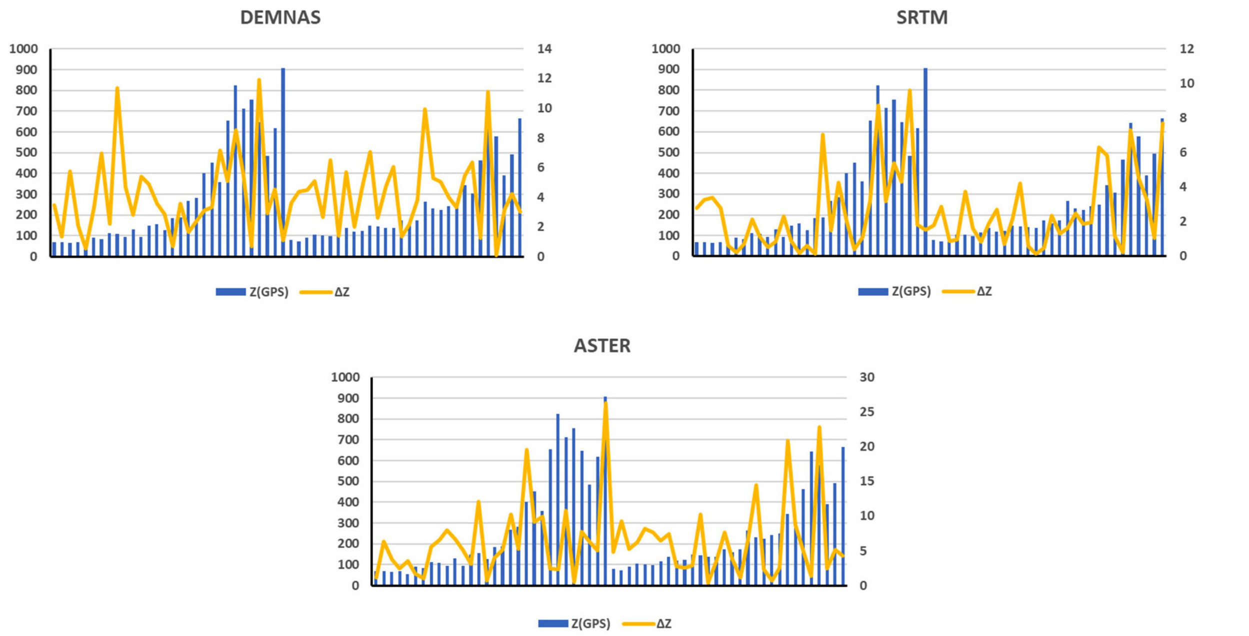


Figure 9. Comparison between the error and the elevation

lower accuracy than SRTM-1. If we refer to the main purpose of DEMNAS creation namely to provide a national DEM which better than global DEM, DEMNAS still needs improvement to increase its accuracy.

The visualization of its statistical test is illustrated in Figure 8. The figures show linear relation between the height from the DEM and the GPS points, tested with the coefficient of determination, denoted R^2. It explains how dependent variable can be predicted by independent variable. R^2 ranges from 0 to 1, which higher value shows stronger correlation among the data. Overall, all DEMs showed high linear relation to the GPS elevation data. DEMNAS and SRTM-1 had same R^2 value, namely 0.9998. Meanwhile, ASTER was a little bit lower with the R^2 value was 0.9989. From those results, it can be concluded that the three DEMs had good vertical accuracy.

We also examined the correlation between the error and the height of DEMs, as presented in Figure 9. Based on the graph, SRTM-1 had correlation between the height and accuracy. We can see that higher elevation in SRTM-1 had higher deviation to GPS elevation data. Similar pattern also happened to ASTER GDEM, but it had better accuracy in high elevation than SRTM-1. Meanwhile, the errors in DEMNAS relatively uniform in all range of elevation, because high error can be occurred in both low and high elevations.

Conclusions

We observed three open-access DEM data that are popular among users and applied widely in any studies. First, we selected DEMNAS, a seamless national DEM that published by BIG as an official geospatial data provider in Indonesia. Then, SRTM-1 and ASTER GDEM were also examined because both of them are popular global DEM data by worldwide users. The performance of those DEMs were evaluated using GPS elevation data that measured using Geodetic GPS. We started by datum unification, where all the data were converted to EGM08 vertical datum. Then, the accuracy was assessed using LE90, after previously RMSE value was obtained. The results showed that SRTM-1 had the best accuracy with 5.529 meters, followed by DEMNAS and ASTER GDEM with 8.172 meters and 13.632 meters, respectively. We also analyzed the linear relation between DEMs and GPS elevation data using the coefficient of determination, and all DEMs showed good R^2 values. Lastly, the correlation between the error and the height of DEMs was also examined. The results were SRTM-1 had correlation between the height and accuracy, as well as ASTER GDEM. In contrast, the errors in DEMNAS were relatively uniform in all range of elevation.

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Author contributions

Danang Budi Susetyo was responsible for data collection, data processing and analysis, and wrote the whole part of the article.

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