Hierarchical Model of Landscape Mapping (Case Study: Multiscale Mapping on Natural Ecosystem Baluran National Park)

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Abstract
The objective of the study was to confirm the linkages between the data source and landscape mapping scale to create a hierarchy of landscape mapping scale. The study was conducted through visual interpretation and manual detection in 2D and 3D multi-scale data to determine multiscale hierarchy followed by field survey. The interaction results of various parameters were grouped by segments according to the depth of information and were then differentiated into two types of data parameters (spatial and attribute data). Delineator boundary was the first process performed in the landscape mapping in Baluran; after that they were formed into units of land, then the database has been created based on the interpretation of aerial photographs and field surveys. Based on the multi-scale landscape analysis, it can be concluded that morphography is delineator boundary for small scale, while the delineator boundary for large-scale mapping is morphometry. The detail of landscape database was obtained based on the number of sampling in the field per 100 hectares, and the database information is closely related to the accuracy of the landscape map.

1. Introduction

1.1 Background

Landscape is a complex condition and composition of the earth's surface and it is influenced by various factors; it also is an important natural resource because landscape is a container or place of growth for socio-economic, cultural and environmental values (Quintana et al., 2005). Landscape is very easy to recognize, especially when it is considered as a scene (Moss and Nickling, 1980). Scientific development about landscape continues to grow from time to time given the importance of landscape applications in the daily life. Several fields such as regional planning, architecture, forestry, agriculture and various other fields have started using landscape analysis applications, primarily in the planning process.

Along with the rapid development of science, researchers from various countries have started developing methodologies in landscape analysis of the regions. In the late nineteenth century, several major US researchers such as Powell (1875) and Wheeler (1889) emphasized landscape analysis on the physiography of a region. At the beginning of the 20th century, Fenneman (1916) developed a methodology for landscape analysis with the identification of the earth's surface configuration. A British researcher, Bourne (1931), grouped landscapes on the basis of common environmental characteristics with geological maps. An Australian researcher, Christian (1958) identified landscapes by interpreting land systems and units. Pain (1985) combined topographic and physiographic factors to perform landscape analysis. Host et al., (1996) began introducing landscapes with terms which are related to ecoregion regarding their research related to biology. Landscape analysis was also done by Spanish researchers, by identifying landscape by classifying the ecological unit of a region.

In Indonesia, landscape analysis is more similar to the style of Dutch researchers (Verstappen, 1983 and van Zuidam, 1983) who emphasized more on the analysis of landforms using remote sensing data. The concept is reinforced by several researchers such as Sartohadi (2001, 2007), Hadmoko et al., (2010) and Samodra et al., (2014) by linking landscapes and landforms as well as geomorphology. In relation to the fact that there are many experts and studies on landscape analysis, the Indonesian government bridges the uniformity of the method and the presentation of landscape analysis as written in Indonesia National Standard (SNI) Drafting of Geomorphology Map of 2002 (SNI, 2002). The applications of landscape analysis that has already been global has led researchers to study and develop in this more deeply and scientifically. One of the efforts is to do landscape mapping. Various methods are carried out by researchers to do landscape mapping (Libohowa et al., 2016). The basis used in landscape mapping has been standardized, i.e. elevation, slope, terrain, relief, morpography, sub surface flow pattern, genesis, geomorphic process as well as morphoarangement (Meikle et al., 2010).

The methods used in landscape mapping are grouped into two categories, namely automation method and manual method (digitazion on screen). Unfortunately, there are still loopholes in the landscape mapping process, namely mapping-scale problems. Mapping scale is an element that must be taken into account in conducting mapping activities, including landscape mapping. Mapping scale is closely related to the mapping accuracy resulted. However, scale factors are still rarely well understood by researchers (Wu, 1999). Standardization of the landscape mapping scale should be done so that the information produced will be equivalent to the data source used. Until the present research was being carried out, there were no researchers who studied the scale hierarchy in landscape mapping. Based on these facts, this study aims to fill the gap in the landscape mapping scale.

1.2 Research Location

The research area was located in Baluran National Park, lies between 7⁰44′53,52″-7⁰55′28,41 S dan 114⁰17′48,09″-114⁰28′02,64″ E. Baluran National Park, known as Africa van Java, is located in Situbondo, East Java, Indonesia (Wianti, 2014) with an area of 25,000 hectares (Figure 1). Baluran National Park has a natural landscape so that it is suitable as a location for multi-scale landscape mapping test. According to the Schmidt and Ferguson classification, Baluran has a dry climate of type F with temperatures ranging from 27.2ºC-30.9ºC. Baluran has a variety of land cover types, types and densities of vegetation. Forest types in Baluran are coastal forests, mangrove forests, mountain rainforests, seasonal forests and even savanna covering up to 40% of Baluran area.

2. Research Method

Landscape mapping from remote sensing data can be done by two methods, (1) automatic detection; and (2) visual interpretation and manual delineation (Debelis et al., 2005). The methods used in the drafting of this multi-scale landscape mapping hierarchy were visual interpretation and manual detection, followed by field surveys. Visual interpretation and manual detection methods to define landscapes cost much and take a long time, but the end result is very accurate and easily recognizable in the field. In this study, numerical analysis was avoided in landscape mapping in order to make the result data able to be widely used.

Landscape mapping is done by analyzing Digital Terrain Model (DTM) data and image data as well as aerial photography (Asner et al., 2014). This is done by multi-layer impose method between DTM data and the texture on aerial image and photographs. The data used in this research were DTM data, satellite image and multi-scale aerial photographs. The DTM data used were in the form of SRTM, TerraSAR-X and DTM data that were made based on the results of aerial photography.

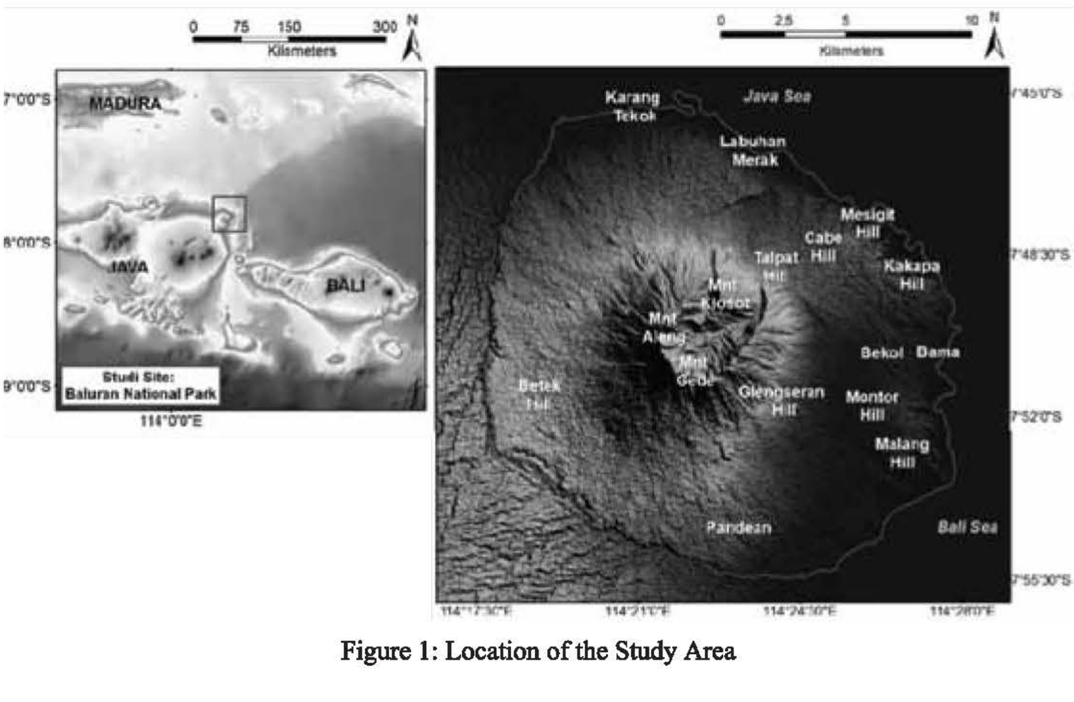

Figure 1: Location of the Study Area

Aerial images and photographs are used to supplement information that is difficult to extract from DTM data (Ali and Kotb, 2010). The imagery used consisted of Landsat TM, BingMaps and orthophoto data. The method used in defining the landscape mapping scale standard was an interpretation test involving several interpreters to analyze Baluran landscape. The validity of the landscape interpretation results were tested in the field by conducting ground truth validation by measuring each parameter in each delineation boundary. The output of this analysis were tabulated to link with the spatial resolution of the data source and the mapping scale.

Selection of basic data equality and determining the parameter are the primary keys in performing multi-scale modeling. These steps are taken into account while grouping the datasets, whether the data are as delineator data or as database. The process was performed by collecting data regarding all parameters that affect the landscape of a region. The preparation of a multi-scale landscape mapping hierarchy was done based on the theoretical framework that had been built through surveys and field tests as well as literature studies, combined with the results of spatial resolution analysis of data sources and mapping scales. Field surveys and literature studies were conducted simultaneously so that any new inputs or findings could be accommodated. Surveys and field tests were conducted from May 2014 to April 2016. The field survey was conducted to collect all the required landscapes data. The data obtained were analyzed spatially and temporally to deepen the results of the study. Quality assessment or field testing is an important component of modeling and the preparation of multi-scale landscape mapping hierarchy.

3. Results and Discussion

3.1. Data Source and Map Scale

The most important starting point in landscape mapping is to determine the mapping scale. Differences in mapping scale will lead to differences in information regarding the landscape of a region (Eisank et al., 2011). The use of appropriate scale can save time and cost of field checking. In addition, mapping scale really determines the correctness of delineation limits (Minar and Evans, 2008). Several studies have shown that in landscape mapping, there are two datasets that are always used, namely aerial photograph data / satellite image data and Digital Elevation Model (DEM) (Migon et al., 2013 and Argyriou et al., 2016). One loophole that researchers often overlook in landscape mapping is ignoring the linkage between the database and the mapping scale. As far as the author's knowledge, until the present time, there has not been any research on landscape mapping that takes into account the equivalence between the data sources and landscape map scales. In the mapping disciplines, many researchers refer to Tobler's equation (1988). Tobler (1988) developed an equation that shows the equivalence between the database resolution and the mapping scale that is resulted. The equation developed by Tobler (1988) is as follows.

$$\text{Mapping Scale} = \text{Spatial resolution of image (in meters)} \times 2 \times 100$$

Equation 1

The equation proposed by Tobler (1988) is global, so the researcher attempted to test Tobler's equations (1988) for thematic mapping, particularly for landscape mapping. The data being tested were differentiated by function. DEM data were used for landscape analysis in non-flat areas, while aerial image data were used for analysis on flat areas. The DEM data that were used consisted of 1) ETOPO (250 m); 2) SRTM 1 arc (30 m); 3) SRTM 3 arc (90 m); 4) TerraSAR-X (6,6 m); and 5) DTM of the aerial photographs (0,17 m).

The DEM data used in this study is terrain data (DTM). The DEM data can be seen in Figure 2. Landscape interpretation was done by the researchers on a maximum scale according to the basic data to compare with the Tobler (1988) pattern. The researchers also involved several other interpreters to test the data source in landscape mapping so that the subjectivity of the researchers could be minimized in the interpretation of landscape.

Baluran region, which has reliefs in the form of mountains and hills in the middle, eases the interpreters to identify the boundaries of different landscapes. Some hills and valleys such as Kakapa, Glengseran, Malang, and Mesigit complexes can be observed by using DTM data with a resolution below 30 meters. Some information in areas with flat reliefs is a little difficult to interpret with DTM with a medium resolution. The DTM data which greatly facilitates the interpretation for flat areas are the DTM data generated from the aerial photograph data. Such DTM data have a spatial resolution of 0.17 meters so that the condition of micro relief in some plains such as in savanna Bekol and Betek appears very clearly. Even, some pyroclastic materials of Mount Baluran eruption could still be interpreted with DTM data of aerial photograph analysis. The test results showed equivalence between data sources (DTM) with landscape mapping scale. The results of the linkage test between the DTM resolution and the landscape mapping scale are presented in Table 1. The same method was applied to landscape mapping in plains. The image data used for the current study includes 1) aerial photographs with UAV data; 2) Bing Maps Imagery (from UMD); and 3) Landsat 8 Image. The interpretation results by the researchers and other interpreters also showed minor differences.

Plain areas such as Bama, savanna Bekol Labuhan Merak, Karang Tekok and Pandean could easily be interpreted with two-dimensional data (2D). 2D data in the form of aerial photographs and images are helpful in showing the surface appearance of the earth that cannot be extracted from three-dimensional data (3D). One very striking example is in the crater wall of Mount Baluran. The interpretation result with 3D data, the crater wall of Mount Baluran appears convex with stone material associated with volcanic sand like other volcanic wall, but 2D data indicate that the crater wall of Baluran is dominated by materials in the form of igneous rock. 2D data can also help in analyzing the differences in vegetation density in Baluran. Based on the interpretation of 2D data, it can be seen very clearly that the vegetation in the west part of Baluran has a higher density compared to the vegetation in the east part. This is influenced by slope factors that affect climate factors, leading to differences in the development of surface soil and moisture of the soil itself.

The slopes facing the south or southeast direction are more affected by the dry eastern monsoon, so that these slopes have a low humidity marked by a low vegetation density. The differences in landscape interpretation of plains tend to be larger than those in hilly or mountainous areas. This fact suggests that the use of DTM is more effective in landscape mapping, and satellite imagery can be highly functional in assisting the interpretation on flat areas. The results of the linkage test between the aerial photography / image resolution with the scale of landscape mapping can be seen in Table 2.

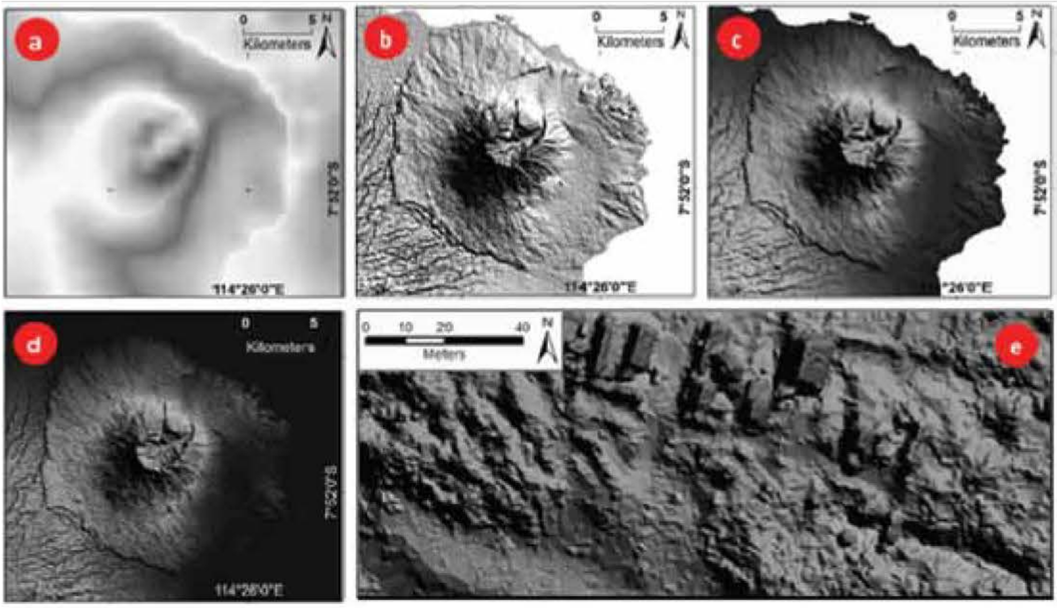

Figure 2: DTM data of the research location, (a) ETOPO; (b) SRTM 1 arc; (c) SRTM 3 arc (d) TerraSAR-X; (e) DTM of aerial photographs

Table 1: Data source and data source resolution in determining maximum scale of map

No.	Data Source	Resolution (m)	Maximum Scale of Map
1.	DTM Foto Udara	0.17	1:300
2.	TerraSAR-X	6.6	1:5,000
3.	SRTM 1 arc	30	1:25,000
4.	SRTM 3 arc	90	1:60,000
5.	E TOPO	250	1:400,000

Source: Analysis, 2017

Table 2: Linkage between aerial photographs / images and landscape mapping scale

No.	Data Source	Resolution (m)	Maximum Scale of Map
1.	Aerial Photographs	0.045	1:70
2.	Aerial Photographs	0.08	1:150
3.	Bing Maps	0.6	1:800
4.	Landsat 8 *Pan Sharpened*	15	1:12,500
5.	Landsat 8	30	1:35,000
6.	Bing Maps	150	1:250,000

Source: Analysis, 2017

Table 3: Comparison of linkage tests between data source resolution and landscape mapping scale from the interpretation results and calculation results using Tobler's equation (1988)

No.	Data Source	Resolution (m)	Maximum landscape mapping scale (Analysis)	Maximum landscape mapping scale (Tobler equation (1988))
1.	DTM Aerial Photographs	0.17	1:300	1:340
2.	TerraSAR-X	6.6	1:5,000	1:13,200
3.	SRTM 1 arc	30	1:25,000	1:60,000
4.	SRTM 3 arc	90	1:60,000	1:180,000
5.	E TOPO	250	1:400,000	1:500,000
6.	Aerial Photographs	0.045	1:70	1:90
7.	Aerial Photographs	0.08	1:150	1:160
8.	Bing Maps	0.6	1:800	1:1,200
9.	Landsat 8 *Pan Sharpened*	15	1:12,500	1:30,000
10.	Landsat 8	30	1:35,000	1:60,000
11.	Bing Maps	150	1:250,000	1:300,000

Based on the results of the linkage test between the database and mapping scale using DTM data and satellite imagery conducted in Baluran National Park area, it can be seen that the levels of information that can be extracted from the two types of data are different. DTM data are three-dimensional data that are easier to use in landscape mapping. The distinguishing elements that are evident in landscape mapping using 3D data are topography, relief and elevation. Image data or aerial photographs in the form of two-dimensional data are used to analyze the landscape on plains. The combination of the two data is preferable so that the interpreters can see the process interaction details of each unit of landscape (Birch et al., 2017).

The next step carried out to test the equivalence of the database and the scale in landscape mapping is to compare the pattern of the interpretation result with the calculation result using Tobler equation (1988) (see Table 3). The test results showed that the maximum scale in landscape mapping from the interpretation results conducted by the researchers has a greater value than that of the calculation results with the Tobler equation (1988). This shows that the equation developed by Tobler (1988) in landscape mapping is underestimate. The equivalence results presented by the researchers can be referred to in the landscape mapping with the same data and scale.

3.2 Interdependence among Parameters in Landscape Mapping

The shape, structure, elements and other parameters in determining the type of landscape are highly dependent on the academic background of the interpreters (Eisank et al., 2011). The issue is increasingly worse in Indonesia regarding the fact that there are many sciences that use landscape applications. Therefore, an interdependence analysis among parameters in landscape interpretation of a region is needed to accommodate various disciplines, especially earth science. Landscape is closely related to the three main constituents namely morphology, geomorphic processes and materials. The constituents of landscapes are further detailed according to the interpretation parameters of the ones interacting with each other. The morphology in Baluran used as the basis of analysis are the slope, relief and morphography. Baluran National Park area has a slope between 0°->45°. Baluran relief consists of flat relief, inclined, gradient, pitched, to mountainous.

The measurement of Baluran slopes is done on the elevation aspect, the direction of the slope, the incision rate, the length of the slope, the terrain, and the flow pattern.

Mount Baluran has an elevation of 1,240 meter above the sea level, indicating that it has mountainous relief (>500 m). It also has regular direction of slope in all directions with cone-shaped volcano. The direction of the slope also affects the soil moisture and also indirectly affects the density of vegetation in Baluran. In fact, the direction of the slope is always associated with insolation. Based on the authors' observation, in some mountains in Indonesia (including Baluran), the direction of the slope not only has relation with insolation, but is also closely related to the direction of the sea. One such example is in Mount Baluran, wherein the vegetation on the southern slope is less dense compared to that on the northern one. If the slope is only associated with insolation, the striking difference in the vegetation density should occur between the east-west directions (the direction of sunlight). The main aspects of the volcanic landform are originated from the morphography of Baluran in the incision, resulting in the surface flow patterns which are formed. The pattern of river flow which is dominated by radial type of flow pattern strengthens the theory that Baluran is a form of volcano.

Geomorphic process has a close relationship with the formation of the process results on the surface of the earth that is observed from the morphology. The association of each interrelated parameter helps in determining the identification of the type of morphological formation in Baluran. The origin of geomorphic processes is influenced by endogenous and exogenous processes. The condition of Baluran National Park that was observed is currently the result of endogenous process, followed by exogenous process. The origin of the volcanic process can be observed in the morphological form of the volcano and the origin of the process was observed from the indication of removal and fracture in some surface area. Exogenous poses can be observed from marine and karst surface formations surrounding Baluran area, close to the coast and denudation which has started to intensively explore Mount Baluran. The intensity of process is the process of surface formation over a period of time. The intensity of process observed up to the present time is the process of land exploration by the transportation and sedimentation process of surface materials.

The soil in Baluran which became the object of the study is the layer composition, the type and nature of the soil. Soil layers were observed from the upper and lower layers as well as the soil horizon. The soil layers in Baluran were found in different thickness in the plains to the mountains (topo sequence). The soil types found also varied; there were soil types from the Order of Entisols and Alfisols. The detailing of the soil type to the classification level of Group was analyzed based on the interpretation of a landscape map with a scale of 1:5,000 and laboratory analysis. The composition of the physical, chemical, and biological properties of the soil becomes as a data in the further analysis. Fast scales performed in the field analysis was done by measuring the salinity, soil moisture, texture, structure, carbonate content, lime content, and soil drainage. Regarding the composition of the soil properties, laboratory tests were carried out to determine the exact value of the soil content and to identify the origin of the soil formation in Baluran.

The observable rocks in Baluran are the rocks on the surface. The identification of the rocks was done by observing the rock found in the field and analysis of geological map. The rocks were identified by lithology, type and stratigraphy of the rock. Rock lithology could be analyzed by the nature or properties, weathering rate and rock age. Rock properties that were observed were physical properties (texture), chemical properties (mineral content of rocks) and rock biotic. The weathering rate indicates the level of intensive land degradation in Baluran. Relative rock age was observed from the arrangement of rock layers, the position of rocks towards other rocks. Absolute rock age is in accordance with the rock formation. The types of rocks observed in Baluran are igneous rocks and sedimentary rocks.

The stratigraphy of Baluran rock was observed based on geological map analysis. Rock stratigraphy is the arrangement of rock layers in accordance with the age of the rock formation. Volcanic rock formations (Qhvb) in Baluran are composed of volcanic rocks of breccia, tuff, and lava which are mostly andesite. Volcanic breccia is brownish gray, consisting of hollow andesite and pumice stone. The composition of brownish-gray lava consists of andesite lava, basalt, tuff, slate, and metamorphic sediments. The most widely observed surface rocks are andesite, basalt and pumice stone. The interaction results of various parameters of Baluran landscape that had been analyzed were then grouped by segments according to the depth of information that can be extracted and differentiated in two types of data parameters i.e. data that can be delineated (vector data) and data which can become database (attribute data) (Figure 3).

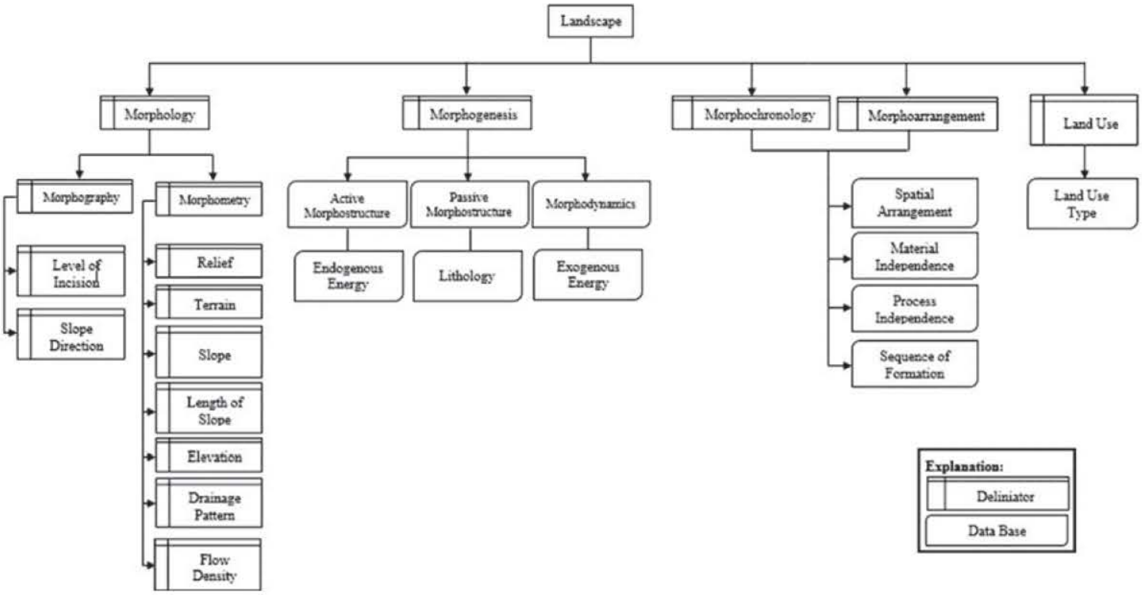

Figure 3: Model of minimum parameter systematics in landscape mapping, Source: Verstappen (1983) with modification, 2017

3.3 Multi-Scale Landscape Mapping Hierarchy

The classification and delineation of landscape units are based on the principle of earth surface characteristic homogeneity. Limiting the landscape units is the biggest challenge in landscape mapping as it requires special skills, especially when limiting the transition from two different landscape units (Fisher et al., 2004). Creating landscape maps requires the naming and classification of the landscape hierarchy attached to interpreters (Quintana et al., 2005). However, the ambiguity of the concept of multi-scale landscape mapping is still common (Quintana et al, 2004). Jelinski and Wu (1996) conducted a literature study and concluded that there is no appropriate theoretical framework for multi-scale landscape mapping. Based on the theory proposed by Jelinski and Wu (1996), the researchers were interested in solving the multi-scale landscape mapping hierarchy issues by carrying out a case study in Baluran. The drafting of a multi-scale landscape mapping hierarchy was conducted based on field testing and not by numerical analysis because not all the parameters of landscape can be used as numeric numbers.

The effort to draft a multi-scale landscape mapping hierarchy is done by interpreting large-scale landscapes. The fact shows that in the drafting of landscape maps, both the researchers and government always do small-scale mapping first. This is based on the ease of initial compilation, followed by detailing in large-scale landscape map. However, such context is not fully correct because when doing large-scale detailing, there will be many major errors on a small scale due to over-generalization. On the basis of such theory in the drafting of multi-scale landscape mapping hierarchy, the procedure of map-making begins from large-scale landscape maps to small-scale ones. The landscape mapping in Baluran is done by delineating TerraSar-X imagery combined with High Resolution Satellite Imagery to produce Landscape Map with a scale of 1:5,000. The samplings were carried out at some points that contained landscape characteristics with striking differences of the parameters of material, morphology, and geomorphic processes. Furthermore, the sampling was also carried out at some points whose interpretation results were questionable. Re-delineation and field surveys were carried out repeatedly to obtain an appropriate pattern for the needs of the analysis of data source and landscape information.

The linkage between map-scale and the resolution of database refers to the linkage test of data source resolution and landscape mapping scale resulted from the field test results (Table 4). The scale can give an overview of the area of each landscape unit, so that the heterogeneity and homogeneity elements can be known. The hierarchical drafting was done by doing inventory on the interaction model among the minimal parameters in landscape mapping (Figure 3). Based on such model, the linkage of each parameter to the delineation unit of each landscape unit was tested.

Table 4: Hierarchy of multi-scale landscape mapping

No.	Scale	Basic Data Resolution (m)		Parameters	Number of sample/ 100ha	Precision (%)
		DTM	RS			
1.	1:250,000	<110	<100	Relief	2	75
				Land Cover		
2.	1:100,000	<45	<42.5	Relief	4	80
				Land Cover		
3.	1:50,000	<20	<15	Relief	8	85
				Elevation		
				Land Cover		
				Level of nicks		
				Flow Pattern		
4.	1:25,000	<11	<10	Relief	16	90
				Elevation		
				Land Cover		
				Level of nicks		
				Flow Pattern		
				Shape of the slope		
5.	1:10,000	<4	<3.5	Relief	16	95
				Elevation		
				Land Cover		
				Level of nicks		
				Flow Pattern		
				Shape of the slope		
				Length of slopes		
				Slopes		
6.	1:5,000	<1.9	<1.5	Relief	32	95
				Elevation		
				Land Cover		
				Level of nicks		
				Flow Pattern		
				Shape of the slope		
				Length of slopes		
				Slopes		
				Material Surface		
				Characteristics material cover		
				Weathering rate		

The result of the linkage between the mapping scale and the parameters were once again tested in the field in order to obtain the information homogeneity and heterogeneity hierarchy within each unit of landscape. The results of the multi-scale landscape mapping hierarchy analysis can be seen in Table 4.

The heuristic study of the preparation of multi-scale landscape map hierarchy is used to distinguish landscape parameters on a certain scale. The authors hope that this multi-scale landscape mapping hierarchy model can be used comprehensively, given the widespread use of landscape analysis in Indonesia. Multi-scale landscape map hierarchy modeling can be a means of exploring theories of different types of landscape heterogeneity. Appropriate methodology will provide better understanding and process characterization through appropriate landscape hierarchy.

4. Conclusion

The results provide an understanding that the procedure in landscape mapping should be equivalent to the landscape classification hierarchy. Landscape mapping classification system is required to be used for multiscale landscape mapping purposes. A multiscale landscape mapping hierarchy can be used to support other thematic mappings that can be derived from landscape maps such as biomass mapping. The result of the multiscale landscape mapping test in Baluran gives an overview of the importance of multiscale landscape mapping hierarchy. The smaller the mapping scale, the larger the mapping unit, the smaller the number of samples, the lower the information depth, the larger the mapping scale, the smaller the mapping unit, the larger the number of samples, the higher the information depth. The formulation of multiscale landscape mapping hierarchy can assist in the drafting of national standards for multi-scale landscape mapping whose standard regulation has not yet been established in Indonesia.

Multi-scale landscape mapping should be done sequentially from a large scale to a small scale so that during the generalization process of the boundary, the delineation boundary bias that is resulted is not too large. Further studies can be conducted in areas that have different landscape characteristics from Baluran, such as karst, denudational or *eolan* areas.

References

Ali, R. R. and Kotb, M. M., 2010, Use of Satellite Data and GIS for Soil Mapping and Capability Assessment. *Nature and Science,* 8(8), 104-115.

Argyriou, A. V., Teeuw, R. M., Rust, D. and Sarris, A., 2016, GIS Multi-Criteria Decision Analysis for Assessment and Mapping of Neotectonic Landscape Deformation: *A Case Study from Crete. Geomorphology,* 253, 262-274.

Asner, G. P., Anderson, C. B., Martin, R. E., Knapp, D. E., Tupayachi, R., Sinca, F. and Malhi, Y., 2014, Landscape-Scale changes in Forest Structure and Functional Traits along an Andes-to-Amazon Elevation Gradient. *Biogeosciences,* 11, 843-856.

Birch, S. P. D., Hayes, A. G., Dietrich, W. E., Howard, A. D., Bristow, C. S., Malaska, M. J., Moore, J. M., Mastrogiuseppe, M., Hofgartner, J. D., Williams, D. A., White, O. L., Soderblom, J. M., Barnes, J. W., Turtle, E. P., Lunine, J. I., Wood, C. A., Neish, C. D., Kirk, R. L., Stofan, E. R., Lorenz, R. D. and Lopes, R. M. C., 2017, Geomorphologic Mapping of Titan's Polar Terrains: Constraining Surface Processes and Landscape Evolution. *Icaru,* 282, 214-236.

Bourne, R., 1931, *Regional Survey and its Relation to Stock-Taking of the Agricultural and Forest Resources of the British Empire. Oxford Forestry Memoir.* 13. Clarendon, Oxford.

Christian, C. S., 1958, The Concept of Land Units and Land Systems. *Proceedings of the 9th Pacific Science Congress,* 20, 74-81.

Debelis, S. P., Bozzo, A. A., Barrios, M. B. and Buján, A., 2005, the Relationship between Soil Characteristics and Vegetation as A Function of Landform Position in an Area of the Flooding Pampa. *Spanish Journal of Agricultural Research,* 3(2), 232-242.

Eisank, C., Draguf, L., Gotz, J. and Blaschke, T., 2011, Developing A Semantic Model of Glacial Landforms for Object-based Terrain Classification-The Example of Glacial Cirques. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* Vol. XXXVIII-4/C7.

Fenneman, N. M., 1916, Physiographic Divisions of the United States Plate I. *Ann Assoc Am Geogr* 6:1898.

Fisher, P., Wood, J. and Cheng, T., 2004, Where is Helvellyn? Fuzziness of Multi-Scale Landscape Morphometry. *Transactions of the Institute of British Geographers,* 29(1), 106-128.

Hadmoko, D. S., Lavigne, F., Sartohadi, J., Hadi, M. and Winaryo, 2010, Landslide Hazard and Risk Assessment and their Application in Risk Management and Landuse Planning in Eastern Flank of Menoreh Mountains, Yogyakarta Province, Indonesia. *Natural Hazard.* 54:623-642.

Host, G. E., Polzer, P. L., Mladendo, D. J., White, M. A. and Crow, T. R., 1996, A Quantitative Approach to Developing Regional Ecosystem Classifications. *Ecol Appl.* 6:608-618.

Jelinski, D. E. and Wu, J., 1996, The Modifiable Areal Unit Problem and Implications for Landscape Ecology. *Landscape Ecol.* 11, 129–140.

Libohowa, Z., Winzeler, H. E., Lee, B., Schoeneberger, P. J., Datta, J. and Owens, P. R. 2016, Geomorphons: Landform and Property Predictions in a Glacial Moraine in Indiana Landscapes. *Catena,* 142, 66-76.

Meikle, C., Stokes, M. and Maddy, D., 2010, Field Mapping and GIS Visualisation of Quaternary River Terrace Landforms: an Example from the Rio Almanzora, SE Spain. *Journal of Maps,* 531-542.

Minar, J. and Evans, I., 2008, Elementary Forms for Land Surface Segmentation: The Theoretical Basis of Terrain Analysis and Geomorphological Mapping. *Geomorphology,* 95, 236–259.

Migon, P., Kasprzak, M. and Traczyk, A., 2013, How High-Resolution DEM Based on Airborne LiDAR helped to Reinterpret Landforms-Examples from the Sudetes. SW Poland. *Landform Anal.* 22, 89–101.

Moss, M. R. and Nickling, W. G., 1980, Landscape Evaluation in Environmental Assessment and Land Use Planning. *Environ Manage.* 4:57–72.

Pain, C. F., 1985, Mapping of Landforms from Landsat Imagery: an Example from Eastern New

South Wales, Australia. *Rem SensEnvir.* 15:55–65.

Powell, J. W., 1875, Physical Features of the Colorado Valley, I Mountains and Valleys. *PopSci Month* 7:384–399.

Quintana, A. G., Hidalgo, J. F. G., Duque, J. F. M., Pedraza, J. and Martin, J. A. G., 2004, Geological Factors of the Guadalajara Landscapes (Central Spain) and their Relevance to Landscape Studies. *Landsc Urban Plan.* 69:417–435.

Quintana, A. G., Duque, J. F. M., Martın, J. A. G., Hidalgo, J. F. G., Pedraza, J., Herranz, P., Rincon, R. and Estevez, H., 2005. Geology and rural landscapes in central Spain (Guadalajara, Castilla—La Mancha). *Environ Geol.* 47: 782–794.

Samodra, G., Chen, G., Sartohadi, J., Hadmoko, D. S. and Kasama, K., 2014, Automated Landform Classification in a Rockfall-Prone Area, Gunung Kelir, Java. *Earth Surf. Dynam.,* 2, 339–348,

Sartohadi, J., 2001, Geomorphological Analysis for Soil Mapping using Remote Sensing and Geographic Information Systems: A Case Study in Western Gunungkidul, Yogyakarta-Indonesia, Leopold-Franzens University of 119 Innsbruck, Institute of Geography, Innsbruck-Austria.

Sartohadi, J., 2007, Terapan Geomorfologi Dalam Pengelolaan Sumberdaya Air. *Alami: Jurnal Air, Lahan, Lingkungan dan Mitigasi Bencana.* Vol. 12, No.1. ISSN: 0853-8514.

SNI: Standar Nasional Indonesia (Indonesia National Standard), 2002, Penyusunan Peta Geomorfologi (Geomorphology Mapping), Badan Standarisasi Nasional.

Tobler, W. R., 1988, *Resolution, Resampling, and all that.* In Building Database for Global Science, eds. H. Mounsey and R. Tomlinson, 129-37. London: Taylor and Francis.

van Zuidam, R. A., 1983, *Guide to Geomorphological Aerial Photographic Interpretation And Mapping*. ITC, Enschede, the Netherlands.

Verstappen, H. T., 1983, *Applied Geomorphology*. Elsevier Science Publisher Co., Amsterdam.

Wheeler, G. M., 1889, United States Geographical Surveys West of the one Hundredth Meridian, Washington Final Reports I-VII.

Wianti, K. F., 2014, Land Tenure Conflict in the Middle of Africa van Java (Baluran National Park). *Procedia Environmental Sciences.* 20 459-467.

Wu, J., 1999, Hierarchy and Scaling: Extrapolating Information along a Scaling Ladder. *Can. J. Remote Sensing*. 25, 367–380.