The effects of DEM specification on watershed model in Mataram City, West Nusa Tenggara Province

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Abstract. One of data resources for hydrologic modelling is Digital Elevation Model (DEM). In hydrologic modelling, watershed delineation is an important step to create boundary of inundation area, so that DEM plays a significant role in watershed model. Nowadays, there are many sources of DEM data available in Indonesia that was provided by Geospatial Information Agency (BIG), including LiDAR and DEMNAS (National DEM). Based on its resolution, DEMNAS is classified as data for medium scale mapping, while LiDAR is used for large scale mapping. For hydrological modelling, medium scale data has been widely applied, while the large-scale hydrological modelling is still limited. The availability of large-scale data is quite large, including the City of Mataram, is a good source to examine its effect for hydrological modelling, so this research is conducted to see the effects of DEM sources, namely LiDAR and DEMNAS, for watershed model generation. Analysis is conducted by comparison to existing official watershed in that area. From seven watersheds, LiDAR produce better geometry in four areas, while DEMNAS is better in the rest. This research is expected to support a policy relating hydrological modelling at large scale.

1. Introduction

A watershed is a land area that is an integral part of a river and its tributaries, which functions to accommodate, store and flow water that comes from rainfall to lakes or to the sea naturally, the boundary on land is a topographic separator and boundaries in the sea to waters that are still affected by land activities (Act No. 37 of 2012 concerning Watershed Management). Watershed planning and management requires knowledge of the physical characteristics of the watershed, which are parameters related to morphometric, topographic, soil, geological, vegetation, land use, hydrological and human conditions. These physical characteristics of the watershed can be a reference in managing watersheds effectively and efficiently, to minimize the occurrence of natural disasters such as landslides, flash floods and geological disasters.

Delineation of watershed boundaries with the manual method using hardcopy topographic maps takes a long time and is subjective. Now, watershed extraction is faster with the availability of DEM data and having the accuracy level higher than the DEM generated from the topographic map [1]. Digital Elevation Model (DEM) data is digital data that describes the geometry of the shape of the earth's surface or parts consisting of a set of coordinate points from the results of sampling. Some of the advantages of DEM are to form terrain such as watersheds, streams, slopes, valleys, and valleys for landforms.

Some studies that use DEM SRTM to delineate watershed boundaries like [2] identified watershed forms and [3] analyzed the physical characteristics of watersheds. [4] delineated several sub-watersheds based on topographic and DEM data for the Selorejo reservoir. Other research showed that resolution of the DEM effected to hydrology application. If using higher resolution DEM can derive more accurate river networks, but highest resolution data may not necessarily offer the best results, depending on the
resolutions selected to compare the extracted networks [5]. Research of [6] used LiDAR to extract hydrology model show that higher DEM grid resolution can produce a more accurate representation of terrain characteristics, this variation does not necessarily improve watershed scale modelling.

[7] delineated the watershed using SRTM DEM (90 m), ASTER DEM (30 m), and LDD DEM (5 m) showed that the size and shape of the watershed obtained were only slightly different. This shows that users of the water resource model must use the ASTER DEM as opposed to a better DEM resolution for the model input to save time for calibration and model validation.

The purpose of this study is to (1) extraction of DEM data to delineate watershed boundaries in the City of Mataram and (2) determine the accuracy of the extraction results from two DEM data.

2. Method
The various methods used in this research, comprises five stages: fill, flow direction creation, watershed through basin generation, watershed delineation, and feature similarity-based accuracy measures (Figure 1). More specifically, each stage is described below.
2.1. Fill
The methods have been selected for the processing of DEM data, representing several main methodologies to address the comparison of DEM results. The first is the DEM correction in the particular Fill technique. As a consequence of underestimating the elevation at certain points, pits and depressions are regarded to be incorrect in the Fill technique. Depressions are filled, increasing the elevation number until it reaches the value of the neighbour cell [8], [9]. When the correction occurs in single cells, the effect does not affect the algorithm of the direction of flow; however, the greater the number of continuously affected cells, it affects the result of the assignment of the direction of flow.

All depressions are considered to be spurious points, leading from elevation underestimation or overestimation. This includes two options: the occurrence of sinks at certain points by underestimating elevation, or the existence of closed depressions produced by a false wall (peak) to overestimate height in some cells [8]. There are flagged points where the assignment of the flow direction is not feasible and at least one neighboring cell has higher elevation. This step allows the separation of inflow sinks and flat area, also consequent infringement of plane fields. At each sink, the respective contributing area is
determined. A sink is a cell with an undefined direction of drainage; there are no lower cells around it. The pour point is the lowest elevation border cell for a sink’s contributing area. This is the point where water would pour out if the sink were filled with water. Related to the DEM value, the z-limit specifies the maximum allowable difference between the sink depth and the pour point and determines which sinks are to be filled and which are to remain untouched [8], [10].

The fill technique can be used to remove peaks. A peak is a cell with no greater neighboring cells. Specify the highest value of the cell as the first input to minus and related cell value as the second input. In the Fill performs (Figure 2), invert the results to obtain a surface that has original cell values with the peaks removed. It is also possible to apply the z-limit to this method. If the z-limit is not indicated, all peaks will be removed. If it is specified, that peak will not be removed if the difference in z-value between a peak and its adjacent neighbor is greater than the z-limit [9].

![Figure 2. Illustrations of lateral profile of Fill application](image)

2.2. Flow Direction Initiation
The capacity to determine the direction of flow from each cell in the raster is one of the keys to deriving hydrological features of a surface and it may be crucial to know the direction of flow along stream networks. A key stage in characterizing terrain patterns using DEM is to determine the flow direction for each pixel of a DEM. This is performed by the method of the Flow Direction [9], [11], [12]. In this research, the method used is commonly referred to as an eight-direction (D8) flow model and follows an approach presented in Jenson and Domingue (J&D method) [12]. This method of deriving value from a DEM is to obtain an accurate representation of flow direction across a surface, and the sinks should be filled before using a flow direction raster. This method described the deterministic of eight-neighbours method (D8) and pointed out differences among depressions and flat areas that were fully accommodated by ArcGIS, in particular Hydrology toolset.

This method requires a surface as an input and produces a raster displaying each cell's direction of flow. If the Output drop raster option is selected, an output raster is developed, displaying a percentage of each cell's highest elevation shift along the flow direction of the trajectory length between cell centers and expressed in percentages [12], [13]. If the Force is selected to flow all edge cells outward an option, all cells at the surface raster edge will flow outward from the surface raster. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. The direction of flow is determined by the direction of steepest descent, or maximum drop, from each cell. This technique has a rule to specify which direction water will flow from a cell. The concept illustrated as follow (Figure 3).
The distance between cell centers is calculated. Therefore, if the cell size is 1, the distance between two orthogonal cells is one, and the gap between two diagonal cells is 1.414 (the square root of 2). If the maximum descent to several cells is the same, until the steepest descent is found, the neighborhood will be enlarged. The output cell is coded with the value representing that direction when a steepest descent direction is discovered. If all neighbors are greater than the processing cell, they will be regarded noise, filled to the lowest value of its neighbors, and have a direction of flow toward that cell. However, if a one-cell sink is adjacent to the raster's physical edge or has at least one neighboring No Data cell, it is not filled because of inadequate neighbor data. All neighboring data must be present in order to be deemed a real one-cell sink. If two cells flow into each other, they are sinking and have an undefined flow direction. For example: It has a value of 1 when water flows in the east direction. It has a value of 16 when water flows to the west. Use the eight-direction pour point model to describe all 8 neighboring directions at a specified stage. The resulting values range from 1, 2, 4, 8, 16, 32, 64 and 128 when operating the flow direction algorithm. You can comprehend which flow direction water travels in the eight-way pour-point model diagram.

2.3. Watershed Through the Basin Generation
A basin is an area that drains into a prevalent outlet water and other substances. Watershed, basin, catchment, or contributing region are other popular terms for a drainage basin. This area is usually described as the complete region that flows to or pours at a specified outlet. The point at which water flows out of a region is a pouring point. Usually this is the smallest point along the drainage basin border. The border between two basins is called a dividing or watershed border of drainage. By defining ridge lines between basins, the drainage basins are delineated within the analysis process. To locate all set of stream networks that belong to the same drainage basin, the input stream direction raster is evaluated. The drainage basins are developed by placing the pour-points at the corners of the assessment window (where water would flow out of the raster), as well as sinks, then identifying the area of each pour point. In this study, by calculating the flow direction and using it in the Hydrology (Arc-Hydro) Tool [14], [15], a basin can be delineated from a DEM. A raster representing the direction of flow must first be developed with the initiation phase of the Flow Direction to provide the area used to determine the catchment area in order to determine the contributing region. Source data may include features such as stream networks that determine the contributing area's characteristics.

The extensive application of DEM data has enhanced the creation of automated instruments that can be used to delineate drainage basins and their related stream networks. The traditional manual delineation technique of the basin begins by digitizing the point of pouring. The snap pour point tool is used to ensure that the digitized points are dragged to the point of highest accumulated flow. In this step the basin tool is used, which requires the input of flow direction (raster layer) and pour point (vector or raster layer). As in the extraction of a stream network, it is important not to use the simplification option while converting the raster map to vector features. Otherwise, the delineated stream network and basins will not match exactly, which is a prerequisite for the following steps to automate counting and join the drainage network [15].

![Figure 3. Flow Direction concept - eight direction model (D8) diagram](image)
Delineation of a watershed entails determining the boundary of the watershed, i.e., the ridgeline. The ridgeline joins the highest points of elevation and thus becomes the watershed boundary. Fixing the drainage course outlet is the most significant element for identifying and delineating a watershed. Basically, the outlet location describes the watershed area. The watershed delineation can be performed manually based on contour lines of topographic maps or as a watershed map derivation. By comparing the results of the automated generation with the watershed map visually, the accuracy of each result is identified.

On the last step, the results of watershed delineation are used to compare to the official watershed map. The similarity assessment of each result was applied to the step of analysis. To perform the assessment, the reference data map is needed, it used the official watershed data as reference data. The official watershed from Indonesian Ministry of Environment and Forestry (KLHK) is used as reference data to assess the automated generation watershed from this research. It is used to generalize certain basins to be one watershed based on their shape similarity.

2.4. Feature Similarity-Based Accuracy Measures
This accuracy assessment method is adapted from [16], to assess the similarity between extracted data and reference data. As mentioned in previous stage, official watershed from Indonesian Ministry of Environment and Forestry (KLHK) is used as reference data. [16] consider the intersection between extracted and reference data to calculate similarity between those objects, defines an improved matching similarity as follows:

$$S_O = \frac{f_A(C \cap R)}{f_A(C \cap R) + \alpha f_A(C - R) + \beta f_A(R - C)}$$  (1)

Where

- $f_A(C \cap R)$ = features of the intersection area of C and R
- $f_A(C - R)$ = features of the area of R to erase the evaluated object C
- $f_A(R - C)$ = the features of the area of the evaluated object C to erase reference object R
- $\alpha$ and $\beta$ = weights

From equation above, extracted watershed is represented in C while official watershed is symbolized as R. By calculating both intersection and non-intersection area, feature similarity in each watershed can be defined.

3. Results and Discussion
There are seven watersheds in research area based on watershed at medium scale watershed map released by Ministry of Environment and Forestry: Kali Mangkung/Dodokan, Kokok Ancar, Kokok Babak, Kokok Batulayar, Kokok Jangkok, Kokok Meninting, and Teloke. This official watershed is used as a reference to delineate watershed from basins. Then, feature similarity-based accuracy assessment is conducted to measure the similarity between extracted watershed and official watershed.

3.1. Feature Similarity-Based Accuracy Result
The feature similarity-based accuracy result for each watershed with LiDAR and DEMNAS data in the research area are as follows:

| No. | Watershed                | Feature Similarity |
|-----|--------------------------|--------------------|
|     |                          | LiDAR              | DEMNAS             |
| 1.  | Kali Mangkung/Dodokan    | 0.866441561        | 0.879288752        |
| 2.  | Kokok Ancar              | 0.777839171        | 0.485359922        |
| 3.  | Kokok Babak              | 0.8433816          | 0.695931032        |
In general, based on Table 1, there is no significant difference between watershed created from LiDAR and DEMNAS. LiDAR produce better watershed in four areas: Kokok Ancar, Kokok Babak, Kokok Jangkok, and Kokok Meninting, while DEMNAS is better in Kali Mangkung/Dodokan, Kokok Batulayar, and Teloke. The most significant gap between those data is in Kokok Batulayar, in which DEMNAS is far better than LiDAR. Meanwhile, in Kokok Ancar, Kokok Babak, and Kokok Jangkok, LiDAR has better accuracy than DEMNAS by about 20-30 percent. The rest of area are only separated by small numbers, no more than 10 percent difference. It indicates that though LiDAR has better resolution and accuracy than DEMNAS, it doesn’t affect the quality of extracted watershed.

3.2. Visual Analysis

Visual analysis is conducted by analysing shape difference between official watershed (in figures below are represented as yellow line), LiDAR (red line), and DEMNAS (blue line). Analysis is based on topographic pattern from DEM and stream network that automatically extracted from flow direction.

3.2.1. Kali Mangkung/Dodokan

Compared to other watersheds, Kali Mangkung/Dodokan watershed produce the most similar shape between LiDAR and DEMNAS. The pattern also similar with official watershed, in which it can be seen in Figure 4 and from Table 1, where the accuracy of both are only separated by no more than 2%.

![Figure 4](image_url)

Figure 4. Comparison of pattern of official watershed, LiDAR and DEMNAS of Kali Mangkung

3.2.2. Kokok Ancar

LiDAR produces much better similarity to official watershed than DEMNAS in Kokok Ancar. Figure 5 shows the pattern of watershed from LiDAR is close to official watershed. Otherwise, watershed from DEMNAS has contrast pattern, with its direction is tend to the south.
This area has flat topography, so it is difficult to decide which one is better if it is analysed from topographic features. So, in this area, analysis based on extracted stream is conducted. Figure 6 shows the difference between extracted stream from LiDAR (pink) and DEMNAS (cyan). Generally, the pattern of both lines is identical, but the difference inside the line circle makes the significant difference in the extracted watershed area. In that circle it can be seen that the stream network from DEMNAS has been changed compared to LiDAR. Circle number 1 is obviously explain that the stream network is different, in which stream network from LiDAR has more outlet than DEMNAS in that area. In circle number 2, stream from DEMNAS change its network to LiDAR’s streamline below. Meanwhile, on circle number 3, it seems that while LiDAR’s stream network still continue, DEMNAS’s stream network has finished and connected from another network.

This difference could be because DEMNAS didn’t use stream network and breakline to create its DTM, and only used mass points [17]. This method may cause the stream pattern has changed, so the algorithm read different flow direction in DTM from DEMNAS. On the other hand, DTM from LiDAR has created by considering stream network by creating the stream from photogrammetry technique. Due to this reason, it is concluded that there is error for watershed extraction from DEMNAS in this area.

3.2.3. Kokok Babak
Kokok Babak watershed is located between Kali Mangkung/Dodokan and Kokok Ancar watershed, so the analysis is same with both watersheds. In general, the pattern of three watersheds in this area is same, though the segment on the border with Kokok Ancar watershed has quite large deviation as explained before (Figure 7).
Figure 7. Comparison of pattern of official watershed, LiDAR and DEMNAS of Kokok Babak

3.2.4. Kokok Batulayar
Table 1 provides information that Kokok Batulayar watershed extracted from LiDAR has poor accuracy because this watershed only took small part in this research area and located on the corner, so the small difference may cause big difference on the percentage. As can be seen in Figure 8, LiDAR pick different breakline compared to official watershed and DEMNAS.

Figure 8. Comparison of pattern of official watershed, LiDAR and DEMNAS of Kokok Batulayar

Watershed should pick the highest breakline as its boundary, so to decide which one is better, we can see from the height of the breaklines. Figure 9 shows that breakline that picked by LiDAR is about 40 meters lower than breakline of DEMNAS and official watershed. So, it is obvious that watershed from DEMNAS is more appropriate in this area and proved that though LiDAR has better resolution and accuracy, it may cause a mistake in watershed delineation.
Figure 9. The height of the breaklines from LiDAR, DEMNAS and official watershed

3.2.5. Kokok Jangkok
In the west side, LiDAR tends to similar with official watershed, while boundary line from DEMNAS has direction to the north (Figure 10). It is because the difference of extracted stream, in which near the outlet DEMNAS has more branch towards north direction (Figure 11, inside red circle). If it is compared to streamline from topographic map at 1:5,000 map scale (Figure 12), that branch is not considered as a main stream, so in this case it can be concluded that LiDAR produce better accuracy for stream extraction in that area.

Figure 10. Comparison of pattern of official watershed, LiDAR and DEMNAS of Kokok Jangkok

Figure 11. Comparison of stream extraction from LiDAR and DEMNAS
Meanwhile, in the west side, LiDAR and DEMNAS produce similar pattern except in the end of the boundary (Figure 13). Otherwise, official watershed has different direction from the middle. In this mountainous area, each breakline has almost same heights (Figure 14), so it is difficult to choose which boundary is better without considering the streamline. Also, watershed boundary from LiDAR choose breakline outside research area, so it cannot be decided the better accuracy for those watersheds in this area.

Figure 12. Stream from topographic map

Figure 13. Comparison of pattern of official watershed, LiDAR and DEMNAS
3.2.6. Kokok Meninting

As can be seen in Figure 15, in the north side, LiDAR and DEMNAS are delineated in different breakline, and official watershed choose same breakline as LiDAR. However, those breaklines actually have similar height as can be seen in Figure 16. That’s why the only factor that can decide why the watershed are generated like that is the stream extracted from DEMs. Figure 17 shows the differences between streamline from topographic map at 1:5,000 scale and extracted stream from LiDAR and DEMNAS. As can be seen, LiDAR shows better similarity to topographic map.
3.3. Teloke
Teloke watershed is located between Kokok Batulayar and Kokok Meninting watershed, so the explanation about its boundary is covered in those watersheds.

4. Conclusion
The purpose of this study is to determine the accuracy of the extraction results from two DEM data. The various methods used in this research, comprises five stages: fill, flow direction creation, watershed through basin generation, watershed delineation, and feature similarity-based accuracy measures. In general, there is no significant difference between watershed created from LiDAR and DEMNAS. LiDAR produce better watershed in four areas: Kokok Ancar, Kokok Babak, Kokok Jangkok, and Kokok Meninting, while DEMNAS is better in Kali Mangkung/Dodokan, Kokok Batulayar, and Teloke. This research is expected to support a policy relating hydrological modelling at large scale.

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