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Sensitivity Analysis of Digital Elevation Model in The Use of Hydrological Applications

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Abstrak

Menilai DEM merupakan langkah penting dalam penerapan hidrologi untuk mengurangi ketidakpastian. Penelitian ini mengkaji tingkat ketidakpastian penggunaan beberapa produk DEM dengan membandingkan derivasi informasi morfometrik DAS berupa batas hidrologi, jaringan aliran sungai, dan titik pertemuan antar jaringan sungai. Penelitian ini menilai tiga produk DEM yaitu SRTM, ASTER GDEM, dan NASADEM dengan peta topografi sebagai data acuan penilaian produk. Evaluasi didasarkan pada dua kriteria: penilaian produk DEM dan ekstraksi morfometri. Penilaian kriteria kedua membandingkan produk morfometri sungai dari beberapa parameter antara lain luas daerah aliran sungai, kepadatan jaringan sungai, dan pertemuan jaringan sungai. Hasil analisis menunjukkan bahwa pada kriteria pertama, produk NASADEM merupakan produk yang memiliki nilai RMSE dan PBIAS yang paling mendekati data acuan. Pengkajian lebih lanjut terhadap produk morfometri sungai menunjukkan bahwa parameter luas DAS ASTER GDEM mempunyai nilai luas terdekat. Pada parameter akurasi horizontal produk jaringan sungai, NASADEM mempunyai nilai rata-rata error terkecil. Selanjutnya dalam penilaian akurasi dalam menentukan pertemuan antara anak sungai dengan sungai utama serta kepadatan aliran sungai, SRTM paling mendekati dibandingkan produk DEM lainnya. Akurasi DEM vertikal dan horizontal harus dipertimbangkan sebelum digunakan dalam aplikasi hidrologi.

Kata Kunci: topografi, hidrologi, jaringan sungai, digital elevation model

Abstract

Assessing DEMs is a critical step in hydrological applications to reduce uncertainties. This study assesses the uncertainty level of using several DEM products by comparing the derivation of watershed morphometric information in the form of hydrological boundaries, river flow networks, and meeting points between river networks. This research assessed three DEM products, namely SRTM, ASTER GDEM, and NASADEM, with the topographic map as reference data for product assessment. The evaluation is based on two criteria: DEM product assessment and morphometric extraction. The second criterion assessment compared river morphometry products from several parameters, including watershed area, river network density, and river network meetings. The analysis results showed that in the first criterion, the NASADEM product was the product with the closest RMSE and PBIAS values to the reference data. Further assessment of river morphometry products shows that the ASTER GDEM watershed area parameter has the closest area value. In the horizontal accuracy parameter of river network products, NASADEM has the smallest average error value. Furthermore, in the accuracy assessment in determining the meeting between tributaries and the main river and the density of river flow, SRTM is the closest compared to other DEM products. The vertical and horizontal accuracy of DEM must be considered before using in hydrologic applications.

***Key words** : topography, hidrology, river network, digital elevation model*

INTRODUCTION

Digital Elevation Model (DEM) is a topographic representation of the earth's surface with a certain level of detail that can be decisive in deriving information on the hydrological boundaries of watersheds. DEMs are widely used as the primary data in hydrological applications such as forecasting and mapping potential flood distribution (Barnard, 2019; Bates et al., 2021; Sahid et al., 2018; Sarkar & Mondal, 2020; Xia, 2019). In addition, many researchers have also examined the impact of using DEM data with different types and resolution levels on the accuracy level in flood modelling applications (Chymyrov, 2021; Hawker, 2018; Muthusamy et al., 2021; Tran et al., 2023). The level of detail in topographic data is a crucial element in determining the accuracy of hydrological model applications (Casas et al., 2006; Dottori et al., 2013; Muthusamy et al., 2021). Furthermore, different types of DEM structures plays an essential role in determining the accuracy of flood inundation modelling results (Sahid et al., 2018).

The availability of DEM data that can be openly accessed up to medium and even high-resolution levels undeniably implies technological development. The ease of access is the impact of the rapid advancement of DEM data processing technology, which could only be produced by conducting field measurements and its prohibitive costs for large areas (Geymen, 2014). However, with remote sensing technology, both active and passive methods can produce DEMs (Geymen, 2014; Jia et al., 2021; Lillesand et al., 2004). Remote sensing techniques have the ability to derive DEM data by capturing elevation information of the earth's surface with photogrammetric, synthetic aperture radar (SAR), and laser altimetry (LiDAR) methods. Photogrammetric methods using very high-resolution image data and hyperspectral imagery are passive, while SAR and LiDAR use active methods (Jia et al., 2021). Rapid advances in remote sensing technology have made DEMs widely available (Deng et al., 2019; Ihsan & Sahid, 2021). The availability of widely accessible DEM data increases the use of hydrological applications, namely the derivation of watershed morphometric information such as determining area boundaries, characteristics, sub-catchments, stream networks, and river density. DEM is crucial data in hydrological modelling that can determine the characteristics of basins, sub-basins, and river networks (Hong et al., 2022; Tran et al., 2023). Technological advances that result in various satellite, aerial photography, and radar technologies to produce elevation data require knowledge of how these data are processed and used correctly to produce credible terrain analysis (Gonga-Saholiariliva et al., 2011).

The importance of topographic data used in hydrological applications is that it is necessary to identify the characteristics of the morphometric extraction and how much difference is generated from different DEM products. Hong et al.,(2022) Comparing the results of watershed hydrological boundary delineation from three different types of DEMs, namely HydroSHEDS, MERIT, and TanDEM-X, the results showed that there are differences in the shape and location of the delineated boundaries that cause uncertainty in the use of hydrological applications. The difference in shape and location resulting from delineating hydrological boundaries can cause uncertainty in calculating the water vloume within the watershed area. Forest land cover, terrain, and slope levels influence significant error rates in hydrologic boundary delineation using DEMs (Moges et al., 2023). Different DEM products can produce significantly different watershed characteristics, such as river networks and boundary delineations. However, higher DEM resolution has a positive impact on hydrological simulation results (Moges et al., 2023; Tran et al., 2023). The use of DEMs with different resolution levels will impact the level of uncertainty of the results obtained because the higher the resolution of DEMs generally has lower uncertainty (Purinton & Bookhagen, 2017). Other researchers mentioned that using ALOS, ASTER, and SRTM DEM data in areas with hilly conditions required increased DEM quality to produce appropriate watershed boundary delineations (Chymyrov, 2021). The importance of knowing how much the vertical accuracy of DEM used in hydrological application studies can minimize the uncertainty of the application results in hydrological studies. The existing conditions of the area with a high level of land cover, varying slopes, and the direction of the slope significantly affect the vertical accuracy of the DEM (Hawker et al., 2019; Uuemaa et al., 2020). Uuemaa et al., (2020), using DEM data ASTER, AW3D30, MERIT, TanDEM-X, SRTM, and NASADEM to test the accuracy of elevation values generated from the six data compared to LiDAR data, the results showed that slope, aspect, and land cover have a significant impact on the level of accuracy of the resulting elevation where areas with forest land use produce overestimated vertical accuracy. DEM data elevation values can lead to differences in watershed boundary delineation and characteristics because watershed boundary determination is described by delineating the highest points of ridge areas.

Assessment of DEM products prior to use is necessary to minimize the level of uncertainty that will result in the use of the data. Analysis to test DEM data sources is sometimes overlooked due to the many applications that provide convenience in water flow prediction, hydrological boundary creation, and hydrological modelling (Gonga-Saholiariliva et al., 2011). Sources of DEM uncertainty in hydrological applications are misuse of DEM data, use of algorithms in deriving topographic information, spatial resolution, interpolation methods, and modification of terrain surfaces to generate DEM (Wechsler, 2007). Other sources of uncertainty in hydrological applications include measurement errors, the level of detail in the representation of aboveground elements, and changes in the spatial resolution of the DEM (Abily et al., 2016). Knowing the factors that cause errors, the location of errors, and their magnitude can be the first step to minimizing errors in the use of data (Gonga-Saholiariliva et al., 2011).

This research focuses on the Cisanggarung watershed in West Java, Indonesia, the second largest watershed in West Java with high spatial dynamics of land cover change (Hidayat et al., 2022) also has complex topographical conditions with upstream rivers in Mount Ciremai and empties into the Java Sea. This study assesses the uncertainty level of using several DEM products by comparing the derivation of watershed morphometric information in the form of hydrological boundaries, river flow networks, and meeting points between river networks. The resulting benefits of this research can contribute to determining the type of DEM before it is utilized in hydrological applications such as flood modelling and water resource management.

RESEARCH METHOD

Study Area and Data

The research was conducted in the Cisanggarung watershed, which is geographically located between 6° 43' 43.66" LS to 7° 9' 53.35" LS and 108° 21' 59.64" East to 108° 53' 0.36" East with an area of 896.93 km2. The Cisanggarung watershed is the second largest watershed in West Java with a river length of approximately 1095.87 km, which has varied morphological complexity because the upstream of the Cisanggarung river is located in Mount Ciremai National Park with an altitude of 3078 meters above sea level. Regarding management, the Cisanggarung watershed is included in the Cimanuk-Cisanggarung river basin management. River basin management is a unit of water resources management area in one or more river basins and/or small islands with an area of ≤ 2,000 km^2.

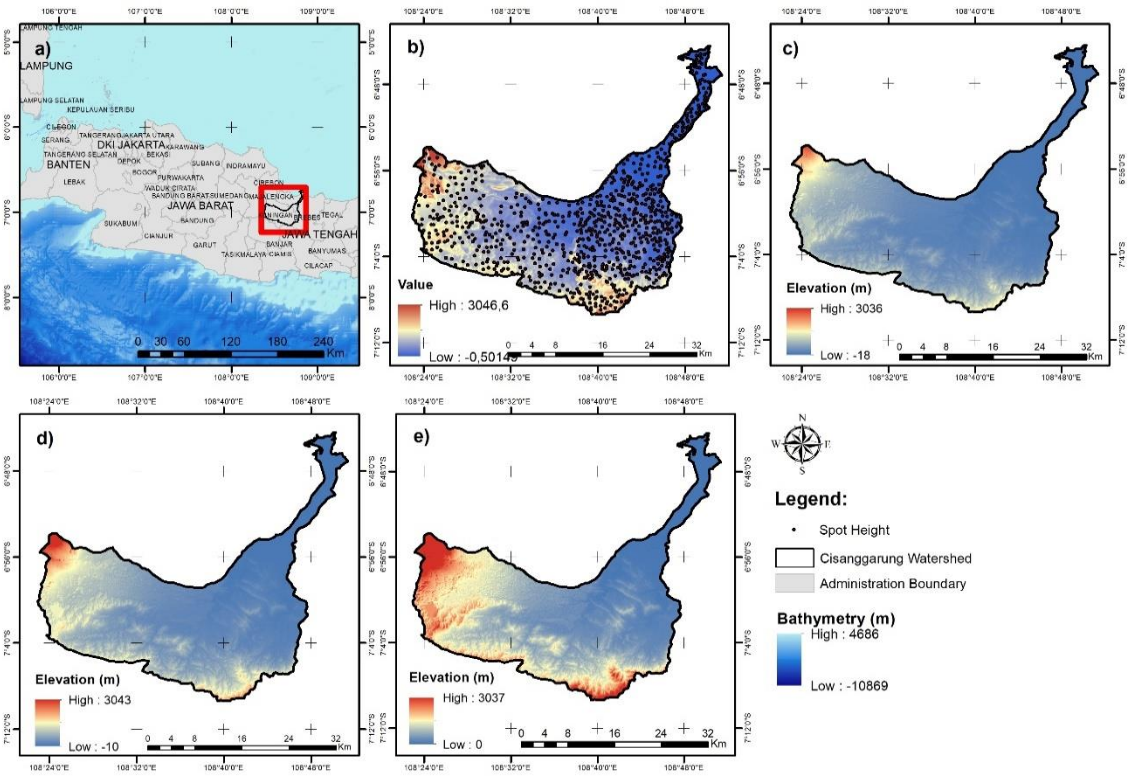

Figure 1. a) Area of interest (AOI) Cisanggarung River Basin, b) Spot height and DEM referenced based on topographic map, c) NASADEM Product, d) SRTM v.3 Product, e) ASTER GDEM v.3 Product

Administratively, the Cisanggarung watershed covers two provinces in Java, namely West Java Province, which includes Cirebon, Kuningan, and Majalengka regencies and Central Java Province, which includes Brebes Regency and Cilacap Regency, with a percentage of area of 96.57% and 3.43% respectively. The northern headwaters of this watershed are located in Cibuntu Village, Pasawahan Subdistrict, Kuningan

Regency, while the main river downstream is in Tawangsari Village, Losari Subdistrict, Cirebon Regency. The downstream area of the Cisanggarung watershed is prone to flood hazards because every year, the downstream area always experiences flood disasters (Muin & Nandiasa, 2019). A major flood disaster in 2017 caused large economic losses and affected victims (Sjarief & Lasminto, 2020). In addition, in 2018 a flood disaster event with a peak discharge of 924 m3/s occurred in the downstream part of the Cisanggarung watershed flooded Ciledug District, Cirebon Regency (Nurdiyanto, 2019).

SRTM Data

The Shuttle Radar Topographic Mission (SRTM) is a cooperative project of several institutions from three countries, namely the United States (NASA & NIMA), Germany (DLR), and Italy (ASI), collaborated to produce DEM data from the earth's surface with a coverage of 600 LU to 560 LS within the spatial reference 90 m and 30 m (Farr & Kobrick, 2000). SRTM product was generated by acquiring two synthetic aperture radars aboard the Space Shuttle Endeavor (Uuemaa et al., 2020). SRTM data is recorded from an orbital altitude of 233 km using two types of SAR, namely the C radar operating at C-Band with a wavelength of 5.6 cm with NASA as the responsible party and the X radar operating at X-Band with a wavelength of 3.1 cm with DLR as the responsible party (Farr et al., 2007). The SRTM product used in this study is SRTM v.3, having a spatial resolution of 30 m developed based on C-band radar interferometry. SRTM DEM data products are currently widely used for various fields of science, such as spatial planning, geology, and archaeology, including hydrology (Chen et al., 2018; Julzarika & Djurdjani, 2019). The SRTM V.3 DEM can be accessible on the page http://earthexplorer.usgs.gov/.

ASTER GDEM Data

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), launched in December 1999, is an instrument on the Terra satellite that has 14 bands and consists of three types of spectra, namely visible and near-infrared (VNIR) with a spatial resolution of 15 m, short wave infrared (SWIR) with a spatial resolution of 30 m, and thermal infrared with 90 m spatial resolution (Abrams et al., 2002). One of the products of ASTER is ASTER GDEM. ASTER GDEM is a global DEM database released in 2009 by the Ministry of Economy Trade and Industry of Japan (METI) and NASA with data coverage of 99% of the earth's surface ranging from 830 LU to 830 LS with the area of each scene is 60 km x 60 km with a spatial resolution of 30m (Jin et al., 2020; Ramsey & Flynn, 2020). ASTER GDEM is created by combining all scenes of existing DEM data, both cloud-masked and non-cloud-masked data, and then applying several algorithms to remove abnormal data (Abrams & Crippen, 2019). Studies related to the use of ASTER GDEM for hydrological studies have been carried out by several researchers, including (Jamal & Ali, 2023) who conducted a comparative study of drainage network extraction using ASTER GDEM, SRTM DEM, and Cartosat-1 DEM in India, Sutisna & Putro, (2019) conducted an accuracy study of ASTER GDEM and SRTM for modelling the Ciliwung watershed, and Arifian et al., (2023) who conducted a comparative study of ASTER GDEM and SRTM for watershed modelling and geomorphological studies. ASTER GDEM data can be obtained for free on NASA's page, namely https://search.earthdata.nasa.gov/search/ or the Japan Space Systems page https://gdemdl.aster.jspacesystems.or.jp. There are three types of ASTER GDEM data versions, namely version 1, version 2, and version 3, published in 2009, 2011, and 2019, respectively (Abrams et al., 2020). In this research, the ASTER GDEM version used is version 3.

NASADEM Data

The NASADEM officially released to the public in February 2020 is the result of reprocessing and development of SRTM data and other DEM data, such as ASTER, ICESat, and GLAS purposed to eliminate voids and some other limitations of SRTM data (Crippen et al., 2016). As the successor of SRTM data, the data quality of NASADEM is considered better than SRTM and is the best performing open-access DEM data compared to other DEM data (Uuemaa et al., 2020). NASADEM has a spatial resolution of 30 m with the same coverage as SRTM, which is between 600 LU and 560 LS (NASADEM_HGT V001, n.d.). Research related to the application of NASADEM has not been carried out much, generally, NASADEM data research is carried out on accuracy testing such as that conducted by (Bhardwaj, 2021; Tran et al., 2023; Uuemaa et al., 2020). One of the studies related to the application of NASADEM data in other fields besides accuracy testing was conducted by (Gesch, 2018) which uses NASADEM as one of several DEM data used in assessing the phenomenon of sea level rise and coastal flood disasters. NASADEM products can be downloaded for free at the link https://search.earthdata.nasa.gov/search?q=nasadem.

Table 1. Summary of the seventh DEM Product used in the study

DEM Product	Spatial Resolution (m)	Provider	Method	Release Date	Source
SRTM v.3	30	NASA & NIMA, DLR, ASI	SAR	2000	earthdata.nasa.gov
ASTER GDEM v.3	30	METI dan NASA	SAR	2019	earthdata.nasa.gov
NASADEM	30	NASA JPL	Reprocessing	2020	earthdata.nasa.gov

Accuracy Assessment

Vertical accuracy is done to test the accuracy of each DEM product, namely SRTM, ASTER GDEM, and NASADEM. Each DEM product is evaluated for its height value by comparing the height value at each location with more accurate high point data, namely spotheight sourced from topographic maps with a scale of 1:25,000 issued by the Geospatial Information Agency (BIG). BIG is the geospatial information agency that released Indonesia's geospatial information database nationally. The reference high point data has a vertical accuracy of approximately half of the contour interval (Specifications for Presenting Maps - Part 2: Scale 1:25,000, 2010) which means that the vertical accuracy of the reference data used is about 6.25 m. Vertical accuracy was tested using Root Mean Square Error (RMSE), Mean Absolute Error (MAE), and Percent Bias (PBIAS) statistics. The three types of tests are used to measure the average error of the elevation (z) information extracted from the DEM product, the smaller the assessing results, the better the estimated value. In the assessment, each height value from the DEM product will be extracted on the spotheight using ArcGIS software which will then be compared with the reference high point value data. Vertical accuracy is compared in the study, catchment area, drainage density, and outlet channel.

Stream and Cathmen Boundary

The pre-processing stage is essential before DEM data is used to derive river network data and its hydrological boundaries. The use of DEM data before surface modification in hydrological analysis will cause interference because DEM grid data has a depression or sink or pit that can result in discontinuous flow which assumes that there is no outflow network in cells that experience depression. Depression or commonly known as sink can disrupt surface flow because depression occurs when there is a sell surrounded by sell with high elevation values or two cells that flow together result in rotating flow so that there is no outlet for the flow (Moges et al., 2023; Wechsler, 2007). The pre-processing stage is vital before DEM data is used to derive river network data and its hydrological boundaries. The use of DEM data before surface modification in hydrological analysis will cause interference because DEM grid data has a depression or sink or pit that can result in discontinuous flow which assumes that there is no outflow network in cells that experience depression. Depression usually known as sink, can disrupt surface flow because depression occurs when there is a sell surrounded by sell with high elevation values or two cells that flow together, resulting in a rotating flow so that there is no outlet for the flow Jenson & Domingue, (1988) which is to reference the flow direction according to the 8 directions, after getting the flow direction for each sell. To get the flow accumulation of each raster cell, it is processed using the flow accumulation tool to get the flow accumulation of each raster cell free from depression. The hydrological boundaries of the watershed are obtained using the watershed tool. This tool determines the outlet (pour point), at which point it will calculate the accumulated flow that leads to the specified outlet. Determination of the outlet in each DEM dataset is done by looking at the flow point from the results of flow accumulation from each dataset. All data processing in this stage uses ArcGIS software with hydrology tools in spatial analysis.

Drainage Density

Drainage density or stream density (D_d) is the ratio value between the length of the river and the watershed area, is one of the components widely used in identifying watershed characteristics and can be used as an assessment aspect in comparing DEM data products (Sukiyah et al., 2018; Tran et al., 2023). In this research, the D_d value will be used as one of the assessment components in comparing several DEM data. The D_d value can be calculated using the following equation introduced by Horton, (1932)

$$D_d = \frac{\sum L}{A_{basin}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (1)$$

Where D_d is the flow density expressed in km/km^2, then ∑L is the total length of the river in Watershed A expressed in km, and Abasin is the area of Watershed A expressed in km^2.

RESULT AND DISCUSSION

DEM Quality Assessment

The quality of the DEM dataset is assessed by evaluating the DEM elevation value with reference elevation point data with a more detailed and reliable level of accuracy. Evaluation of the quality of DEM elevation values in this study was carried out by pixel to point analysis, namely by extracting the elevation value of each DEM at the location of the reference elevation point and then comparing the elevation value of each DEM with a reference elevation point of 1738 points sourced from a topographic map of scale 1 : 25,000 to get the RMSE and Percent Bias (PBIAS) values (Figure 1). The results of the vertical accuracy assessment show that the three DEM datasets SRTM, ASTER, and NASADEM produce RMSE values of 14.87 m, 18.14 m, and 14.4 m respectively. The RMSE value of NASADEM shows a smaller number compared to other DEM data, so this product has a better level of vertical accuracy. In addition, the percent bias evaluation (PBIAS) results of each DEM dataset show that NASDEM has the smallest value of 0.6% compared to the DEM dataset (Table 2). Consistent with what was done by Tran et al., (2023) and Uuemaa et al., (2020) SRTM and NASADEM DEM data have a better level of accuracy when compared to ASTER GDEM v.3 data. The poor accuracy of the ASTER GDEM product is due to artifacts and local inaccuracies caused by the stereopair merging process of optical imagery and cloud-dominated conditions (Tan et al., 2018). The maximum elevation value characteristics of the three DEM datasets were also assessed (Figure 1). The results of comparing the maximum elevation value of each DEM product namely SRTM, ASTER, NASADEM have values of 3.6 m, 9.6 m, and 10.6 m. The comparison of maximum elevation values shows that SRTM Product is the DEM data closest to the maximum elevation value of reference data with a difference level of 0.12%. Regarding maximum elevation values ASTER and NASADEM have a greater difference in elevation values of 9.6 m and 10.6 m with a percentage difference of 0.32% and 0.35%.

Table 2. Comparison of DEM product accuracy vertical results

DEM Product	RMSE (m)	MAE (m)	PBIAS (%)
SRTM	14.87	6.64	0.8
ASTER	18.14	10.03	-1.7
NASADEM	**14.4**	**6.24**	**0.6**

Further detailed assessment, namely a comparison of the distribution of elevation values on flat, undulating, hilly, and very steep slope classes, was carried out to determine the quality of the distribution of elevation values of DEM products on each slope class. The comparison with reference data showed that all DEM products, SRTM, ASTER, and NASADEM, underestimated elevation values (below the reference) on all slope classes (Table 3). The results show that the elevation values produced by DEM SRTM, ASTER, and NASADEM products are lower than the reference elevation values. The largest percentage of elevation difference is the distribution of elevation values in the hilly slope class, which is from 10% - 30% slope (Figure 2). A higher difference in value when compared to the reference elevation value of DEM SRTM and NASADEM products have almost the same percentage number, in contrast to ASTER products which have a greater percentage value.

Table 3. Product DEM Comparison basen on slope classification

DEM Product	Differences	Flat (m) (0 - 5%)	Wavy (m) (5 - 10%)	Hilly (m) (10 - 30%)	Very Steep (m) (> 30%)
SRTM	Above	31.55	19.74	17.32	22.22
	Same	0.00	0.00	0.00	0.00
	Below	68.44	80.25	82.68	77.77
ASTER	Above	24.84	17.07	15.93	21.46
	Same	0.00	0.00	0.00	0.00
	Below	75.15	82.92	84.07	78.53
NASADEM	Above	31.10	18.74	17.04	22.27
	Same	0.00	0.00	0.00	0.00
	Below	68.90	81.25	82.95	77.73

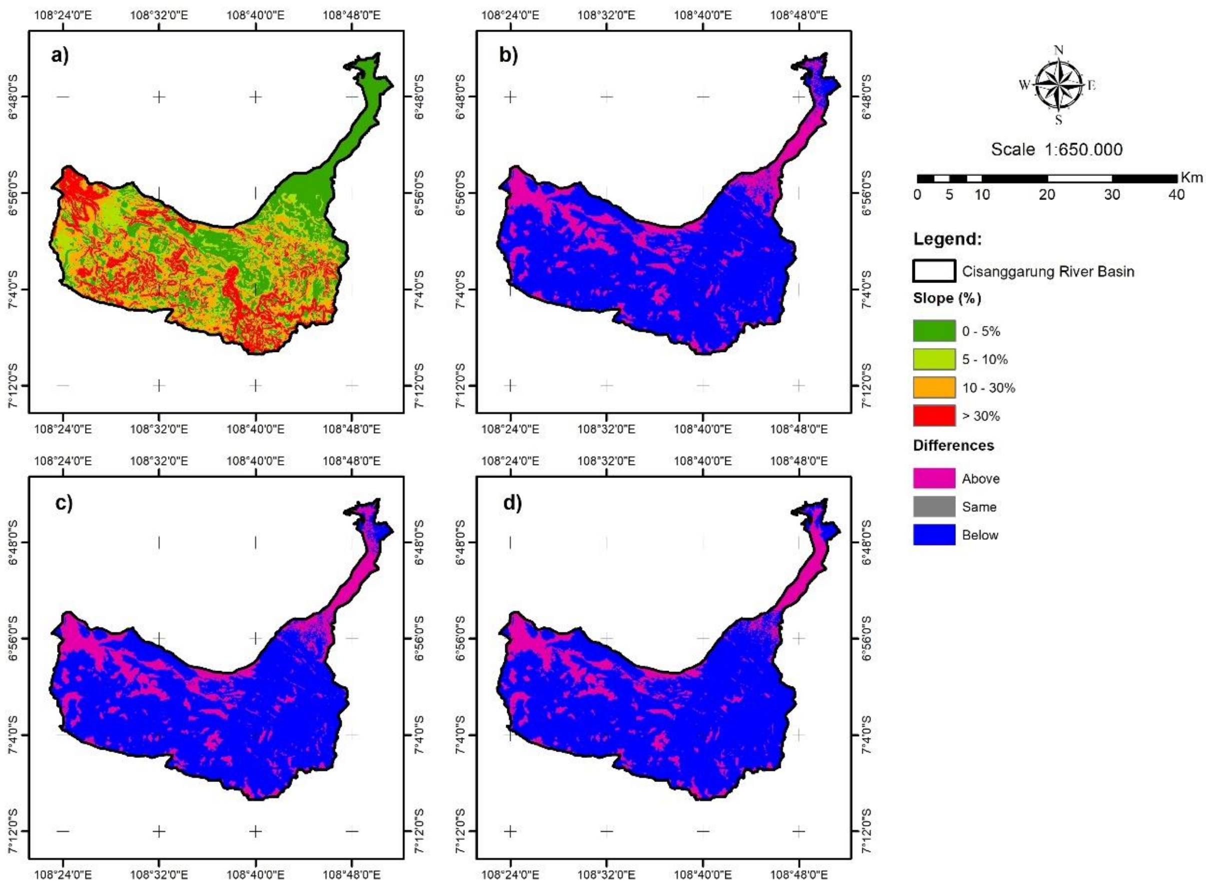

Figure 2. Image a) shows slope information based on the referenced DEM, image b), c), and d) depict surface differences among DEM's data product NASADEM, SRTM v.3, and ASTER GDEM v.3 respectively comparing to the DEM References based on topographic map

Vertical evaluation of the accuracy of the elevation values of the DEM products was carried out on two categories of areas, namely low-lying areas with an elevation of about 0-450 meters above sea level (low-land topographic) and highland areas with an elevation of more than 450 meters above sea level (high-land topographic) (Tran et al., 2023). The statistical analysis results show that the three DEM products have smaller PBIAS values in the highland area. The DEM product that has the smallest bias value is NASADEM. In line with this, the RMSE value of this product is smaller when compared to other DEM products (Table 4). Based on the evaluation of elevation values compared to the 1:25,000 scale topographic map data of the Cisanggarung watershed area, the NASADEM DEM product has a better level of accuracy than the SRTM and ASTER DEM products.

Table 4. Statistical analysis DEM Products in low land and high land

DEM Product	Low-land region (0-450 msl)				High-land region (>450 msl)			
	RMSE (m)	MAE (m)	MSE (m)	PBIAS (%)	RMSE (m)	MAE (m)	MSE (m)	PBIAS (%)
SRTM	7.58	6.11	57.5	1.5	29.56	9.09	873.9	0.1
ASTER	12.09	9.11	146.27	-3.6	32.25	14.53	1039.86	-0.5
NASADEM	7.29	5.8	53.11	1.1	28.69	8.9	823.1	0

River Basin and Stream Networking

The spatial resolution size of the DEM product will significantly affect the quality of the extraction results of the hydrological boundary of a catchment area. The analysis of the reduction of catchment hydrological boundaries conducted from three DEM products, namely SRTM, ASTER, and NASADEM, shows that the three DEM products failed to reduce the hydrological boundaries in the low land area (Figure 3). The SRTM and NASADEM products in the low land area class failed to delimit the catchment area to the southeast of the Cisanggarung River Watershed. In contrast, the ASTER product could delimit the area almost in accordance with the reference data. In contrast, to the north the SRTM and NASADEM products can delimit the hydrological boundary almost following the position of the reference data, while the ASTER product deviates in delimiting it. Then in the area towards the final outlet that leads to the estuary, all DEM products failed to limit the hydrological boundary compared to the reference data hydrological boundary. Based on these conditions, the SRTM, ASTER, and NASADEM concerning the extraction of basin boundaries in areas with low land area topographic classes are less representative of field hydrological boundaries. On the contrary, in areas with high land area topography classes, all DEM products have hydrological boundaries almost similar to the reference data. These results are the same as those expressed by Tran et al., (2023) mentioned that many studies have shown that extracting hydrological boundaries especially in low land areas using DEM is problematic. The inability of DEM products to extract hydrological boundary information is related to the failure of DEM to estimate flow direction in low land areas Tran et al., (2023) due to the greater error value in the topography class. Of course, the difference in the results of delineation of hydrological boundaries has an impact on the difference in shape and area which contributes to the uncertainty in the use of hydrological applications. The difference in shape which will undoubtedly have a different area can cause rainfall calculations. The use of different DEM data will have an impact on differences in the shape and area of hydrological boundaries (Hong et al., 2022). The level of difference in the NASADEM product area has a smaller percentage value when compared to other DEM products at 24.35%, which is almost the same as the SRTM product at 26.09%. While for the ASTER product the resulting hydrological boundary area is greater than the reference data area (Table 5).

Table 5. Comparison among catchment area pada tiga produk DEM

No	DEM Products	Catchment Area (km^2)	Area Differences (km^2)	Differences (%)
1	SRTM	662.88	234.05	26.09
2	ASTER	1073.65	-176.72	-19.70
3	NASADEM	678.53	218.4	24.35
4	Topographic map*	896.93		

The extraction of the river network from the DEM products of SRTM, ASTER, and NASADEM was then carried out to assess the uncertainty of the location and the meeting point between the main river and its tributaries (Figure 4). The assessment was conducted to see the level of horizontal accuracy of the extracted river compared to the reference data of the river network sourced from topographic maps with a scale of 1: 25.000. The horizontal accuracy level of the river network reference data has an accuracy level of 0.3 mm (Specifications for Presenting Maps - Part 2: Scale 1:25,000, 2010). The results of the comparison of the closest distance to assess the horizontal accuracy between the confluence point of the river (outlet) and the main river extracted from each DEM product indicate that the NASADEM product has an average horizontal error of 199.12 m, then the SRTM product of 377.55 m, and the ASTER product of 450.16 m. Furthermore, the assessment of the accuracy of the confluence point between the main river and its tributaries was carried out by calculating the number of reference points (outlets) of 18 points with the accuracy of DEM products in extracting the confluence between the main river and its tributaries. The comparison results show that the SRTM product has a greater accuracy of extracting the confluence between the main river and its tributaries compared to other products, which is about 27.78% with an average horizontal distance error of 106.91 m. The NASADEM and ASTER DEM products have the same accuracy of extracting the confluence between the main river and its tributaries, which is 22.22% with an average horizontal distance error of 88.42 m and 95.57 m, respectively. The large level of uncertainty in the horizontal distance between DEM products and reference data will significantly impact the level of accuracy in the use of hydrological applications, especially in mapping the potential hazards of flood inundation distribution. Then, DEM data must be assessed not only for vertical accuracy but also for horizontal errors.

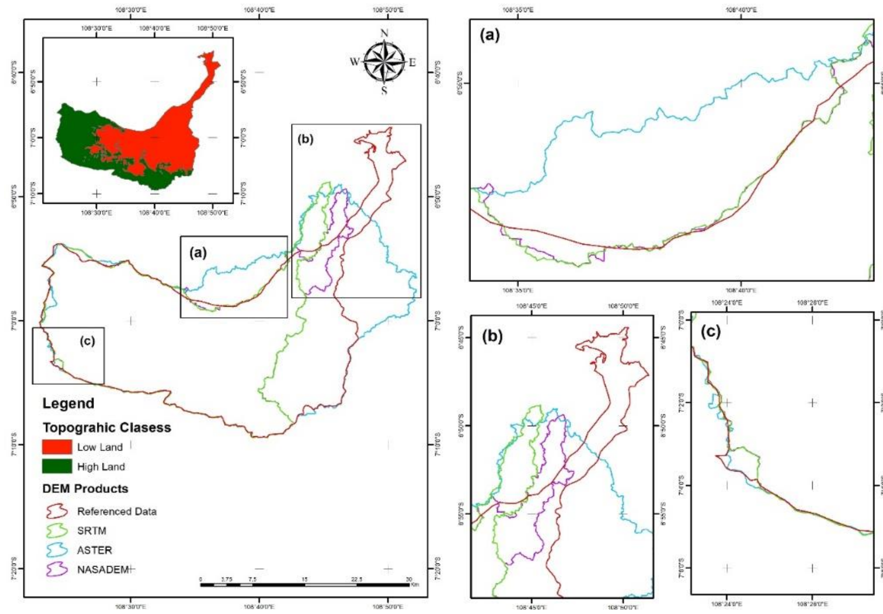

Figure 3. Extraction of different watershed, (a) and (b) low land regions, (c) high land regions

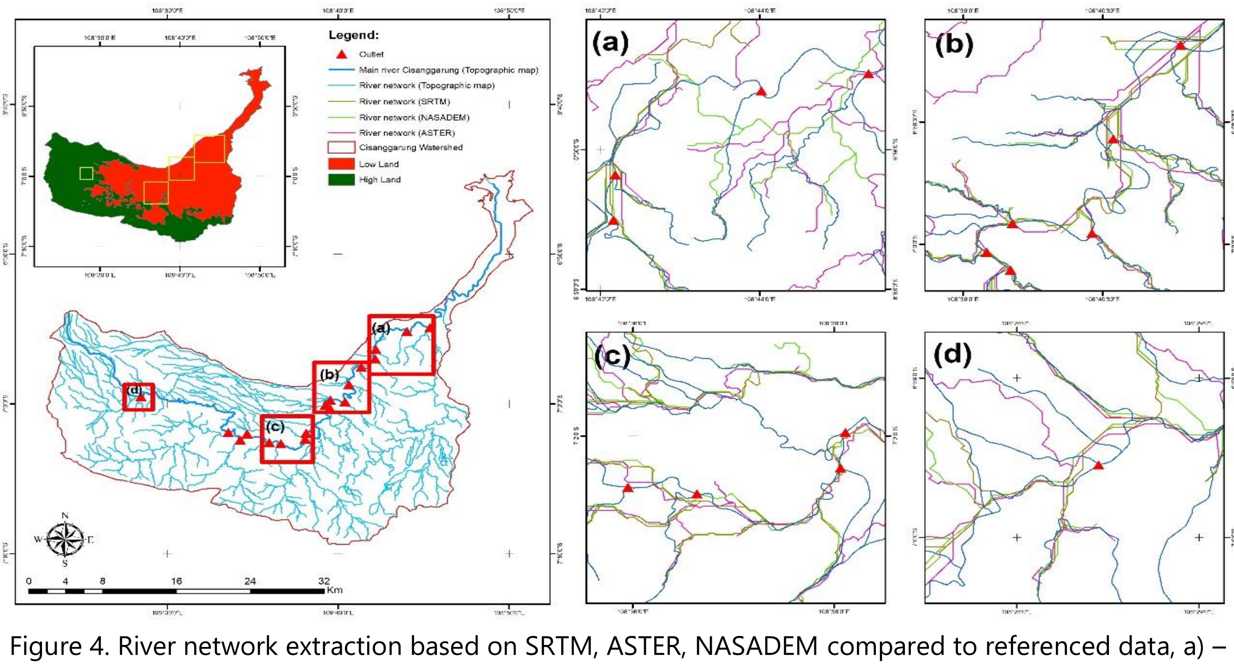

Figure 4. River network extraction based on SRTM, ASTER, NASADEM compared to referenced data, a) – c) located in low land regions, d) high land areas.

Drainage Dentisy

River density is an index that can be used to identify the character of a river basin because the density index value will affect the size of the input of river flow from a catchment (Gregory & Walling, 1968). The denser the river network, the more inputs flow into the main river. Furthermore, the value of river density is a key component in the assessment of flood hazard and risk (Echogdali et al., 2018; Pallard et al., 2009; Waseem et al., 2023) and landslides (Nurdin & Kubota, 2018). As is known, flash floods can occur in rivers that have the potential for landslides as a result of landslide material covering the river flow which then breaks down or is carried directly by the flow of water (Chauhan et al., 2022; Ha et al., 2022). River density values from these three DEM products were generated and then analyzed from the same process and procedure to reduce errors due to differences in the methods used. The threshold value used to extract rivers from the flow accumulation DEM value is 1000, assuming that this value is sufficient to represent river networks that are not too small.

Table 6. Comparison among River Length, Watershed Area, and River Density in three DEM products

No	DEM Products	Total Panjang Sungai (km)	Length (%)	Drainage Density (km/km^2)	Drainage Density (%)
1	SRTM	582.7	46.83	0.879	28.07
2	ASTER	941.92	14.05	0.877	28.23
3	NASADEM	584.58	46.66	0.862	29.46
4	Topographic map*	1095.87		1.222	

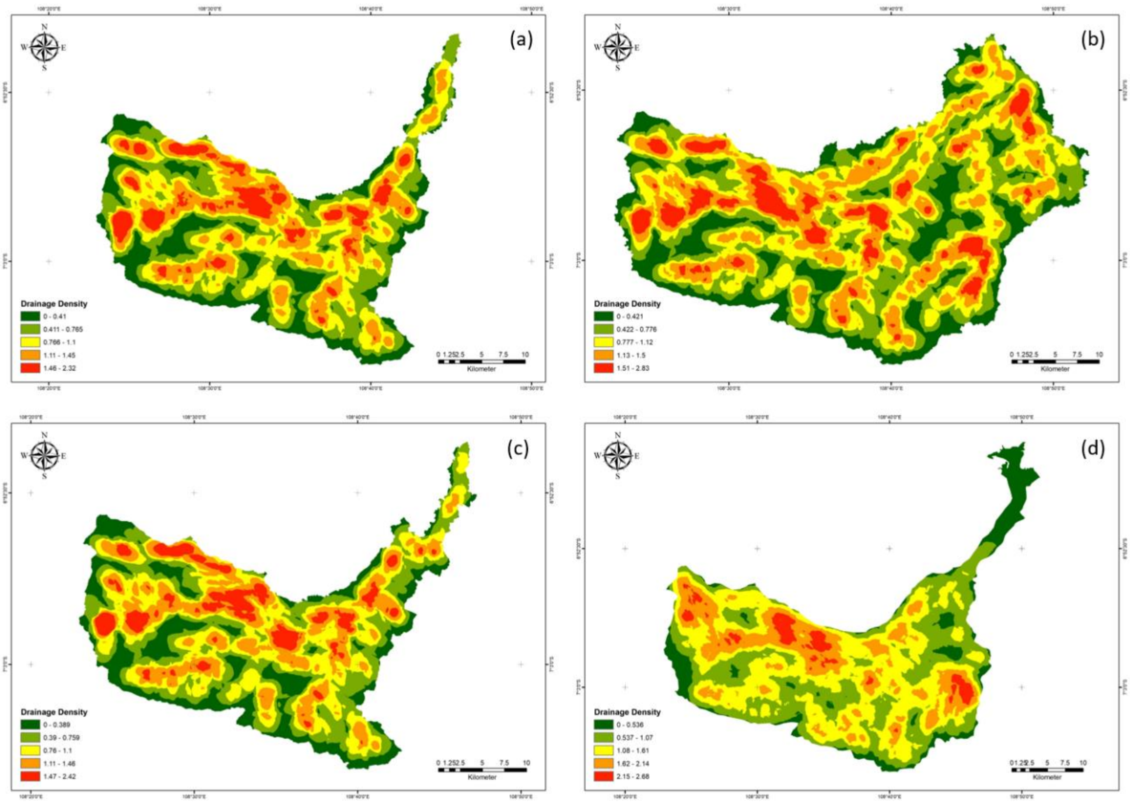

Figure 5. Comparison of River Density Distribution of Three DEM Products (a) SRTM, (b) ASTER, (c) NASADEM, and (d) RBI. The highest density value is marked in red and the lowest is marked in green

The river density of each DEM product has a difference where the slightest difference compared to the reference data is 28.07% which is the SRTM DEM product. ASTER and NASADEM DEM products have different values of river flow density when compared to SRTM products. The difference in the value of flow density can be seen in the shape of the watershed generated from each DEM product (Figure 5). Based on the classification of density values used by (Chandrashekar et al., 2015; Ferozur Rahaman, 2017; Sukristiyanti et al., 2018). River density values are divided into five classes in km/km^2 including very coarse (<2), coarse (2-4), medium (4-6), good (6-8), and very good (>8). Density value ranging from 0.86 - 0.87, the overall river density value of the three products is included in the very coarse category. The lower density value of a river area indicates a high level of permeability and infiltration. Otherwise, the higher river density indicates the area is in an impermeable area, sparse vegetation, or hills (Choudhari et al., 2018). The difference shows that in using DEM data in hydrological studies, it is necessary to consider in advance the level of difference in river flow density generated from the DEM data used. Figure 4 shows the distribution of river flow density from each product where the density generally occurs in the upper reaches of the river area. The identification of flow density can be used as an initial indication to identify the level of vulnerability to flood or landslide disasters in the observed area (Budiarti et al., 2017; Suriadi et al., 2014).

CONCLUSION

The assessment was conducted to obtain quality information from three DEM data types: SRTM, ASTER GDEM, and NASADEM for hydrologic application. The assessment parameters were carried out on several two aspects. The first aspect is an initial assessment of the quality of DEM data by comparing the vertical accuracy and distribution of elevation values on the slope of the three DEM data against topographic reference data. The next aspect is assessing watershed extraction regarding the three DEM products compared to the topographic reference. The assessment of watershed products is carried out on several parameters, namely the watershed's shape, the river network's horizontal accuracy based on the meeting point of tributaries with the main river, and the river density. The results of the analysis show that in the assessment of vertical accuracy values and the value of height distribution on the slope of the three DEM data, NASADEM data has the closest value to the reference topographic data shown by the results of RMSE and PBIAS values better than SRTM and ASTER GDEM. Furthermore, the assessment is carried out on the product in the form of river morphometry, where the assessment is carried out on the watershed area, the horizontal accuracy of the river network, the meeting point of tributaries with the main river and the value of river density. Depending on the shape and the size of the watershed extraction, ASTER GDEM products are slightly better than SRTM and NASADEM products with an area difference of -19.7%, which means that the watershed area produced from ASTER GDEM data is 19% larger than the reference watershed area. Horizontal accuracy assessment shows that NASADEM data is better than SRTM and ASTER GDEM with an average error of 199.12 m against the topographic reference product. For the product assessment of the confluence point of tributaries with the main river, SRTM data has greater accuracy than NASADEM and ASTER GDEM. In the river density value, SRTM data has the closest value to the reference topography with a percentage difference of 28.08%.

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