Mapping geomorphological environments of bendo watershed ijen mountain, banyuwangi east of java

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Abstract. Geomorphology is a comprehensive landscape study that reviews a space from the aspects of morphology, chronology, arrangements and processes. Accompanied by observation and field validation, the rapid development of remote sensing technology greatly helped the geomorphological mapping process. This research is aimed at geomorphological mapping of the Bendo Watershed area which can then be used as a basis for various spatial studies. The hybrid approach and on screen image interpretation (OSII) method on DEM data, optical satellites, and lithology units was carried out to obtain morphological, morphochronological and morphoarrangement information, while morphoprocess information was obtained through field observations. Sixteen units of landforms have been successfully mapped consisting of the origin of volcanic and fluvial processes with upstream morphological characteristics in the form of slopes of the Ijen Complex and downstream in the form of fluvial plains. Overall surface material is a product of volcanoes in the upstream area with a process of erosion and dominant landslides. Mapped landform units can be a unit of analysis and basic information for regional planning studies, land evaluation, and disaster.

1. Introduction
Geomorphological maps have a broad scope of studies as representation, analysis, and visualization of the shape of the earth's surface and the processes that occur in a space. A space in geomorphology is reviewed through four main approaches, namely morphological, morphochronological, morphoprocess, and morphological arrangements [1-5]. Geomorphological mapping is considered a technique that produces basic data that can be used in other scientific practices such as environment [6-8], disaster [2,9], regional development and land evaluation [10,11]. Geomorphological mapping requires field methods in data acquisition. Field visits are needed to describe the shape, position in the topographic base map used [2]. Although the field survey for geomorphological mapping is time consuming and subjective [4], [6], [12], field mapping is a direct method of field assessment and geomorphological analysis, validation, and information gathering for subsequent analysis [6]. Field mapping also provides experience for surveyors to get used to and recognize field landscape conditions [12].

Techniques in geomorphological mapping experienced rapid development due to the existence of remote sensing technology and geographic information systems (GIS). The 2-dimensional model and 3-dimensional earth surface and physiological changes can be observed using remote sensing results that are useful for geomorphological mapping [4,5,8,13-15]. The disadvantages of field geomorphological survey can be covered by remote sensing data in the form of 3-dimensional models. The availability of Digital Elevation Model (DEM) data with less than 10 m spatial resolution can map geomorphological features quickly and precisely so that field activities are only in the form of validation and follow-up observations [6,13]. Observation of physiography from the land surface, especially bare land can be observed clearly using temporally high-resolution remote sensing data systems [14]. Moreover, the role...
of geographic information systems makes it easier to store data and extraction of input data into new spatial data in vector form that is capable of storing information needed in making geomorphological maps [2, 6, 16]. The study of geomorphology is an important step in various spatial analyzes including land use, especially in relatively complex mountainous areas. Volcanic land is a dynamic land that is closely related to geophysical processes, eruption, and is upstream of various watersheds. As a tool, geomorphology has a major contribution in the watersheds management related to sustainable use of space to prevent negative impacts of development. These problems include floods, erosion, translocation of sediments and pollutants, and its accumulation on waterways and the surrounding areas due to spatial use [17]. Therefore, watershed management must be balanced between human activities and various geomorphological environments [18]. This study focused on geomorphological studies on the Bendo watershed which originated in the Ijen Mountains Complex, Banyuwangi, East Java. The upper reaches of the Bendo watershed are located on Mount Ijen, Mount Merapi, and Mount Rante, while downstream of the Bendo River empties into the Banyuwangi City (coastal area). The variety of physiography on Bendo watershed can represent topokuen in the Ijen Mountains and Banyuwangi from upstream to downstream. The geomorphological study of the Bendo watershed can be used as a basis for various studies such as regional planning, land evaluation, and disaster.

2. Methods
Remote sensing technology, geographic information systems, and field surveys are used for making geomorphological maps of Bendo watershed. Morphological information was obtained from digital elevation model (DEM) data processing, morphochronological information and soil surface material obtained from the geological map of the Ijen sheet, while morphological information was obtained from optical system remote sensing data. Geomorphological mapping of Bendo watershed consists of stages of data collection and data analysis. The research flow of Bendo watershed geomorphological mapping is illustrated in Figure 1.

![Figure 1](image)

**Figure 1.** Research flow of geomorphological mapping on Bendo Watershed

2.1. Research Area
Geomorphological mapping research was carried out on the Bendo watershed, Banyuwangi, East Java with an absolute location of 114°12'53.43" E to 114°23'11.45" E and 8°03'36" S to 8°13'19.17" S. Relatively, the location of the study was located in Licin District, Glagah District, Giri District, Kalipuro District, and Banyuwangi District, East Java Province. Bendo watershed’s upstream located in the Ijen Mountains Complex, namely Mt. Ijen, Mt. Merapi, and Mt. Rante elongated watersheds up to Bali Strait.
in the Banyuwangi District. The elevation of the study area ranges from -3.78 to 3269.52 above sea level as wide as 40.13 km². The study area is presented in Figure 2.

2.2. Data Collection Procedures
This research uses secondary data types namely remote sensing products such as Sentinel-2 and Digital Elevation Model (DEM) data. Surface rock information was obtained from the Ijen Geological Sheet Scale 1: 50,000 which was obtained from the Center for Volcanology and Geological Disaster Mitigation (PVMBG) in 1988. While the primary data used were process observations and several land characteristics in the field. The Sentinel-2 product used is Sentinel-2B with the acquisition date of August 13, 2018 in the Banyuwangi area which has been processed to level-1C. Level-1C is Sentinel data which has not provided Top-Of-Atmosphere (TOA) reflectance with multispectral sub-pixel registration [20]. For Geomorphological Mapping, Sentinel-2 products are used as optical information on the shape and cover of land in the study area. Some studies use remote sensing optical systems to get spatial and cognitive information using a combination of original colors or certain combinations [21], [22]. To generate landscape, this research use DEMNAS data which classified as detailed and assists the morphological mapping activities of an area, although it is DSM data that has not fully displayed the actual elevation [23]. DEM data with a spatial resolution less than 10 m can help map out regional morphology in detail in a short time [13]. For support information, geological maps are needed to make geomorphological maps as lithological information. Units in geomorphological studies are related to endogenous factors such as geology and the underlying structure [5]. The geological map of the Ijen sheet scale 1: 50,000 was used in this study. A survey is needed to examine the geological and geomorphological components in the field [2]. In addition to validation, field surveys are also useful for providing experience to surveyors to get used to and recognize conditions in the field and add further information [6].

2.3. Data Analysis Method
Data analysis methods include watershed extraction process, morphological extraction, and on screen image interpretation using a hybrid approach. The Digital Elevation Model (DEM) provides altitude information in the form of raster spatial data. Altitude data can be extracted into information about spatial morphology including watersheds because the simple data structure and easily operated by various processes in geographic information systems [24]. The watershed extraction process is based on
the "eight-pour point" algorithm based on pit filling, calculation of flow direction and accumulation of flow in DEM data [25].

Topographic Position Index (TPI) is an analysis of raster-based elevated data that compares the digital number to a pixel with the surrounding area, producing positive and negative indices. Pixels that have a positive index indicate that the area is higher than the surrounding area, the negative index value indicates that the area is lower than the surrounding area, while the index close to zero indicates that the area is a flat area [26]. Since DEM data is the basic data for making TPI (see Equation 1), geomorphological studies have been greatly helped because of the presence of high-resolution DEM data for morphological analysis.

\[
TPI_i = M_0 - \sum_{n=1}^{m} \frac{M_n}{n}
\]

where \(M_0\) is evaluated value of elevation model, \(M_n\) is elevation on grid, and \(n\) is the total number of points around it used in the evaluation.

Another analysis used in obtaining morphological information is the slope and hillshade slope extraction. The degree of slope and impression of 3 dimensions makes it easy to identify land forms on screen image interpretation [1]. On screen image interpretation using a hybrid approach. This method is a combination of morphological data (TPI, slope, hillshade), morpho-management (true color sentinel 2B), and morphochronology (geological map) observed together using the on screen image interpretation (OSII) approach. Hybrid / mixed approaches can represent micro geomorphological units tapped from TPI and macro geomorphological units obtained from OSII [21,28].

| Symbol | Landform unit | Area (km²) |
|--------|--------------|------------|
| P/5/F/4/SE | Alluvial Plains Ijen Volcano Complex eroded slightly | 5.41 |
| M/1/V/9/IE | Phreatic air fall deposits on the upper slopes of Mt. Ijen eroded intensively | 0.54 |
| M/2/V/11/ME | Pyroclastic air fall on middle slope of Mt. Kukusan eroded moderately | 0.33 |
| M/1/V/1/IE | Lava flow deposits 2 on the upper slopes of Mt. Rante eroded intensively | 4.56 |
| M/1/V/6/SE | Pyroclastic flow deposits 1 on the upper slope of Mt. Merapi eroded slightly | 2.32 |
| M/2/V/1/SE | Lava flow deposits 2 on the middle slopes of Mt. Rante eroded slightly | 0.16 |
| M/3/V/2/SE | Pyroclastic flow deposits 3 on the down slope of Mt. Rante eroded slightly | 1.11 |
| M/3/V/5/SE | Pyroclastic deposits 2 on the down slope of Mt. Merapi eroded slightly | 2.14 |
| M/3/V/8/SE | Lava flow deposits 2 on the down slope of Mt. Merapi eroded slightly | 5.46 |
| U/4/V/7/SE | Lahar flow deposits 1 on the foothill of Mt. Merapi eroded slightly | 5.57 |
| U/4/V/3/SE | Rock deposit on foothill of Mt. Kemenang eroded slightly | 4.52 |
| M/2/V/10/ME | Pyroclastic air fall deposits on the middle slope of Ijen Volcano Complex eroded moderately | 1.59 |
| U/5/V/10/SE | Pyroclastic air fall deposit on the plains Ijen Volcano Complex eroded slightly | 1.62 |
| M/1/V/11/ME | Pyroclastic air fall on the upper slope of Mt. Kukusan eroded moderately | 0.24 |
| M/2/V/10/SE | Pyroclastic air fall deposits on the middle slope of Ijen Volcano Complex eroded slightly | 0.83 |
| U/3/V/7/SE | Lahar flow deposits 1 on the down slope of Mt. Merapi eroded slightly | 3.72 |

3. Results and Discussion
Sixteen classes of landform units in Bendo Watershed were successfully mapped within study area. Bendo watershed is dominated by a form of land originating from volcanic processes in the upstream area, while the downstream area of Bendo watershed is formed as a fluvial land. Detailed of Bendo watershed landform showed in Table 2. Geomorphology was mapped based on three basic classification type such morphological, morphochronological, and morphological conditions. While the morphoprocess was identified along with the field survey. The scale of analysis in the study used a scale of 1: 50,000, but for cartographic purposes the scale used in the layout was 1: 35,000 (Figure 2).

3.1. Morphology Condition of Bendo Watershed
Upper area of Bendo Watershed located in the Ijen Mountain Complex which consisting of the East side of Mount Rante, the southwestern side of Mount Ijen, and the west side of Mount Merapi. Downstream of the Bendo watershed topographically empties into the Bali Strait precisely in urban
areas, Kec. Banyuwangi which is relatively flat. Remote sensing technology can be used as slope analysis and morphology for geomorphological analysis in an area [5], as well as the Bendo watershed, generally the slopes are classified into 6 slope classes [29], while TPI is used to map the slope area more rigidly.

Figure 3. Bendo Watershed geomorphological map

The topographic position index displays information about the position of a land on the surrounding land. Regions that have a positive TPI value indicate that the area is higher than the surrounding area, in the Bendo watershed it can be a hill, or a ridge. Regions that have TPI values close to 0 indicate that the area is flat, in the Bendo watershed in the form of agricultural land, alluvial plains, and inter-volcanic plains. TPI which has a negative value indicates that the area is lower than the surrounding area, in the Bendo watershed in the form of valleys and basins. (Figure 4) This study uses the TPI study with a 25...
m analysis scale to obtain micro-morphological results from the area around the mapping. The greater the scale of analysis, the greater the generalization. Selection of the scale of the TPI conditional analysis according to the research period [26].

**Figure 4.** Topographic position index with hillshade appearance and field conditions, there is a description of the slope class and the slope percentage in each image showing slope information.

TPI, hillshade, and slope extraction are morphological information on the Bendo watershed. Next, on screen image interpretation, true color Sentinel 2B, generalizations are used as morphological and morphological arrangements. Optical images are used to see the appearance of the original location of the study so that it can provide a boundary / arrangement of field conditions other than topography [21]. The morphology of the geomorphological map of the study was classified as 4 classes (plain, wavy, hilly, and mountainous), while the morphorangement were classified as 5 classes (upper slope, middle slope, lower slope, foothill, plain).

3.2. **Morphocronological Condition and Surface Material of Bendo Watershed**

Geomorphological studies include the study of lithology and bedrock. Hence, it is necessary to have lithology and surface material information to obtain morphocronological information within study area. Interpretation of geomorphology of land will be more accurate if supporting data is available including topography, geology, hydrology, and sedimentology [2,18]. Bendo Watershed is located on the toposkuen of the upstream downstream Ijen Volcano Complex. Based on the Geological Map of the Ijen Caldera Complex there are 11 lithology units in Bendo Watershed (Table 3). Volcanic material dominates lithology units in the upstream to the middle of the Bendo watershed, especially the Ijen Complex volcanic material. The type of material produced varies from falling eruption deposits, lava, and lava which then forms the soil. Geology provides basic material information and material results in the study area as a comprehensive analysis along with morphology so that geomorphology can be used as basic information for various studies including land use and land evaluation [10,30].
Table 2. Bendo Watershed's geological formation and surface material

| Symbol | Formation                              | Surface Material                                                                 |
|--------|----------------------------------------|----------------------------------------------------------------------------------|
| Kjp    | Mt. Kukusan Air Fall Deposits          | Scoria deposits, alkaline andesite lytic fragments, and Mt. Kukusan pyroclastic fall ash |
| KK-jp  | The Ijen Caldera Complex Air Fall Deposits | Scoria deposits, andesite fragments, pumice, pyroclastic fall ash Ijen Caldera Complex |
| Ljp    | Ijen Crater Phreatic Air Fall Deposits | Andesite fragmented deposits, pumice, ash, scoria, mud, rocks falling phreatic Ijen Crater |
| M-2    | Mt. Merapi-2 Lava Flow                 | The precipitate is composed of basalt, augite, oxidant, and olivine from the lava flow 2 of Mt. Merapi |
| M-Ih1  | Mt. Merapi-1 Lahar Deposits            | Sand and mud deposits, andesite fragments of basalt and pumice from lahkar 1 sedimentation of Mt. Merapi |
| Map1   | Mt. Merapi-1 Pyroclastic Deposits      | Andesite lithic fragments of basalt magmatic deposits from pyroclastic deposits 1 of Mt. Merapi |
| Map2   | Mt. Merapi-2 Pyroclastic Deposits      | Rough ash deposits with basaltic andesite fragments and scoria from pyroclastic deposits 2 of Mt. Merapi |
| Qa     | Alluvial                               | Alluvial Clay                                                                     |
| QpV2   | Mt. Kemuning Volcanic Rock             | Lahar deposite and tuff of Mt. Kemuning                                          |
| Ra-ap3 | Mt. Rante-2 Pyroclastic Flow Deposits  | Medium ash deposits with lytic fragments, basalt andesite, pumice stone from pyroclastic flow 3 of Mt. Rante |
| Ra-l2  | Mt. Rante-2 Lava Flow                  | Basalt composition, porphyritic-hypocrystalline, augite, oxide, olivine lava flow of Mt. Rante |

3.3. Morphoprocess Condition of Bendo Watershed

As a watershed, the Bendo watershed has a digital role in the study of lithology and slope. Watersheds integrate water flows that carry and move lithology and sedimentation [17]. Slope aspects also affect material allocation so that a comprehensive study of geomorphology describes the processes that occur in a space (morphoprocess) [1], [6], [21]. The field study classifies the dominant processes that occur in the Bendo Watershed consisting of Erosion and Landslides. Erosion is the dominant process that occurs in watersheds, especially the Bendo watershed which has a slope class greater than 8% wider than the area classified as data (table 4) has a high erosion potential. Erosion events are influenced by surface material, rainfall, land cover, and land processing and slope aspects.

Table 3. Bendo watershed slope classes

| Slope classes     | Area (km) | Area (%) |
|-------------------|-----------|----------|
| Smooth Plain/flat Plain (0%-2%) | 2.29 | 5.71 |
| Gentle ramps (3%-7%) | 8.38 | 20.89 |
| Gentle slope (8%-13%) | 10.45 | 26.03 |
| Rather steep (14%-20%) | 6.77 | 16.87 |
| Steep slope (21%-55%) | 8.91 | 22.19 |
| Extremely steep (>56%) | 3.32 | 8.28 |

Some erosion events in the Bendo watershed were detected quite strongly, and some others were not detected. Large erosion generally occurs in the upper reaches of the Bendo watershed, especially on bare land on the slopes of the Mount Ijen Complex. The downstream area does not indicate erosion due to the gentle slope aspect. Landslides are often found on the slopes of Mount Ijen and Mount Merapi (Figure 5). Areas classified as bare land are only covered by shrubs with the potential for very high erosion and landslides, especially when the area has very steep slopes and easily released eruption material. Soil erosion and landslides are prone to volcanic eruption material in areas that have steep slopes [31]. Based on the landslide material and the process there are 3 types of longs found in the field, among others, earth slides, slide debris, and rock fall. Morphoprocess information obtained from the field becomes an input in a geomorphological map that indicates the dominant process that occurs in a space. Different processes on the same land will affect different usage and maintenance characteristics.
Figure 5. Bendo watershed landslide phenomenon (a) rockfall, (b) debris slide (c) earth slide

4. Conclusion
The remote sensing technology play an important role to study geomorphological fiture within study area. From all aspects offered, the detailed digital elevation scale model provides detailed information on morphology through topographic modeling. Within analysis of slope, TPI, and hillshade morphological information can be easily mapped. In addition, there is still need survey on geomorphological information in the field to adjust the results of remote sensing processing. Field surveys are considered to be an important step in this study. There are 16 units of landforms based on morphological, morphocronological, morphoarrangement and morphoprocess analysis. In general, Bendo watershed is a water catchment area that represents the toposkuen of the Ijen Mountains Complex. The Lithologically dominated by volcanic and fluvial material with a dominant process of erosion and landslide. Comprehensive analysis of geomorphology can be used as basic information on the analysis of various landscape studies.

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