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Line generalization evaluation on contour map generated from SRTM and ASTER GDEM

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Abstract

A contour map is one of many layers that composed Informasi Geospasial Dasar (IGD), which according to Act. No 4 2011 serves as a reference for any thematic map. The provision of contour map at a different level of scale is needed since mapping activities will always refer to map scale based on the mapping area. This research aims to analyze automated contour generation quality to produce 1:50.000 contour map, by means of using open access Digital Elevation Model (DEM) data, such as Shuttle Radar Topographic Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM).

The automated contour generation was done by using contour interpolation in Quantum GIS software. Furthermore, simplification and smoothing algorithm was applied to both data, in order to improve their visual appearance. In this case, there are four algorithms used in the study, namely Douglas-Peucker, Visvalingam, Chaikin, and McMaster. Quality assessment, both qualitative and quantitative assessment, was done to each derived contour map to ensure the applicability of the procedure.

The result shows that contour map generated from SRTM has a better quality than contour map generated from ASTER GDEM. Nevertheless, both data has a similar pattern on each topographical classes, which tends to produce bad quality contour line in the flat area. The more mountainous the area, the better the contour line. Meanwhile, of all generalization algorithm applied in this study, Chaikin's algorithm is the best algorithm in terms of smoothing the contour line and improving visual quality, but still doesn't significantly improved the metric accuracy. The contour line can be either directly added to the Digital Cartographic Model of Topographic Map (Rupabumi Map), or used as compliance data in a thematic map.

Keywords: Contour map, SRTM, ASTER GDEM, Automated extraction, generalization algorithm.

1. Introduction

The abundance of remote sensing data has opened many opportunities for its applications in many fields. Various sensors and platforms have been developed to suit the needs of diverse applications. Some of the remote sensing products even distributed as open access data, which will increase the opportunity to widespread usage. The open access data were provided by several web portals, such as Global Visualization, Earth Explorer, Ersdac, and Cgiar-csi, which can be easily accessed by a registered user. Generally, the open access data has been through quality and feasibility tests. Besides, many researchers has also tested its applicability (Hayakawa et al., 2008; Ahmed et al., 2010).

Digital Surface Model (DSM) is one of many open access remote sensing data that store the elevation above mean sea level. The DSM can be produced either using active or passive remote sensing system. Two well-known sources of DSM data were Shuttle Radar Topographic Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM). Both data have been used in many applications (Kanoua and Merkel, 2016). Technically, the vertical and horizontal accuracy of both data were provided by the author and/or tested by researcher (Kolecka and Kozak, 2013).

The advantage of DSM data is that the user can produce many of its derivative products such as contour, slope, aspect, profile, and hillshade (Chang, 2006). A contour map is one of many layers that composed the topographic map, i.e Rupabumi Map (RBI). The RBI map is available at multi-scale, range from 1:10.000 to 1:250.000. Ideally, the RBI map should cover all of the Indonesian area, but until now the available RBI map doesn't cover all area equally.

One Map Policy and Act No.4 2011 implied that the provision of Basic Geospatial Information (IGD) is intended to be the reference of any thematic map. The strategy of IGD fulfillment can be achieved through focusing on mapping IGD on the scale of 1:5.000 and 1:25.000, while the smaller scale map can be made by generalization (Susetyo, 2015). The DSM data provide an alternative of making contour map at the scale of 1:50.000, especially in areas that have no more detailed map.

SRTM is popular data to be used in medium map scale research, with 16 m vertical accuracy (Rodriguez et al., 2006; Slater et al., 2006; Farr et al., 2007). Nowadays there are many organizations produced their own version of SRTM data but mostly provided at 1-arcsecond (30 m) and 3 arcseconds (90 m) spatial resolution. On the other hand, ASTER GDEM is a product of optical remote sensing that can also provide 1 arcsecond spatial resolution of DEM data. Theoretically, both data can be used to produce 1:60.000 map scale (Tobler, 1987) or 1:30.000 (Richards and Jia, 2006). This paper will elaborate the results of automatic extraction of contour map using SRTM and ASTER GDEM data and how several generalization algorithms affect its applicability

2. Research Methods

2.1. Study area

The study area is located in Kemalang Sub-district, which provide various topographical classes (Figure 1). The topographic variation is expected since the resulting contour must be assessed in each topographic classes. Kemalang sub-district has an elongated shape, situated in the southeastern part of Merapi Volcano. The elevation range between 420 to 2100 meters above sea level.

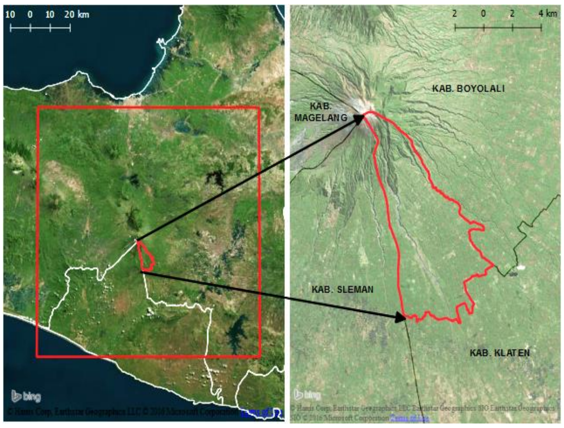

Figure 1. Research area

2.2. Data

ASTER image GDEM version 2 has elevation data proportional to SRTM elevation data, but with less consistent quality. The cause of this lack of consistency is that ASTER uses an optical image that will be constrained when there is cloud cover. On the other hand, SRTM is an active system (Radar), which has the ability to penetrate cloud cover. Both images will be constrained as they acquire data on steep and rough terrain, but in this case, ASTER is superior because it has a nadir view (in its stereo image). Thus ASTER GDEM data can be used to fill in empty data in SRTM images, especially in areas with steep slopes. Data acquisition constraints can also be felt when recording relatively flat areas with subtle textures, such as deserts. The perfect reflection effect causes many radar signals that are not reflected back to the sensor, so the level of data detail is reduced. Similarly for ASTER, which will experience constraints in the stereoscopic process due to lack of relief displacement.

The SRTM image used is version 3 which is an enhanced version by National Aeronautics and Space Administration (NASA) by charging altitude data from various sources on previously empty data (no data). Data filling (void/gaps filling) is done by NASA using ASTER GDEM height data and Global Multi-resolution Terrain Elevation Data (GMTED2010). The ASTER GDEM v.2 image used has the same spatial resolution as the SRTM image, which is 1 arcsecond (± 30 meters). ASTER GDEM v.2 is able to provide better altitude data than its predecessor version, as some annoying image scenes are not used anymore and use a smaller kernel in processing..

The elevation data contained in the SRTM and ASTER GDEM imagery refers to the geoid model Earth Gravitational Model 1996 (EGM96), while for the coordinate system referred to is the geographic coordinate system of the ellipsoid World Geodetic System 1984 (WGS84).

2.3. Methods

2.3.1 Contour Interpolation

DEM data has a raster format, while contour maps represent line data stored in vector format. Thus the process of transforming DEM information into contour maps involves converting raster data into vector data. The extraction algorithm can vary from one software to another. Some provide a choice of contour intervals, and some provide a smoothness of line settings.

In this study, GDAL Contour Generate, which can be found in Quantum GIS software, was used. The algorithm will produce contour maps on the contour interval as per user's desire. There is an option to identify pixels that are not included in the creation of contour lines, such as NoData pixels. The way the algorithm works is to change the midpoint of a pixel into a data point that has an elevation value corresponding to the pixel value. Contour interpolation is done linearly along the line connecting between points (Figure 2).

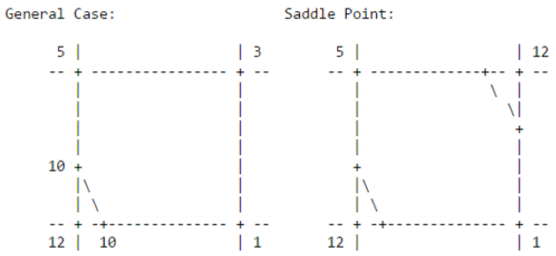

Figure 2. The principle of contour lines interpolation in GDAL

2.3.2. Quality Assessment

The quality assessment of contour maps is qualitatively done by comparing the quality of lines generated from SRTM and ASTER GDEM. Visually, a good contour line quality will follow the general principles of contour line drawing, for example, no contour lines are intersected, not many contour lines with narrow areas, and the appearance of contour lines are smooth. The qualitative assessment is indeed subjective so that in this research the quantitative assessment will also be done.

The latter method is done by assessing the accuracy of the contour line position compared to random sample points. The contour map of RBI is used as a reference for the distribution of sample points, assuming the contour map presented on the RBI map has good horizontal and vertical accuracy. The sample point is placed at a random location with a uniform distribution at various elevation values. However, it will be very difficult to find the sample point exactly on the resulting contour line, so in this study, the tolerance value of 12.5 meters is determined, which is half of the contour interval on the 1:50,000 scale contour map. Figure 3 summarizes the methods used in this study.

2.3.3. Line Generalization

The contour lines that are automatically generated by using software usually has the appearance of a broken line. This is the result of a rigid contour line drawing at the interpolation point, which in this case is presented in the grid/pixel. From this point of view, it is natural, but visually unacceptable. Ideally, the contour line is a flexible and continuous line. Therefore, there is a need to improve the visual appearance of the contour line.

In line with this, one of the challenges in cartography is the selection of data in accordance with resolution/scale (Bostock, 2012; Shahriari and Tao, 2002). The vector data model stores the point data in vertices and draws the lines of each vertex according to the data. The more vertices, ideally the more detailed the data stored. There are several methods to be able to reduce vertices (line simplification) or line smoothing (smoothing lines) to accommodate the line data visualization.

2.3.3 Line Simplify Algorithm

a) Douglas-Peucker

The Douglas–Peucker algorithm is an algorithm for reducing the number of points in a curve that is approximated by a series of points. However, the reduction is done with regard to preserve directional trends in a line using a tolerance factor (Ekdemir, 2011).
The first point in the line to be simplified will be defined as 'anchor' and the last point as 'floater'. A straight line is drawn from both points and then the perpendicular distance is selected as the basis of tolerance. If there is a point that has a distance less than the tolerance then it will be removed, and vice versa (Karthaus, 2012). The most distant point will be used for recalculation.

b) Reumann-Witkam

This algorithm categorized as the Local Processing Routine group but it has no constraint in conducting the evaluation (Ekdemir, 2011). In general, this generalization method is similar to the Douglas-Peucker algorithm, except that the straight line used is between two adjacent vertices. The user-defined threshold value will be drawn perpendicular towards the line. If there is a point that enters the area formed by the threshold value, then the point will be deleted.

2.3.4 Line Smoothing Algorithm

a) Chaikin

This algorithm was initiated by George Chaikin in 1974, with the aim of forming curves based on existing points. The Chaikin algorithm is one of the pioneers of the cutting corner algorithm to produce curves from multiple control points or control polygons. Unlike the previous two algorithms that attempt to reduce the point, the Chaikin algorithm has the purpose of smoothing the appearance of the line, so that it will add points/vertex. Determination of the additional point is the core of the Chaikin algorithm.
The new points are generated from the cutting of the old line/polygon on the angled part. The new points are located on the proportion of 0.75 from the first line and 0.25 from the second line.

b) McMaster

The McMaster algorithm falls into the line smoothing category but has a difference when compared to the Chaikin algorithm. The main difference between the two is that the McMaster algorithm does not add new points, but rather shifts the old point to be placed in a position visually seen as a curve. The point shift is unique because, before the shift will be determined first the new point which is the result of the average position of some point (Ekdemir, 2011).
The user needs to determine the number of points used to calculate the new position, this is known as Look Ahead. The position (x,y) of the new point is calculated using the average formula of the selected points as determined in the look ahead. In order to avoid extreme movement, a line is drawn to connect the new point and the middle point of calculation points. The point for generalization is then placed in the middle of that line.

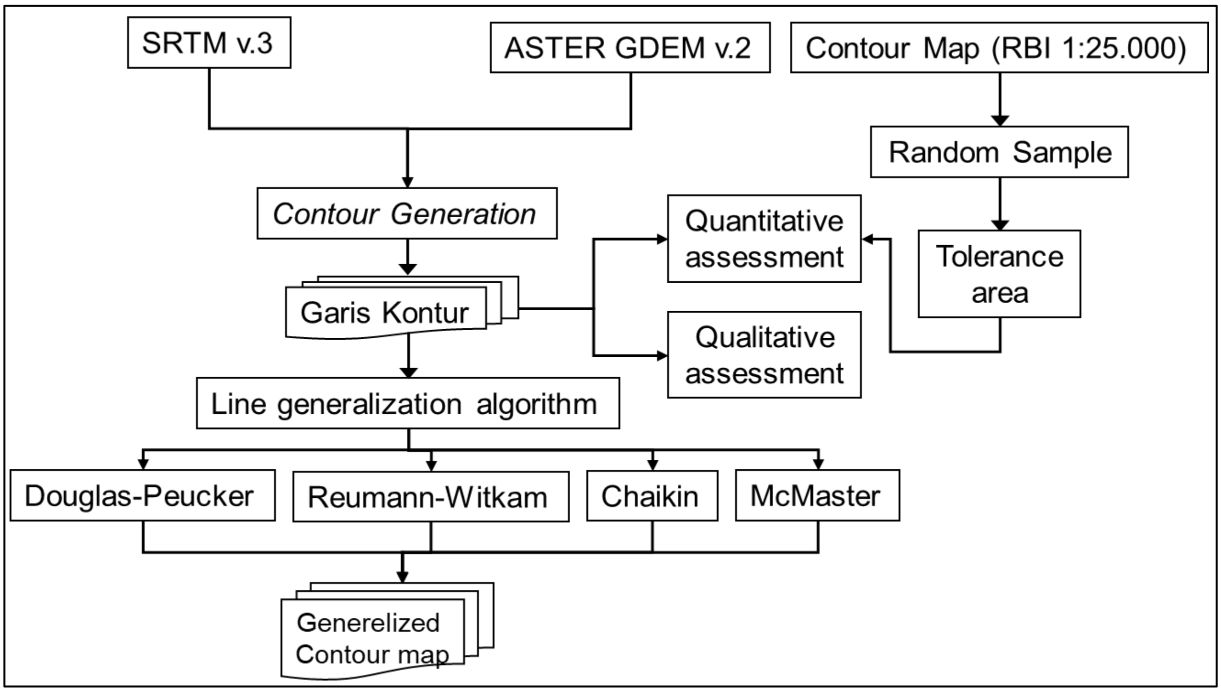

Figure 3. Flow diagram of the study

3. Result and Discussion

3.1. Error pattern

Contour lines derived from ASTER GDEM image v.2 in flat areas have significant differences compared to contour lines of SRTM image v.3. The different characteristics of both data are likely to cause the different pattern of the generated contour line. However, both data shows many errors in depicting contour line in flat areas. This is inseparable from the system used by both acquisition systems.

Both data have deficiencies to produce a good elevation data in flat area as a consequence of its respective systems. SRTM will lose many signals because the flat place is a perfect signal reflector. Meanwhile, flat area conditions will complicate the optical image of ASTER GDEM in distinguishing topography.

The contour line that generated automatically has a big obstacle in mapping contour in a flat area, either using SRTM or ASTER GDEM as the data source. Beside intersected contour lines, there are a closed loop contour lines with a less significant area in the resulted contour map. It is as if in a flat area has some wavy topography. Thus technically, the process of generating the contour lines on the flat area can be done by software using both data, but the contour line produced is not visually accurate. Higher resolution data is required for the creation of high-quality contour lines on flat areas.

The number of contour line faults diminishes as it shifts on the steeper slope and the mountainous topography. There are not many contour lines intersection found, especially in a place that has a high elevation difference. Both dem data has a good response in acquiring elevation data in the hilly and mountainous topography. SRTM harness the reflection of radar waves, in which has a capability of penetrating certain particle. Meanwhile, ASTER GDEM utilizes stereoscopic view of its nadir and backward of the red band.

Technically both data used can be used to generate contour map with a 25 m interval. Although, some geometric errors such as spikes, narrow closed loops, contour lines intersections, and contour lines that follow the traces of the raster data grid are still found and therefore should be anticipated. Actually, the contour intervals can be made smaller than 25 m, but there are consequences of geometric errors will be higher given the DEM has a maximum vertical accuracy of 17 m.

3.2. Qualitative Assessment

Several qualitative parameters are applied to assess the quality of the contour lines derived from both DEM, including spikes, narrow closed loops, contour line intersections, grid raster traces, the appearance in each topography (flat, wavy, hilly, and mountainous), and line shift position. Overall, the contour line derived from the SRTM has better visual quality than the contour line derived from ASTER GDEM, as the results shows a much less narrow closed loop contour line. To correct or eliminate the narrow closed loop requires special handling, for example by the operation of object delineation by area. But by then the contour lines must first be converted to polygons.

Grid traces of raster data are inevitable in vector data creation using raster as its source. However, contour lines should have a smooth line in order to represent topography in the map. The result of automatic contour generation shows that in some area, the contour lines are tracing the grid of the raster data (Figure 4b). Another impact of grid traces effect is the presence of contour lines that have narrow angles (spike). It is also aesthetically

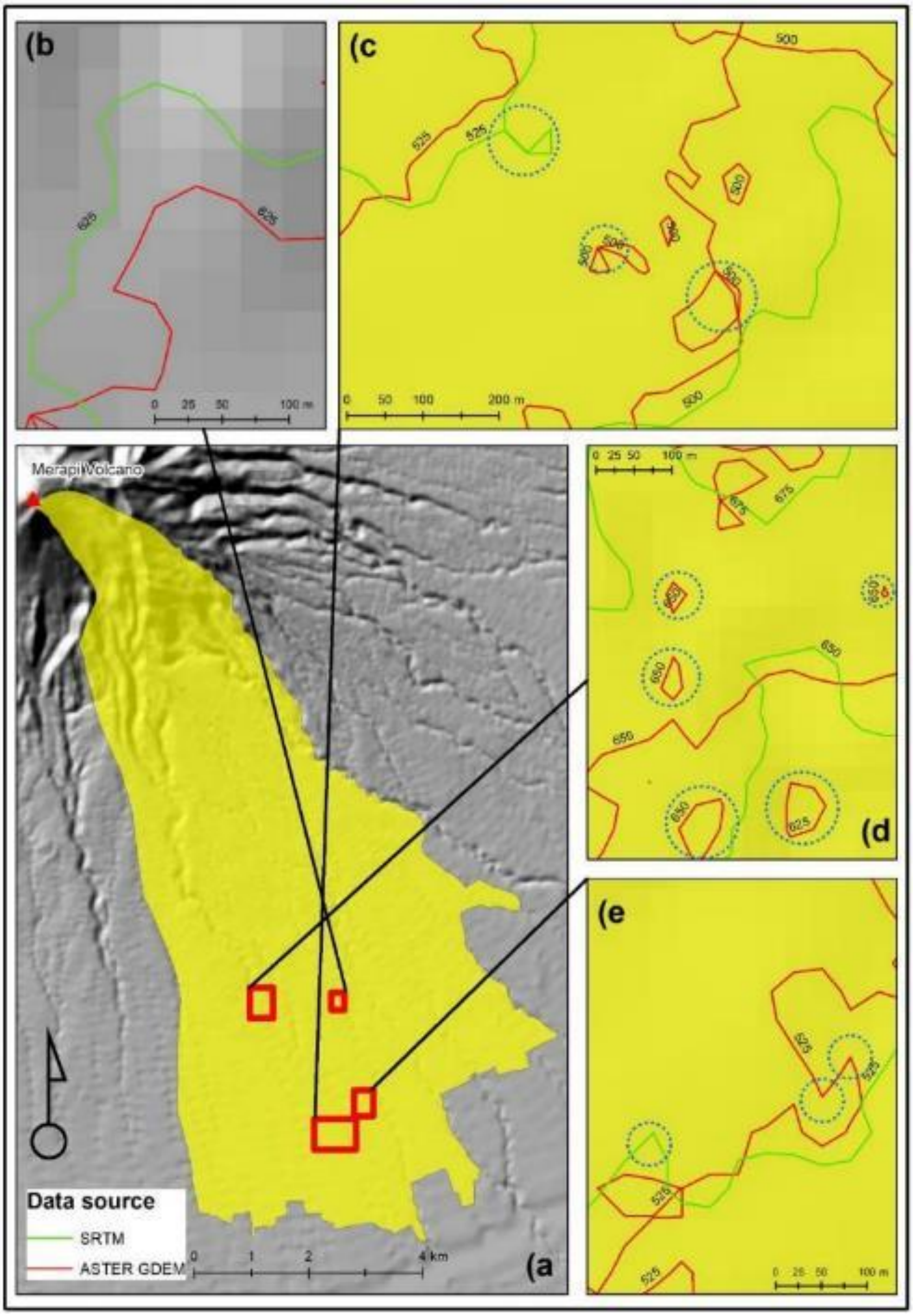

Figure 4. Qualitative parameters applied to contour map in study area (a), namely b) raster grid traces, c) line intersections, d) narrowly closed loop, and e) spikes.

unacceptable for a contour line to have too many spikes (Figure 4.e). Line smoothing algorithm is expected to be used to overcome the problem, so that the contour lines can be aestethically pleasing.

Both data used in this study provide a full elevation data and it has been mentioned before that both data tend to produce a poor quality of contour line on flat areas. This is reflected in the number of narrowly closed loop contours produced in flat areas (Figure 4d). The narrowly closed loop line can be generated because the elevation data in flat area are not as accurate as the data in hilly and mountainous area. Flat areas are also suffering a lot of contour line intersection, even though the contour line should not intersect (Figure 4c).

The results of the qualitative assessment are presented in Table 1.1. Asterisk was used to indicate the visual assessment, in which the more asterisk the better the visual quality. Thus the accumulation of stars present in each result can be used as a judgment on the quality of contour lines. In this case, the contour line derived from SRTM data is slightly better than that of ASTER GDEM.

Table 1. Qualitative assessment of contour lines

No.	Parameters	SRTM	ASTER GDEM
1.	Spike	*	*
2.	Closed loop	**	*
3.	Intersection	**	**
4.	Grid trace	***	***
5.	Flat topography	*	*
6.	Wavy topography	**	**
7.	Hilly topography	***	**
8.	Mountainous topography	***	***
9.	Position shifting	***	***
Total asterisks		20	18

3.3 Quantitative Assessment

Assessment of the quality of the contour line quantitatively is done by means of A total of 50 test points taken randomly based on contour lines on contour maps of 1: 25.000. A tolerance of 12.5 m is given to assess whether the contour line can be well described or not. The tolerance value represents half of the contour interval on the 1: 50,000 scale contour map. The spread of the test point is concentrated in the north because it has a denser contour line than the south (Figure 5).

Contour lines derived from SRTM v.3 image quantitatively deliver the most satisfactory results (Table 2). A total of 15 of the 50 test points are intersecting to contour lines that have the same elevation. This result is almost twice the accuracy of contour lines generated from ASTER GDEM v.2 image, so it will be used in the next process. This quantitative test results also confirm the previous findings, in which the contour line derived from the SRTM v.3 image has a better quality than the contour line derived from the ASTER image GDEM v.2.

Table 2. Quantitative assessment

No.	Data source	Correct elevation	Percentage
1.	SRTM v.3	15	30
2.	ASTER GDEM v.2	9	18

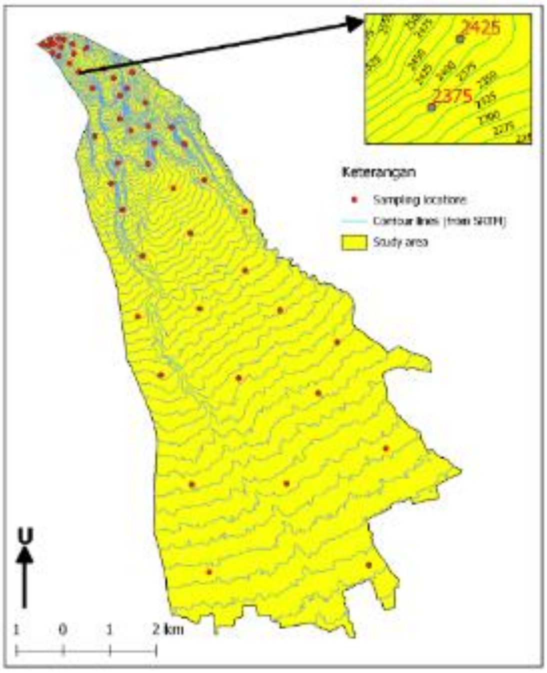

Figure 5. Sampling locations for quantitative assessment

3.4. Contour Line Generalization

The result of automatic contour line derived from raster data has the characteristic of broken lines, as a result of the line drawing process using the vertex that traces the raster grid. Visually the result is less satisfactory because generally the contour lines on the map are depicted with lines that are arc rich and smooth line. Therefore, it is necessary to generalize the contour lines that have been produced before to meet the appropriate visual quality. For this purpose, the following four applications of the algorithm are presented to contour lines derived from SRTM v.3 image, since the contour line has a slightly better visual quality than that of ASTER GDEM v.2 image, .

The generalization execution on each algorithm is performed using commonly used parameters. This is intended to determine the ability of each algorithm in general. The Douglas-Peucker and Reumann-Witkam algorithms have the same parameter, the epsilon value (ε), which is the buffer area of the line used in generalization. Meanwhile, Chaikin algorithm has level and weight parameters, and McMaster algorithm has Slide and Look ahead parameters.

Generalization results using the Douglas-Peucker algorithm indicate the reduction of vertices, so as to reduce the size of its storage. However, visually what generates from the generalization makes the contour line less visible because there are many indentations with angles that are too sharp. There are even contour lines of different elevations and lie on very steep slopes, which then intersect after generalization. When compared to the contour line before generalization, the pattern of change does not shift too far because some of the original points that lie outside the epsilon value are retained in position. Under these conditions, the Douglas-

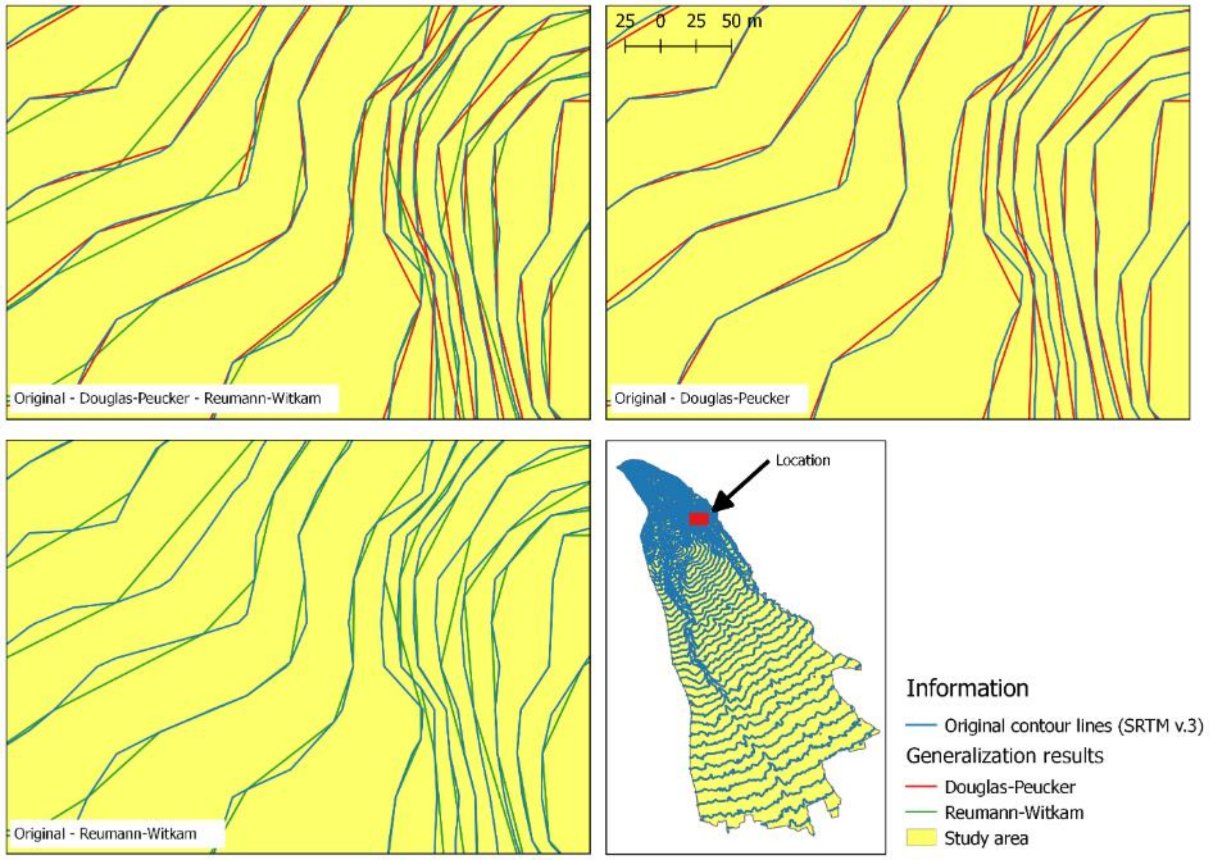

Figure 6. The comparison of original contour line generated from SRTM v.3 and the generalization result of Douglas-Peucker and Reumann-Witkam algorithm

Peucker algorithm is highly relevant if used for downscaling, for example from a scale of 1: 50,000 to a scale of 1: 100,000.

A similar pattern is also shown by the contour lines of the generalized Reumann-Witkam results, which in many cases shift the contour lines from their original position even though some points are retained like the previous results. It also indicates that this algorithm would be more suitable if used for downscaling data. The difference of the original contour line with the generalization result using the two algorithms can be seen in Figure 6. The generalized contour line shift in the Reumann-Witkam algorithm tends to be farther than the Douglas-Peucker algorithm.

Interest generalization is one of them wanted to make it look more natural contour to reduce the appearance of lines broken. The view is the result of the lack of vertices to represent the line. The results generalize to the two algorithms are not able to overcome the problems Visibility contour lines are broken because it aims to reduce the vertex.

Unlike the two previous algorithms, algorithms Chaikin and McMaster generate contour lines are not too far from its original position (Figure 7). In areas with tight contour lines, there is no intersection of contour lines as in the previous two algorithms. Chaikin's algorithm even slightly modifies the contour lines, since the changes only happen at too sharp corners. In plain on a scale of 1: 5,000 is still difficult to distinguish the original contour lines with contour lines Chaikin result of generalization algorithms. Meanwhile, the result of a shift McMaster algorithm contour lines at a distance that is not too far when compared with the two previous algorithms.

Looking at the contour line pattern results of Chaikin and McMaster generalization algorithm, then both algorithm can be used for smoothing process and can be used for upscaling process in certain limitation. The intended limit is no significant post-position change post-display features are generalized. Contour lines of generalization results are also appropriate to be used in the process of visualization and presentation of data because indentations are illustrated more naturally so as not to disturb the attention of the map user.

Based on the number of vertices, the Douglas-Peucker and Reumann-Witkam algorithms are able to generate new data with fewer vertices than the original data (Figure 8). Even the newly generated data has less than 50% the number of vertices of the original data. On the other hand, the Chaikin algorithm doubles the number of vertices of the original data by nearly 200%, although visually the original data difference with the generalized result data is not too far away. The addition of vertices occurs on each of the old line segments, thus significant changes occur in segments that have sharp corners. McMaster algorithm data results do not experience addition or reduction in the number of vertices because theoretically has a goal to shift the point. A large number of vertices will have a direct impact on the size of the data if more and more vertices on a data the size will be greater.

line. Although in previous results it is known that the generalized contour lines using the Douglas-Peucker algorithm have the potential to intersect each other. On the other hand, the McMaster algorithm has the worst ability to match the contour line position according to the 1: 25,000 scale contour line.

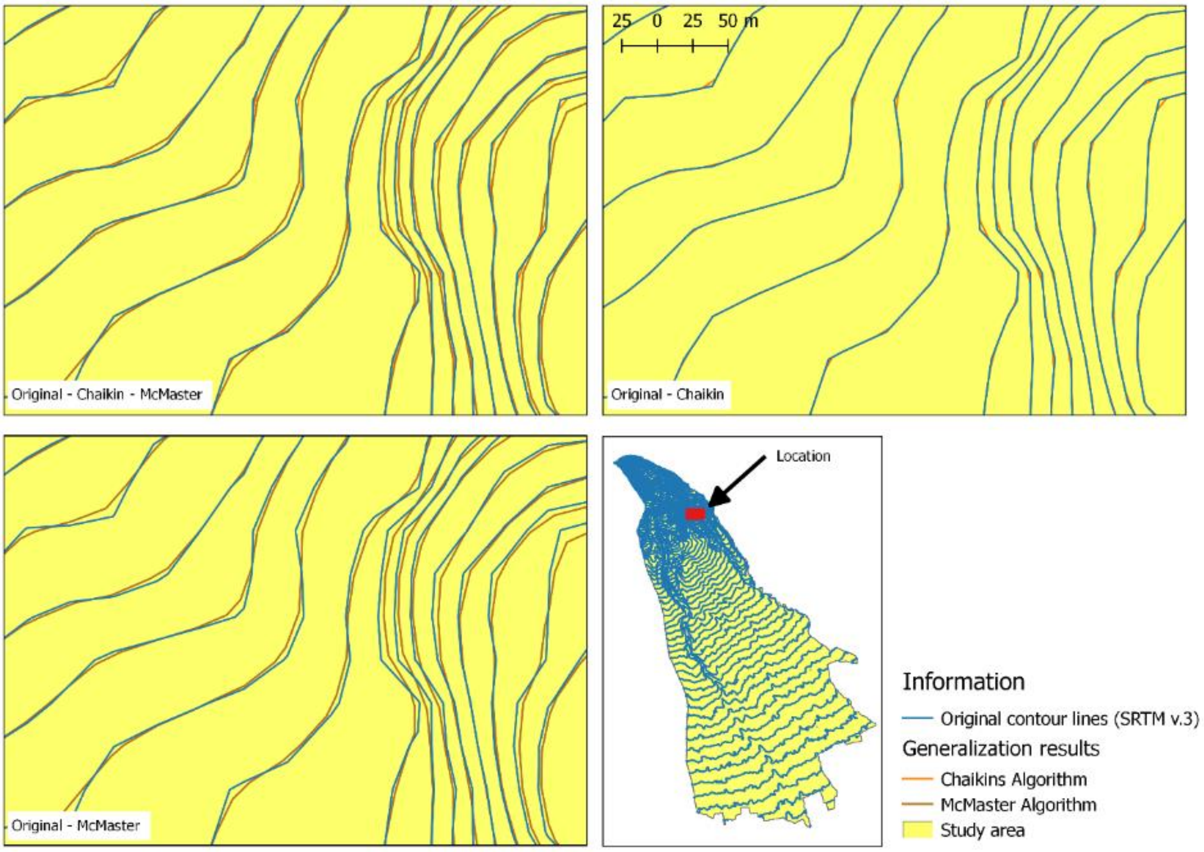

Figure 7 The comparison of original contour line generated from SRTM v.3 and the generalization result of Chaikins and McMaster algorithm

The quality of the contour lines is quantitatively assessed using the same method as the pre-generalized rating. The test point used plus 50 more points for this second test is able to present a different point of view. The spread of test points is still prioritized on areas that have a steep slope because there are many contour lines contained in the area. The buffer zone is made up of two radii, 12.5 meters, and 25 meters. It is intended to know the effect of adding buffer area to data accuracy.

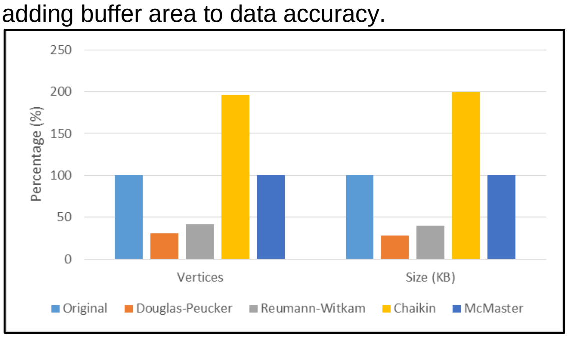

Figure 8. Number of vertices and file size of original and generalized contour line

Accuracy measurements in the 12.5-meter buffer zone show that the Douglas-Peucker algorithm provides the highest accuracy with a value of 30%, respectively followed by the Reumann-Witkam, Chaikin, and McMaster algorithms (Figure 9). With the highest accuracy then logically the Douglas-Peucker algorithm in this experiment provides the best possible capability in terms of contour line positioning according to the 1: 25,000 scale contour

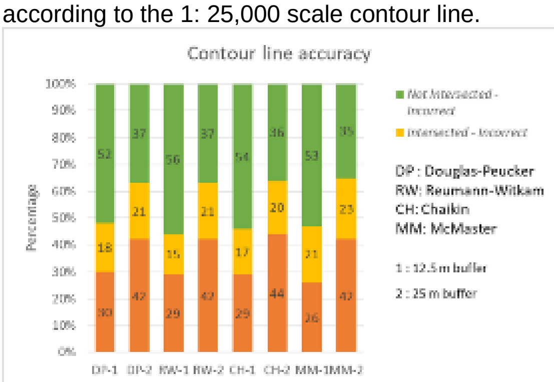

Figure 9. Positional accuracy of the contour line

Accuracy measurements in the 25-meter buffer zone show improved accuracy values for both the algorithm and overall accuracy. The increase of accuracy value is reasonable because with the increasing area of the buffer, the contour line opportunities for entry into the greater. The Chaikin algorithm, in this case, has the highest value, with 44% of the buffer area intersecting with the corresponding contour line (Figure 9). Meanwhile, three other algorithms have the same accuracy value, which is equal to 42%. This not too distant value difference indicates that positionally, the shift of contour line position caused by each algorithm has more or less the same effect. Thus a further determination process is needed to summarize recommendations on the preparation of contour maps of 1: 50,000 scale.

The calculated accuracy in this experiment only concerns the location of the contour line but does not pay attention to geometric errors that may be present in the generalization contour line. Forms geometric errors in question are the existence of duplicated nodes and segment intersection. Table 3 presents the number of geometric errors on each contour line both prior to generalization or afterward. The original contour line (SRTM v.3) initially has 16 errors in the form of intersection segment. Among the four generalizations algorithm used only Chaikin algorithm that can reduce the number of errors to 6 errors. Of course, this can be taken into consideration, that the certainty of the contour line position should be supported with a minimal data geometric error. The Reumann-Witkam algorithm, on the other hand, adds geometric errors, especially duplicated nodes.

Table 3. Geometric error

No.	Contour	Geometric error		Total
		Segment Intersection	Duplicated Nodes	
1.	Original	16	0	16
2.	Douglas-Peucker	9	9	18
3.	Reumann-Witkam	9	73	82
4.	Chaikin	6	0	6
5.	McMaster	16	0	16

4. Conclusion

Technically a lot of software has supported the reduction of contour line data automatically from DEM or DSM data. Contour intervals can be set up freely by any user ideally customized according to the scale and standard set. The more detailed contour intervals set in the software will not necessarily make the contoured line data down into detail anyway. The resistance of spatial resolution to DEM or DSM data should be noted in the contour line degradation.

The results of SRTM and ASTER GDEM data processing use various software, showing that contour lines derived from SRTM v.3 data with Quantum GIS software are able to present the highest quality, both qualitatively and quantitatively. However, it should be emphasized that the quality of the derived contour line also depends on the topographic condition of the mapped area. In areas with flat topography, the quality of contour lines produced has a very poor quality. New to the topography of surging contour lines began to acceptable results and reached its peak quality in areas with mountainous topography. This is inseparable from the characteristics of SRTM and ASTER GDEM data that have weaknesses in data acquisition in flat areas.

Visually, contour lines that are automatically derived from the software will have a broken view as the effect of the vertex limitations in the contour line. Four generalization algorithms have been tested in experiments using standard parameters, successively the Douglas-Peucker, Reumann-Witkam, Chaikin, and McMaster algorithms. The Douglas-Peucker generalization contour line does provide the best positioning accuracy, but if considered overall Chaikin's algorithm is superior in displaying a 1: 50,000 scale contour map. In this case, geometric errors generated by each algorithm are also taken into account.

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