Identification of topographic elements composition based on landform boundaries from radar interferometry segmentation (preliminary study on digital landform mapping)

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Abstract. Dense vegetation that covers most landscapes in Indonesia becomes a common limitation in mapping the landforms in tropical region. This paper aims to examine the use of radar interferometry for landform mapping in tropical region; to examine the application of segmentation method to develop landform type boundaries; and to identify the topographic elements composition for each type of landform. Using Idrisi® and “eCognition ®” softwares, toposhape analysis, segmentation and multi-spectral classification were applied to identify the composition of topographic elements i.e. the types of land-cover from Landsat 8, elevation, slope, relief intensity and curvatures from SRTM (DEM). Visual interpretation on DEM and land-cover fusion imagery was conducted to derive basic control maps of landform and land-cover. The result shows that in segmentation method, shape and compactness levels are essential in obtaining land-cover, elevation, and slope class units to determine the most accurate class borders of each element. Despite a complex procedure applied in determining landform classification, the combination of topographic elements segmentation result presents a distinct border of each landform class. The comparison between landform maps derived from segmentation process and visual interpretation method demonstrates slight dissimilarities, meaning that multi-stage segmentation approach can improve and provide more effective digital landform mapping method in tropical region. Topographic elements on each type of landforms show distinctive composition key containing the percentage of each curvature elements per area unit. Supported by GIS programming and modeling in the future, this finding is significant in reducing effort in landform mapping using visual interpretation method for a very large coverage but in detail scale level.

1. Introduction

The application of remote sensing in geomorphic mapping has been developing vastly, coinciding with the launching of radar interferometry and its ability to provide digital surface/elevation model (DSM/DEM) [1]. One of the important parameters in geomorphic mapping is land physical characteristics information derived from landform classification and mapping, both in regional or global level. Landform, as the main element in geomorphic mapping, is a natural object feature that divides the earth surface into one main spatial unit [2]. It comprises the information of relief, elevation and the common land activities that dominating the landscape processes. DEM provides more promising data to the researchers in increasing the quality of landform mapping, because it consists of elevation information with 3-dimentional relief features. Nowadays, landform classification using DSM/DEM is one of basic research domain in digital terrain analysis, including GIS landscape integrated studies. The common free access and reliable 3-dimentional relief data used in many mapping applications is Shuttle Radar Topography Mission (SRTM) (Figure 1). This imagery has horizontal and vertical spatial resolution of 90 m and 10-16 m respectively. However, it only provides a DSM features instead of DEM, because when a surface covered by very dense vegetation, it is only a small part of soil surface reflectance that is received by sensor [3]. Therefore, addition corrections of radiometric and geometric (vertical) are needed to obtain more accurate elevation values (DEM).
Landform mapping using remote sensing imagery in Indonesia mostly involves visual interpretation technique to manually obtain landform features instead of digitally. Generally, visual image interpretations for land-use/land-cover and landform application utilize multi-spectral imageries from Landsat images combined with DEM from SRTM [4,5]. The use of DEM in applying digital technique is more focused on the modelling of land-cover changes, hydrology, natural disaster, and general land physiographic changing using multi-temporal data [6,7]. The feature elements of landforms are diversely complex in each type of classification, and the requirement of high experience and understanding of their characteristics is needed in interpreting them. Indonesian geographical condition located in tropical country where vegetation covering most of its earth surface, is a common issue in remote sensing studies, especially in gaining the accurate feature of landforms. This issue also causes the landform identification with visual interpretation could not be easily done by the amateurs. This current study is expected to provide a preliminary concept and procedure to map landform in a rapid but reliable way.

Landform digital mapping is a process to obtain landform information from digital data like DEM, satellite imagery and aerial photos [8]. The development of remote sensing technology provides digital data with higher spectral and spatial resolution. However, such consequences are inevitable that this more meticulous data will have more complex information which results in producing some technical issues, in this case in how to combine the enormous topographic elements information derived from pixel based image analysis. With preconceived assumption that topographic elements associates with segments as the cells groups which have equal values, then object based image analysis (OBIA) becomes the valuable approach for landform mapping. Derivation of land-cover and landform using OBIA have been so prominent in the last couple of years, because of its speciality in overcome this pixel analysis issues which is only calculating the image pixel values instead of considering geometric and contextual information [9;10]. Thus, OBIA have been well-proven for classifying landform from DEM [11; 12] because the object contextual model of the identified landform is more reliable compared to per-pixel traditional method [5]. The results of classification from previous studies only provide topographic elements in every mapping unit, such as information of elevation, slope, relied and curvature, but do not conclude their type of landform. On the other hand, there is a need to provide rapid digital landform identification to assist researchers in determining type of landform in a very large landscape such as in Indonesia such as the applications on land-suitability and planning which need a fine scale of landform map. Further study on how to develop a landform type criteria based on topographic elements information from multi-segmentation process will assist the researcher in generate a program language system for automatic landform type identification.

In general, OBIA includes two working steps, which are segmentation and classification. OBIA stands out as a promising technique among the diversity of digital mapping methods for landcover/landuse object classifications. OBIA has the ability to produce uniform objects and then associate those objects into contextual information on the higher framework level [4: 5]. OBIA application for land-cover mapping purpose, generally speaking, grows more rapidly because it is relatively simpler (but not effortless) than for landform mapping [5]. In OBIA, land form classification is based on expert judgment.
and knowledge-based on DEM, satellite image and/or over both combinations. The extended algorithm to reduce the uniform segments from the image segmentation result is explored through multi resolutions segmentation (MRS). The newest usage of OBIA for combined land-cover and landform mapping has just been applied for mapping the vegetation, canal, and mud flats using very high spatial resolution imageries [7, 8, 9]. Therefore, in this paper, the aims of the study are to examine the ability of radar interferometry imagery in mapping landforms using segmentation method, and to identify the topographic elements composition of each landform mapping unit derived from “toposhape” analysis.

2. Study area, conceptual basic, material and method

2.1 Study area

This study was conducted in Yogyakarta and surrounding areas where its topography characteristics are a combination of flat to mountainous landscape features. The volcano landform, on the north part of this area, is complemented by karst and structural landforms on the east and west parts respectively. This landform complexity assists this study to identify the terrain-shape of each type of landform using topographic composition that represents elevation, slope, basin, relief intensity, and curvature.

2.2 Conceptual basic

Landform is an object that being studied as a part of Geomorphology [11]. Landform is a terrain surface feature which naturally formed by a certain process. The landform itself however is limited and discontinued by nature. In landform mapping, the use of DEM has been recently common in gaining more accurate landform information. The available method consist of mere visual interpretation, and supported by multispectral fusion or combination of image and DEM, contour map, and photogrammetry or radar interferometry to provide better visual topography appearance compared to the 2-dimensional appearance [12, 13]. On the other hand, there are many aspects we can gain from the image with digital approach, although will bear the consequences of complexities and difficulties. Moreover, years of experience and flight hours dealing with multi-scale land form mapping, is critical prerequisite. This research will use the classification of landform with 1:250,000 scale [14] as basic segmentation of DEM and InSAR Image [14, 15, 16, 17]. This landform classification includes: volcanic, structural, fluvial, and karst using elemental landform approaches: elevation, slope, relief intensity and curvature (basin, valley and others slopes represented by “toposhape” fatures). Marine and aeolian landforms are excluded into consideration as the sample areas didn’t meet the minimum requirements for this study.

2.3 Material and method

The main method used in this study is designed to facilitate the need of classifying landform using digital technique. It involves some digital image processing to gain landform boundaries and characteristics. It includes radar image processing, using ENVI 5.0, “toposhape” identification using Idrisi® and segmentation processes using eCogniton®. Three steps of digital analysis activities were conducted after image radiometric and geometric pre-processing (Figure 2). First step was conducting visual interpretation on Landsat 8 with several band composites to produce different landform type boundaries using multi-level landform mapping approach [18], a method that is available to assist user to gain more accurate landform interpretation from several remote sensing imageries. These landform boundaries become a foundation to separate information on the process of topographic elements identification.

Second was segmenting the DEM based on the elevation region into high- and low-land classes (Table 1), followed by similar step but was based on the slope and elevation classification [17] (Table 1). The third step was classifying “toposhape” identification (using Idrisi®) per unit area based on landform boundaries from step 2 that has been compared to landform boundary from visual interpretation. The detail topographic elements are provided in Table 2.
Table 1. Elevation and slope classification for segmentation purpose [17].

| Class | Elevation – relative height (m) | Slope (%) |
|-------|--------------------------------|-----------|
| 1     | <50 : lowlands                  | 0-2       : flat or almost flat |
| 2     | 50-200 : low hills              | 3-7       : gently sloping      |
| 3     | 200-500 : hills                 | 8-13      : sloping             |
| 4     | 500-1000 : high hills           | 14-20     : moderately steep    |
| 5     | >1000 : mountains               | 21-55     : steep               |
| 6     | -                              | 56-140    : very steep          |
| 7     | -                              | >140      : extremely steep     |

Figure 2. Research flowchart of land elements identification.

Table 2. Slope curvature topographic element identified using “toposhape” features in Idrisi®.

| No. | Type of slope curvature       | No. | Type of slope curvature       |
|-----|--------------------------------|-----|--------------------------------|
| 1   | Peak                          | 7   | Saddle hillside               |
| 2   | Ridge                         | 8   | Slope hillside                |
| 3   | Saddle                        | 9   | Concave hillside              |
| 4   | Ravine                        | 10  | Inflection hillside           |
| 5   | Pit                           | 11  | Unknown hillside              |
| 6   | Convex hillside               |     |                                |

3. Result and discussion

The first result provides landform boundaries generated using visual interpretation methods. Multi-level landform interpretation analysis [18], supported by geological and topographic maps, and DEM developed from SRTM, was applied to identify more accurate landform boundaries visually. The segmentation process for SRTM (Figure 2) in this study was utilizing eCognition® software. The segmentation process applied multi-resolution segmentation algorithm method which reduced the average heterogeneity of the objects in the image locally, on the available resolution. In this method, the user can apply various scale parameters to obtain the best object unit in accordance with the classification and resolution. The final classification produced landform boundaries based on the best scale parameters on segmentation process.
The identification of landform boundaries from several scale parameters in segmentation processes shows various details of boundaries. This study use range of scale parameter from 50-250 with 50 unit increments. The lowest value of scale parameter 50 was chosen according to the possible map scale that can be generate from SRTM imagery. Figure 3 shows the image results from segmentation with scale parameter of 50 and 200, indicating that the boundaries generating from scale parameter 50 is finer compared to its of 200. The observation applied on segmentation image result with other different scale parameter presents similar result that the smaller value of scale parameter the finer boundaries of landform is produced. For this reason, the scale parameter of ‘50’ segmentation image is chosen as the main image result from segmentation process.

The landform boundaries results from segmentation method and visual interpretation were compared to examine their accuracy. This study uses an assumption that landform boundaries obtained from visual interpretation is more accurate than the one from digital processing since the visual interpretation involves expertise judgment and several afore mentioned supportive data to determine the boundaries.

Figure 3. Landform classification imagery from segmentation method in various scale parameters. Figure A and B showing segmentation results and their classification using scale parameter 50 and 200 respectively.

Subsequently, these examined landform unit boundaries were overlain with “toposhape” analysis result to reveal the composition of the topographic elements of each landform unit represented by type of slope curvature (Table 2). Field survey was conducted based on the temporary result of classification and landform. The result shows that dividing the area based on elevation and slope from segmentation process to assist land elements identification does not significantly contribute to its composition diversity. Therefore, the composition identification was done directly using landform boundaries.
Figure 4. Topographic element imagery analysis results from (A) “toposhape” identification (using Idrisi®), and (B) landform visual interpretation on SRTM and Landsat, combined with the “toposhape” analysis result.

Figure 5 shows various results of topographic elements represented by number of peak, ridge, saddle, ravine, pit, convex hillside, saddle hillside, slope hillside, concave hillside, inflection hillside, and unknown hillside. Those numbers of topographic elements from “toposhape” analysis are displayed using graphs to perceive their pattern, distribution and importantly their composition in each landform unit which are presented in percentage (%). Largely, the graphs shows different pattern on volcanic, structural, fluvial and karst landform type area units. Field survey was conducted randomly to validate the accuracy of the slope, elevation, relief and “toposhape” analysis result in the every single landform type. The obstacle found in the field commonly dealt with the vegetation and build-up area land-covers that conceal the original shape of these covered land. In this case, the expertise on landform analysis is needed to confirm the accurate type of “toposhape”.

On the volcanic landform (Figure 5.A), the dominant topographic elements are ravine (>17%) and inflection hillside (> 20 %). Those compositions are showing the dominant of valley and inflection points that commonly occurred in young volcanic areas. Concave and saddle hillside (both are below 10% of the composition) complement the features of valleys and slopes. The structural landform composition shows three dominants land elements which are ridge (13-15%), ravine (15%), convex hillside (14%), saddle hillside (16%), concave hillside (13%), and inflection hillside (17) (Figure 5.B). The various elements dominance on structural landform presents the roughness of landscape textures seen on the satellite imagery. High slope, erosion and dissected valley on different resistant layers have created the diversity of this structural’s topographic elements. Conversely, the fluvial topographic elements composition (Figure 5.C) shows highest number of flat “toposhape” element type which is more than 5%. This percentage is considered high compared to ones on other landforms which are below 1%. However, the flat “toposhape” in fluvial landform was expected to have much higher percentage (> 5). Observing that Yogyakarta flood plains are dissected by many rivers which have steep and large valleys on its middle part, the low percentage of flat “toposhape” actually is able to present specific characteristics on this fluvial landform. In spite of this, another study on topographic elements of various fluvial landforms needs to be explored specifically.

Karst landform “toposhape” composition (Figure 5.D) shows high percentage on ridge and ravine topographic elements (>10%). The karst landform in Gunung Kidul district is characterized by cone karst with sinusoidal hills mixed together with enclosed star-shape depression and linked valleys [11]. These ridget elements mostly represent the high dissected cone shape karst landscape that during dry season (time of this SRTM imagery recorded) emerge observably because the vegetation leaves are withering. On the other side, on the cone areas where the vegetation are not classified as withering type, the appearance of cone karst is concealed by vegetation of which the grow direction is shaping the cone as a sharper ridge. The abundant depression and interconnected valley are identified by high percentage of ravine topographic element. Intensive solution processes followed by erosion during rainy season produce deeper valley that lead to more depression formation.
Figure 5. The boundaries of (A) volcanic, (B) structural, (C) fluvial and (D) karst landforms based on visual interpretation and their each composition of topographic elements presented in a line graph showing the percentage of each elements number compared to the total.

4. Conclusion

This preliminary study on identifying topographic element composition on each landform class provides important conclusion on how this study can lead into a better result. More sample areas of each type of landform are obviously needed to ensure that the elements compositions are exclusively consistent in every type of landform. General understanding on geomorphological processes occurred on land formation are the main factors in determining the validation of “toposhape” analysis result. For example, the topographic element composition for fluvial landform in Yogyakarta that have steep valley and large riverbank is not always applicable on others fluvial plains. Further analysis of “toposhape” identification
has to be applied on other fluvial landforms, i.e. Semarang or Surabaya (estuarine and delta) which have different characteristics with the ones in Yogyakarta.

The same landform type from different areas does not guarantee that similar topographic element composition could be occurred among them. However, these possible differences compositions have a good chance to emerge a new sub-landform classification. Further study in applying segmentation process in digital landform classification is also worth to adopt to examine its delineation and boundaries accuracies. In summary, this current study result is important as one of foundations for the development of landform digital mapping in tropical country.

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