An investigation of Digital Elevation Model (DEM) structure influence on flood modelling

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Abstract. Flood is one of the natural calamities that cause huge losses and damages. Flood hazard zonation has been widely produced to face the impact of the disaster. DEM as the primary data to construct the earth surface has been developed from rough to fine resolution. Aster GDEM v.2 within 1arc spatial resolution has an ability to derived DEM and TIN data as bases river geometrics data. Maximum daily peak discharges used to calculate flood peak discharge. Furthermore, steady flow analysis has been used to produce flood inundation model based on four scenarios with return periods 5yr, 10yr, 50yr, and 100yr. The model results have been validated using UAV flood map in 2016 by means of pixel by pixel operation and the result shows that the vertical variance between grid DEM and TIN data about 0.3 m.

1. Introduction
Flood is one of the most disaster commonly ensued in a year as well as damaged catastrophe [19]. Generally it is not only influence on human life but also economics [30]. Anthropogenic activities and climate change are common factors that bring about flood event, namely agricultural activities, land-use change, extreme rainfall which result in reducing river capacity to receive the discharge in when the intense rainfall happen [9] [14].

In addition, the reason Cimanuk River upper part was flooded in September 2016 can be indirectly explained by extreme rain fall that struck seven districts in Garut along Cimanuk River. Approximately 6.361 people were injured and homeless, 33 died, 20 individuals went missing, and 1766 houses broke because of the flood disaster [3]. Flood-prone zone mapping based on return period or probability is important to reduce flood impacts. Flood modelling has been used by many researchers to examine the flood event in order to face its negative impacts [27] [31] [36].

Recently, HEC-RAS provided from U.S. Army Corps of Engineers (USACE) has become popular analysing and routing flood modelling. It is a freeware software that can be downloading freely from USACE site and it has helped to create flood mapping [16]. Moreover, HEC-RAS as a hydrologic analysis and GIS within HEC-GeoRAS as software to derive river profile can be combined to visualize 2D of the flood inundated area. The combination of HEC-RAS and HEC-GeoRAS can be accurate to visualize the flood extent and it can widely simulate flood disaster [11] [24].

On the other hand, in order to gain reliable hydrologic model, it needs more data, for instance, hydrologic data, DEM, land-use (LU), soil, river bathymetry [12]. Nowadays, only a few data can be accessed freely, for example, the DEM data with high resolution may not accessible for everyone also the data is restricted. On the contrary, the level precise topographic data as an input data for terrain models is a key element of the accuracy of hydraulic flood modelling [5]. Consequently, many researchers have developed DEM as an alternative data to obtain reliable flood modelling. This
research attempts to compare two different basis data (DEM) between regular Grid DEM and TIN data derived from ASTER GDEM V2. The value between structure Grid DEM and TIN are different, even though used in similar region. Grid DEM data is suitable of plain area and TIN for rough area along man-made object [37] [38]. What of those data that can correctly result in flood inundation model. Simulation of inundation or extent area will use HEC-RAS and GIS based on the return period of the flood. Models validation use flood event in 2016. The operations processed pixel by pixel and using raster calculator in ArcGIS. The purposes of this paper are to identify the bias vertical of the ASTER GDEM v.2, construct river geometries, identify appropriate ASTER GDEM v.2 to build flood modelling, develop reliable flood inundation model both from Grid DEM and TIN data.

2. The Methods and Data

2.1. Geographic setting
Cimanuk river is the main river in Cimanuk Watershed which has total drainage approximately 3.636 km$^2$ [25]. The upper part of this river from Mt. Papandayan (±1805m above sea level) to flow through to the lower part of the river in Indramayu Regency. The main river has distance about 337.67 km [32] [33]. Lying on administrative boundaries, Cimanuk Watershed is included in 4 regencies which are Garut Regency, Sumedang Regency, Majalengka Regency, and Indramayu Regency.

![Figure 1](image.png)

**Figure 1.** Map A the location of the Cimanuk Watershed in West Java Province. Image B shows the location of the research area around the upper part of the Cimanuk River. Map C illustrate the position of the research area.

The upper part of the Cimanuk River was chosen for this study which has distance around 25.5 km (figure1). Geographically, the upper part of Cimanuk Watershed is located among 107º 49’ 57,74”E –
107° 57′ 47,77”E and 7° 8′ 20,43”S – 7° 17′ 37,58”S. Administratively, the site area is located in Garut Regency contained by 6 districts, consists of Bayongbong, Tarogong Kidul, Cilawu, Garut Kota, Banyuresmi, and Karangpawitan from the upper to lower part respectively. The average annual rainfall is about 4000mm and maximum peak discharge is approximately 1222 m³/s over 10 years from 2007-2016. Similarly, the highest maximum discharge that has ever recorded was 1470 m³/s in 1978 [1]. The complexity of the hydrological condition at the upper part of the catchment is influenced by various land-use (LU) changes. As many researchers believe that the changing of the LU function have significant contribution of the runoff pattern [18] [21] [35].

2.2. Data and Analysis

2.2.1. ASTER GDEM v.2 characteristics. The advanced space-borne thermal emission and reflection radiometer global digital elevation model (ASTER GDEM) v.2 released on 17 October 2011 was freely downloaded from USGS (www.earthexplorer.usgs.gov). It is developed by Joining space program between NASA and the Ministry of Economy, Trade, and Industry (METI) of Japan [17] [29]. This version has an improvement from previous ASTER GDEM v1 launched onboard NASA’s Terra spacecraft in December 1999 [2] in which several benefits from the inclusion of additional scenes to reduce artifacts, higher horizontal resolution using a smaller correlation kernel (5 x 5 versus 9 x 9 used for GDEM 1.0). In line with this, the data are delivered in tiles of 1° by 1° referenced to the WGS84 ellipsoid and EGM96 geoid. An improved water mask can be more accurate to define the water surface. Furthermore, a 5-m overall bias observed in GDEM 1.0 was removed in the newer version [22]. It provides the first complete land surface model over the whole globe [17].

2.2.2. Regular grid DEM and TIN data. Digital Elevation Model (DEM) is a 3D digital representation of terrain surface which has an ability to represent the topographic features such as river system [8] [34]. A DEM has important role to modulating the Earth surface that can be represented as a raster (grid) or a vector-based like Triangular Irregular Network (TIN) [6]. Both of them are the most important shape to represent the landscape which has own characteristics and different usages [34]. The benefit of the regular Grid-based model are to minimize data storage and also due to simplicity of the data structure [37]. The data is efficient to represent terrain form with small slope variability. However, Triangulated Irregular Network (TIN) is a vector based which commonly used to represent any continuous and complex terrain [26]. Consequently, the data storage is much larger and more complex than more complex than a grid-based structure. Therefore, an efficient solution for terrain representation can be achieved by applying a TIN-based model to represent rough areas and man-made objects and a Grid-based model to represent relatively plain areas [37]. In this research, we used both regular grid DEM and TIN data that derived from ASTER GDEMv2 which have 1arc (30m) spatial resolution.
2.2.3. Bias vertical accuracy assessment. Prior to build the geometric data, height information needs to be validated, as DEM from imagery satellite catches the canopy height of the forest or tree rather than record bare earth elevation [10]. The topographic map with scale 1:25,000 within vertical accuracy about 6.25 m released by Geospatial Information Agency (BIG) has been applied as a referenced map. The datum is based on local sea water level in Tanjung Priok with horizontal accuracy approximately 0.3 mm and National Geodetic datum 1995 (DGN-95) or similarly with the WGS-84 (BSN, 2010). The height's information is calculated in metric format, thus transformation of the datum to metric coordinate (UTM) has been operated by means of project transformation in ArcGIS. In addition, the referenced map should has higher accuracy than the calculated map [6]. Hence, the assumption of the research is the topographic map more accurate. Root mean square error (RMSE) has been calculated to get the vertical bias correction in each (200) random point around the study area.

\[
RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (H_{DEMi} - H_{refi})^2}
\]

Where RMSE = root mean square error, \( H_{DEMi} \) = DEM elevation at the point i, \( H_{refi} \) = reference elevation at the point i, and N = the number of ground check points.

2.2.4. Hydrological analysis. The calculation of flood frequency has been computed based on daily maximum peak discharges from Cibatu station which is collected from BBWS Cimanuk-Cisanggarung. The Cibatu station was chosen to get maximum daily discharge due to the location within the outlet and the availability of the data around 10 years from 2007-2016. Statistically, log normal distribution has been selected due to the fit result of the reoccurrence statistic computation compared with other distributions method. The four scenarios return periods 5yr, 10yr, 50yr and 100yr were used to produce the flood’s peak discharge as an input data to simulate flood modelling. Landuse types are also obtained from BBWS Cimanuk-Cisanggarung which will be used as input data to get the value of manning’s coefficient by performing hydraulic modelling. Manning coefficient is important data to get the friction value when the water flows through to downstream area [15].

2.2.5. Hydraulic Analysis. The combination of GIS application ArcGIS v.10.4, HEC-GeoRAS v. 10.4 and hydraulic application HEC-RAS v.5.0.3 have capability to perform the 2D flood modelling [23]. Both HEC-RAS and HEC-GeoRAS are freely available software which can be downloaded from US Army Corps of Engineers-Hydrologic Engineering Center (http://www.hec.usace.army.mil). HEC-GeoRAS is a GIS tool to create river geometries and attributing them as an input data [20]. Either TIN or Grid DEM data is used as a terrain basis data to digitize the river center line, banks, flow direction, and the start and end stations of a river reach [10]. The 2D steady flow analysis has been applied to produce inundated area in which this model is applicable to accomplish in the flat region [7]. The main data to process the simulation are (1) flood peak discharges from 4 return periods and (2) DEM data to derive the river geometries. The derivative of river geometric from both DEM requires ArcGIS and HEC-GeoRAS which is utilized to create RAS theme in HEC-RAS, namely stream center line, main channel bank, flow path center line, and cross-sectional (Cutline). Moreover, the validation process has been computed by comparing the

Figure 2. Image a and a2 are a simple representation of grid DEM that comprises a rectangular shape. The image b and b2 are representation of an irregular DEM. Image b2 depicts simple form of TIN data.
model results with UAV flood hazard map on 23 September 2016 Garut whom published by BNPB 2016 (http://geospasial.bnpb.go.id).

| Land-use types | Manning Values |
|----------------|---------------|
| Cultivated Crops | 0.035 |
| Developed, High Intensity | 0.15 |
| Mix Garden/Pasture/Hay | 0.1 |
| Open Space | 0.04 |
| Open Water | 0.04 |
| Pasture/Hay | 0.1 |
| Shrub/Scrub | 0.1 |

3. Results and Discussions

3.1. River Geometry
Different types of DEMs obtained from ASTER GDEM v.2 have been utilized to construct a river geometric data. Although Grid DEM originally acquired from the USGS data, TIN data was constructed by means of 3D analyst in ArcGIS v. 10.4. The flood inundation model was performed using river geometrics data from both DEMs, namely river center line, cross section, bank, and flow path. In case constructing of the data, an assessment of the vertical accuracy has done to reduce elevation error value (figure.3).

The assessment of vertical accuracy has been calculated from 200 random points distributed around the research area by using map algebra prior to use the origin data. The results show that total RMSE is 9.09 m (table 2). Although the calculation result is higher than total bias of [6] assessment, the RMSE is close in [28] study. Both of them work out to assess the vertical accuracy from ASTER GDEM v.2 and the conclusion show ±7.97 m and ±9.27 m respectively. The factors that influence of the different elevation are depend on surface variability and geographic location [6] [28]. In addition, this research also assessing the height accuracy based on the land-use types and the study shows that the higher bias vertical is 10.9 m located in open space area and the lower value is 6.5 m in developed area (table 3). Another factor that might render the variety are resolution and level accuracy of the referenced map. In tandem with this, the forest area is ignored because there is no forest area in research location.
Figure 3. Vertical Bias Correction Map of referenced DEM and ASTER GDEM v.2. The red colours in the map show that elevation from referenced DEM higher than ASTER GDEM v.2. On the contrary, green colours depict elevation value from referenced DEM lower than other.

Table 2. Basic statistics calculation from comparing of grid and TIN with referenced DEM.

| Statistics          | Grid DEM Value (m) | TIN Value (m) |
|---------------------|--------------------|---------------|
| Maximum (m)         | 41.47              | 7.99          |
| Minimum (m)         | -31.80             | -9.27         |
| Mean (m)            | 3.67               | -0.15         |
| Standard Deviation (m) | 8.32              | 3.10          |
| RMSE (m)            | 9.09               | 3.10          |

Moreover, the corrected DEM which has original form as a Grid DEM has been applied to construct a TIN data. A transformation needed to gain TIN data by using 3D analyst in ArcGIS. Aforementioned, the Grid DEM has rectangular shapes, on the other hand TIN data is the vector base developed from triangular shapes. As mentioned before that transforming the Grid DEM to TIN data needs recalculation of the vertical value. Clearly shows in table 2 that data transformation has reduce the RMSE about ±6 m comparing to the referenced map. In other word, it means that reconstruction Grid DEM becoming TIN data has changed the vertical value.
Table 3. Vertical bias correction based on the land-cover types.

| Land-use Types                | RMSE (m) |
|------------------------------|----------|
| Cultivated Crops             | 6.9      |
| Developed, High Intensity    | 6.5      |
| Mix Garden/Pasture/Hay       | 7.8      |
| Open Space                   | 10.9     |
| Pasture/Hay                  | 7.9      |
| Shrub/Scrub                  | 8.9      |

In addition, the river’s geometries have been collected after the assessment of the vertical value, for instance cross sections, banks and flow paths. They have been manually digitized by means of HEC-GeoRAS v.10.4 software. Besides then, the river centerline has been performed using spatial analyst in GIS to get the precious location of the center stream. At least 209 cross sections have been built manually from the each DEM data in the same location (figure 4.). Although automatically cross section built is available, it require fine DEM’s resolution to apply this function due to the limitation of the software. A DEM within spatial resolution near 30 m is not adequately distributed well all the river when creating automatically cross section. Sometimes the elevation of the banks is higher than the streamline [10]. The lack detail of the cross section have been built to simulate the flood inundation model. Selecting cross sections before performing the model needed because sometimes meeting point of the bank information is settled in right location (figure 5).

![Figure 4](image)

Figure 4. Examples of the cross sections’ profile graphs derived from the ASTER GDEM v.2 from upper (a) to downstream (i) respectively.

3.2. Flood inundation model
Underlying on the daily maximum peak discharges over 10 years starting from 2007-2016, these data have been used to calculate the flood frequency in Cimanuk River. As mentioned before, the log normal distribution has been selected due to the fit statistical analysis using chi-square. It shows that the calculation value of the statistical analysis less than basic chi-square table, namely 12 and 14.067 respectively. Thus the log normal analysis can be performed to analyse the flood frequency analysis. Furthermore, the calculation of the 4 return periods shows that flood peak discharges for 5yr, 10yr,
50yr and 100yr return periods are 152.18 m³/s, 207.40 m³/s, 463.44 m³/s and 619.06 m³/s respectively. Likewise, the cross sections have been evaluated since the results of the simulation over the cross areas.

Figure 5. Two examples of the hydraulic simulation from two kind DEM as the input data. Figure left shows the simulation with Grid DEM while figure right depicts the output proceeding with TIN data at the same cross-section.

Moreover, a steady flow simulation using HEC-RAS v. 5 has been utilized in order to get inundated area. The simulation has been performed based on both of grid DEM and TIN data. The results show that the total area of the flood inundation from both DEM have difference. For example, in the 5 return period calculated within input data as the Grid DEM and TIN data is about 461.17 ha and 445.76 ha subsequently. To sum up, the total calculation shows that there are different area approximately 15.41 ha or equal to 154.100 m² when the flood inundation model perform both of DEMs. The total flooded area from Grid DEM tend to higher than TIN. All of the calculation of the return periods shows in table 3. As mention before that there are about 3.10 m the elevation difference between both DEM. As a consequence, the depth flood from both DEM also has difference. It is ± 0.4 m the deep variance.

| Data                                      | Return Period |
|--------------------------------------------|---------------|
| Flood Extend                               | 5yr           | 10yr          | 50yr          | 100yr         |
| Grid DEM-Extend Flood Inundation (ha)      | 461.17        | 470.64        | 547.63        | 570.34        |
| TIN Data-Extend Flood Inundation (ha)      | 445.76        | 467.01        | 532.04        | 564.79        |
| Total Area Differences (ha)               | 15.41          | 3.63            | 15.59          | 5.55          |
| Total Area Differences (%)                | 3.34            | 0.77            | 2.85            | 0.97          |
| Flood Depth                               |               |                |                |               |
| RMSE Flood Depth (m)                      | 0.38           | 0.58           | 0.38           | 0.38          |
| Mean flood depth differences (m)          | 0.43           |                |                |               |

In addition, the UAV flood hazard map Garut on 23 September 2016 has been used to validate the flood modelling. It has been utilized due to the minimum information of all regions about the flood map. The validation has been calculated by means of map algebra analysis with comparing the results of the modelling with the original flood extent. It is compared to examine the total pixel of the model within the total pixel from referenced flood map. Moreover, we have chose the 5yr return period to validate the result because of the extent of the flood area similar to the UAV map. Both of the flood extents from return period based on Grid and TIN data has been evaluated. The results show that the total area of the grid DEM and TIN data within referenced map about 60% and 57.5% respectively. Approximately the Grid DEM data has 3.2% higher value included in the referenced map than TIN.
Figure 6. Flood Inundation Model Map, image A1, A2, A3 and A4 are the flood inundation underlying from the simulation for 10yr, 50yr and 100yr by using Grid DEM. On the contrary, image B1, B2, B3 and B4 the result of the flood area for each return periods (10yr, 50yr and 100yr) by using TIN data.

4. Conclusions
Flood inundation modeling likely should be possible to develop based on ASTER GDEM v.2. Since several processing should be done to cope with the roughness of the resolution. Assessing of vertical accuracy should be performed before extract the height information. Based on the referenced DEM from topographic map with scale 1:25,000, approximately 9.09 m the RMSE value. In case of the assessment of the vertical accuracy, the referenced data should be more accurate than others in order to get the closest value (bare earth). In addition, ASTER GDEM v.2 also can be used to derive the river geometries data after the bias correction has been analyzed. In case, this is the finest resolution that can be freely downloaded for everyone. Constructing the river geometries data namely streamline, bank, cross section, and flow path should be produced by means of the DEM with collaboration HEC-GeoRAS and ArcGIS. Evaluating and rechecking the river geometries after the flood simulation needs owing to the miss widely of the cross sections also banks location. Transforming Grid DEM into TIN data might be changed of the vertical elevation about 3.10 m (RMSE) in case of the ASTER GDEM v.2.
Underlying from the flood simulation results. Transforming the data from Grid DEM to TIN should influence the total flood area as well as depth of the water surface. Moreover, the total covering areas from Grid DEM tend to higher than flood covering area from the TIN data. Hence, it is wise to choose what types of the DEM data and also evaluate the vertical accuracy when converting Grid DEM into TIN data. Moreover, the flood frequency analysis is useful to develop flood hazard zonation.

5. Acknowledgments
Authors express their sincere gratitude to USGS and BIG for making this work possible by processing and distributing free the DEMs as well as topographic data to the scientific community. Also, the authors would like to thank three anonymous reviewers for their helpful comments. The authors are grateful to the supervisors, also to BBWS Cimanuk-Cisanggarung, and PSDA West Java.

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