Developing land capability to reduce land degradation and disaster incident in Bendo Watershed, Banyuwangi

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Abstract. Land degradation have caused decline in land productivity and triggering landslide incident in Bendo Watershed. This area has been selected as study area which represent characteristic upland area of the region. The research examines land capability analysis in order to reduce land degradation and disaster incidents and for sustainable use of land resources. The geomorphology approach was used along with sixteen of landform unit as unit sample. Further, artificial neural network models were used to classify land capabilities. Network architecture 10-8-1 was used on classification process due to the lowest error value factors. The findings of the study present that 20,46% of Bendo watershed are prone to land degradation. Physical characteristic within area are contributing increasing land degradation. The capability classes of Bendo watershed ranges from class II to class VII. The upstream areas have erosion and intensive landslides as its limited factors, hence tend to have poor land capability classes. While the middle to downstream areas of Bendo watershed have better land capability classes with more diverse land use recommendations.

Keywords: land capability, degradation, neural network, land conflict analysis

1. Introduction

Land degradation is a common ecological problem, especially on dry land regions. Increasing human need for land is a major factor causing land degradation since land degradation involves complex interactions between humans and the environment (1,2). As a result, the decline in land quality, erosion and landslides, hydrological disasters, and other social economic impacts occurred (3,4). Efforts to avoid this condition by utilizing land with appropriatel, ecologically feasible, economically viable, and socially desirable (5,6).

In this study we used watershed boundary as our study area. Watershed is an appropriate unit of space for managing environmental problems since it is have strong relation with pedological and geomorphological characteristics (7,8). In addition, watershed also consists of integration between biotic and abiotic components. The relationship between the components are dynamic (9). Within watershed, uncertainty of land degradation impacts may occur. Hence, it is need a comprehensive solution. Land capability analysis is one of important analysis to reduce land degradation problem. It is include the hydrological and soil characteristics analysis (5,10,11) and also relates to mitigating land from degradation problem (1,12–14).

The basic land capability analysis we used was based on the land characteristic and the identification of limited factors. As an assessment, land is grouped into VII classes according to their potential component where the higher the class the more restricted the use is allowed (15–18). The first three
classes are suitable for agricultural use while the rest have limited functions such as grasslands and protected forests. The land criteria used in evaluating land capabilities are physiographic properties and land limiting factors such as erosion, landslides, and floods.

Furthermore, in order to analyse the land capability, remote sensing and geographic information systems are used as calculation tools, zoning, area tabulation, and reclassification of spatial and non-spatial data on land characteristics (19–21). Neural network is used as a valuation method considering that the land capability parameter has a separate class with a constant value range (22,23). In addition, artificial neural networks are able to accommodate inputs that have different structure and stretch of pixel values, so uncertainty can be avoided (22,24). Evaluation subjectivity can be minimized by this system based on weighting ability and self-training. In some studies, the results of the artificial neural networks classification are superior to other models (25–27).

This study focuses on land capability evaluation in Bendo Watershed Ijen Mountain, Banyuwangi, East Java. The Upper Bendo Watershed is located on Mount Ijen, Mount Merapi, and Mount Rante, while downstream of the Bendo Watershed is located on the urban coast of Banyuwangi (28,29).

2. Study Area

Administratively, Bendo Watershed (4013.27 ha) is located in the north of Banyuwangi Regency (360,590.91 ha). Bendo Watershed covers 5 sub-districts (Licin District, Glagah District, Giri District, Kalipuro District, and Banyuwangi District). Stream water flows to the southeast, which originates in Ijen Mountains complex, namely Mount Ijen, Mount Merapi, and Mount Rante. Elongated shape with downstream being in the Bali Strait (Figure 1).

It is located between 14°12'53.43" E to 114°23'11.45" E and -8°03'36" S to -8°13'19.17" S, Datum WGS 1984. The north is the mountainous plateau of Ijen, the southeast is the foot of Mount Ijen. Altitude ranged from -3.78 to 3269.52 m above sea level (Figure 2a). Slope conditions are relatively flat to the sloping in the middle to the downstream, while the upstream is classified as steep to very steep. Riverbanks are clearly delineated quite a bit steep in the middle area and increase until the upstream, while downstream riverbanks classified as flat (Figure 2b).

The Bendo watershed is filled with the complex geological formation of the Ijen Mountains and its sedimentation. Ijen Caldera fall deposits originating from the caldera formation since 300,000 - 50,000 years ago (30). The next eruption phase forms a type of poligenetic volcano (Mount Merapi, Kukusan, and Rante) on the caldera wall, while the Ijen Crater is a monogenetic type mountain. Poligenetic volcano groups produce lava flows, pyroclastic flows, and basaltic - andesitic pyroclastic falls. Meanwhile, the monogenetic volcano group produces cylindrical cones with basaltic and andesite-basaltic lava flows (30). The geological formation of the Bendo watershed consists of: (a) lava flows, lahars, and pyroclastic deposits of Mount Merapi, (b) lava flows and pyroclastic flows of Mount Rante, (c) pyroclastic fall flows of Ijen Crater, (d) fall deposits of Mount Kukusan, and (e) Mount Kemuning rocks (Figure 2c). Alluvial deposits are found in the downstream of the Bendo Watershed as a result of the material deposition from the Ijen Mountains Complex to the Bali Strait (30).
Various physiographic of the Bendo Watershed have an impact on rainfall conditions related to water availability. Rainfall ranges from 1415.5 mm - 1850 mm occur in the downstream area to the middle of the watershed, while rainfall ranges from 1850 mm - 2375 mm located in small part of the middle and upstream areas (figure 2d). Regional rainfall is one of the land characteristics which supports the water availability and external factors of erosion and landslides (4,18,31).

Figure 1. Geographical location of Bendo Watershed
The preservation of watersheds needs to be maintained through conservative use. For a system, watersheds are processors that process inputs (rainfall and human intervention) with sustainable or detrimental outputs \(^9\). There are 10 land use classes in the Bendo watershed. Built-up areas are concentrated in the downstream, agricultural land are located in the middle to downstream areas, while dryland forests, shrubs and bare land are located upstream (figure 3).
3. Method

3.1. Workflow
In general, this study consisted of three main steps including identifying existing land use, evaluating land capability, and identifying existing land use conflicts with land capability (figure 4). Remote sensing products from Sentinel-2 multispectral images with a spatial resolution of 10 meters were used to identify existing land use, while land characteristics were collected using geomorphological zoning sourced from Digital Elevation Model (DEM) data, geological information, and field surveys. Analysis of artificial neural networks is used as a land capability classification model. Identification of land use conflicts and land capability is processed by Geographic Information Systems using overlay functions and spatial calculations.

Figure 3. Existing land use of Bendo Watershed
3.2. Data Collection Procedures

This study utilizes primary data and secondary data as parameters of analysis. Secondary data consists of remote sensing products (satellite Sentinel-2), Digital Elevation Model (DEM), geological maps, Indonesian Digital topographic maps, and annual rainfall data from rain gauge stations around Bendo Watershed. Primary data consists of the results of field observations (soil depth, coarse fragment, surface fragment, outcrops, and soil drainage), while the results of laboratory processing are soil salinity. The limiting factors (erosion hazard and flood hazard) are obtained from the processing of primary data and secondary research data.

3.2.1. Sentinel-2 Product. Multispectral imagery Sentinel-2 was chosen as a medium of identification of existing land use in the Bendo watershed with a spatial resolution of 10 m (true color and near infrared channels) and 5 days’ temporal resolution. Sentinel-2 is the ideal product for 1:50,000 mapping considering the relatively medium spatial resolution (32). The satellite European Space Agency (ESA) product used is Sentinel-2B, the acquisition date of August 13, 2018 in Banyuwangi Regency which has been processed to level-1C. Level-1C is sentinel data that has not been corrected for Top-Of-Atmosphere (TOA), in detail in table 1 (33).

| Table 1. Sentinel-2 Level-1C Product Characteristics |
|-----------------------------------------------|
| **Characteristic** | **Description** |
| High-level Description | Top-of-atmosphere reflectance in cartographic geometry |
| Production | System generation |
| Distribution | On-line distribution |
| Data Volume | 600 MB (each 100x100 km²) |
| Orto-image projection | UTM/WGS84 |

3.2.2. Digital Elevation Model DEMNAS. DEM National (DEMNAS) is an Indonesian digital elevation model product with high spatial resolution. DEMNAS is built from IFSAR data (5m resolution), TERRASAR-X (5m resolution) and ALOS PALSAR (11.25m resolution), by adding stereo-plotting Mass point data. DEMNAS spatial is 0.27-arcsecond, using the vertical datum EGM2008 (34). Briefly the National DEM specifications are presented in table 2 (34).

| Table 2. DEMNAS Characteristic |
|--------------------------------|
| **Item** | **Description** |
| Name file | DEMNAS_xxxx-yyyy-v1.0.tif (for 1:50K Map Sheet Number) |
| Resolution | 0.27-arcsecond |
| Datum | EGM2008 |
DEMNAS is used for geomorphological zoning of the Bendo Watershed. It is classified as a detailed remote sensing product and helps mapping of land morphological characteristics. The use of digital elevation models with spatial resolution <10 m can be used in various studies including land capability analysis with detailed and short time morphological mapping functions (35).

3.2.3. Geological Maps, Indonesian Digital Topographic Maps, and Regional Rainfall Data. Lithology information in geomorphological land units is tapped from the geological map. Geological Map of Ijen Sheet Scale 1: 50,000 was obtained from the Center for Volcanology and Geological Disaster Mitigation (PVMBG) in 1988. Zoning geological maps describe differences in soil material produced, erosion conditions, and weathering that are widely used in land evaluation (36). Indonesian Digital Topographic Maps (scale 1: 50,000) products of the Geospatial Information Agency are used to determine the administrative boundaries of the research area. Climate conditions are obtained from regional rainfall data. Rainfall data is an input of land capability which acts as water availability. Rainfall conditions affect the potential of land because it has an impact on erosion events (37), the higher the rainfall the higher the ability to erode the soil thus limiting land use (18,31). Annual rainfall at 3 rain gauge stations (Banyuwangi Station, Licin Station, and Glagah Station) are used to produce regional rainfall in the Bendo Watershed.

3.2.4. Field survey and Laboratory. Land characteristic data collected using field survey by purposive sampling based on landform units as the smallest unit analysis. Geomorphological zoning was chosen due to the comprehensive approach offered and it can be used for land analysis (38–40). Soil depth, coarse fragment, surface fragment, soil drainage, outcrop, surface temperature, soil structure, and soil samples (for texture analysis, organic matter, salinity, and soil permeability) are the land capability parameters used. Geohazard information consists of flood and erosion phenomena obtained from the processing of primary and secondary data and field validation surveys.

3.3. Data Analysis Method

Data analysis methods include classification of land use, classification of land capability using artificial neural network analysis, and analysis of land use conflicts on land capability.

3.3.1. Land Use Classification. Radiometric correction of Sentinel-2B product is done to calibrate the DN value of each pixel to reflectance value. Radiometric correction is needed to improve the visual quality of the image and improve pixel values according to the spectral reflectance of each object (24). The radiometric correction used is DOS1 Atmospheric Correction in the SCP QGIS Toolbox with the following equation:

\[
\rho = \frac{\pi (L_{sat} - L_p) d^2}{E_0 \cos(\theta_s)}
\]

where, \(\rho\) is the value of surface reflectance, \(L_{sat}\) is emission on satellite, \(L_p\) is emission of media, \(d\) is distance of earth and sun according to astronomical measure, \(E_0\) is exoatmospheric solar radiation, and \(\theta_s\) is angle of sunenitic (41). The radiometric correction process is continued by clipping data according to Bendo Watershed and the land use classification process.

Spatial resolution of Sentinel-2B is included in medium resolution imagery that can be classified based on object orientation (OBIA). Some studies state that object-based land cover classification in medium to high resolution remote sensing images produces more accurate results than pixel based classification (42,43). Multispectral segmentation is selected by inputting the true color channel and near infrared Sentinel-2B data, the parameter segmentation scale is determined by trial and error starting
from 10-200. The land use classification is adjusted to the Indonesian National Standard of Land Use and Land Cover Classification (44).

3.3.2. Neural Network as Land Capability Model, Land characteristics is converted into vector format spatial data and assessed according to the class of land capability. Thematic maps of land capability parameters are converted in raster format to get the smallest information (pixels) from the layer, pixel-based spatial analysis (cell based modelling) is widely used to model land conditions (19,22,25,45). Spatial data in raster format is converted in ASCII format to get the extraction of each pixel in the form of a matrix, then Notepad ++ is used to store and manipulate coordinate data. Matrix of each parameter is converted into a column form as input data analysis using matrix conversion program with the algorithm \( M_{11\ldots n}, M_{j1\ldots n} \rightarrow M_{i1} M_{j1\ldots n} \) which is presented in Fortran.

Artificial neural network is supervised classification systems relying on iterations on neurons. Consisting of 3 main layers, namely input layer, hidden layer, and output layer. Parameters of land capability in the form of ASCII become input layer, hidden layer as analysis, and output is the result index. The classification process classifies inputs into 3 parts consisting of training sets (15%), validation sets (15%), and test sets (70%). The ability of iterations in artificial neural networks is useful for evaluating errors until they reach the specified limit (24,25,45). Levenberg-Marquardt (LM) algorithm is used to calculate weights between input layer and hidden layer, between hidden layer and output layer with repetition classification system. LM is chosen because it has the function of minimizing the sum-square error function (46). The classification is stopped if one of the following conditions is met, (a) the iteration reaches the specified limit, (b) the target error achieved is \( = 0 \), (c) the gradient is smaller than the minimum gradient, (d) \( mu \) value exceeds \( mu_{max} \), and (e) validation increases more than \( max_{fail} \). The classification output is converted back into vector format and classified according to the land capability class.

3.3.3. Land Conflict Analysis. The basic principle of land use conflict when actual land use deviates from optimal use, in this case the use is based on land capability. The land capability class is narrowed down to 4 hierarchical class functions (table 3) (47,48), as well as actual land use. Consisting of agricultural land, pastures, pastures / forests, protected forests.

| Land capability or actual use | Land capability code | Land use actual code |
|------------------------------|----------------------|---------------------|
| Agriculture                  | 1                    | 1                   |
| Pasture                      | 2                    | 2                   |
| Pasture/Forest               | 3                    | 3                   |
| Forest                       | 4                    | 4                   |

Analysis of land use conflict was identified from the difference between land capability class hierarchy and the actual land use class. The value of the difference becomes the level of conflict called conflict class (table 4) (47,48). Geographic information systems are used to map the distribution of conflicts spatially with vector-based processing (12). Conflict class determines the urgency regarding land management in accordance with the land capability class.

| Conflict Classes | Land Capability – Land Use Actual | Recommendation |
|------------------|----------------------------------|----------------|
| Class 1          | 4 – 3 = 1                        | Pose a risk or permanent limitations when used for annual crops and pasture. Its use must be guided conservatively |
|                  | 3 – 2 = 1                        |                |
|                  | 2 – 1 = 1                        |                |
| Class 2          | 4 – 2 = 2                        | Land that is not suitable for intensive planting but can still be used for grasslands, can be |
|                  | 3 – 1 = 2                        |                |
Land not suitable for intensive planting and pastures, can be handled by reforestation or environmental preservation

4. Results and Discussion

4.1. Land Use Classification

Based on land use classification, 10 land use classes were successfully identified (table 5). Paddy fields become the dominant land use in Bendo Watershed (20.10%) which is concentrated in the middle to downstream areas. Dryland forest is in the upstream area with a percentage of 18.43%, followed by built-up land, mixed gardens, shrubs, moor, pastures, bare land, water bodies, and wetland forests. Spatially land use can be witnessed in Figure 3.

| Land use     | Land use classes for conflict analysis | Area (ha) | Percentage |
|--------------|---------------------------------------|-----------|------------|
| Paddy field  | Class 1                               | 806.80    | 20.10      |
| Dryland forest| Class 4                               | 739.77    | 18.43      |
| Built-up area| Class 1                               | 564.49    | 14.07      |
| Mixed Gardens| Class 3                               | 500.72    | 12.48      |
| Shrubs       | Class 3                               | 495.29    | 12.34      |
| Moor         | Class 3                               | 380.40    | 9.48       |
| Pastures     | Class 2                               | 263.05    | 6.55       |
| Bare land    | Class 1                               | 246.89    | 6.15       |
| Water bodies | Class 4                               | 8.68      | 0.22       |
| Wetland forest| Class 4                               | 7.16      | 0.18       |

Land use conflict analysis requires more general land use parameters in its classification to facilitate identification of differences between land use and land capability. The actual land use classified into 4 classes (figure 5) consists of class 1 as an agricultural area or equivalent to agricultural functions, class 2 as a pastures or similar use, class 3 as a pastures / forest or similar land class, while class 4 as a forest that has a protected function (12,47,48). Classification is hierarchical which considers the relationship between land use, ecological functions, and vulnerability to degradation / disasters (4,6,47).
The higher grade value is equivalent to the higher ecological value of the land use. Paddy fields, bare land, and built-up are classified as class 1 because utilization is more dominant than ecological functions (49,50). Pastures are classified as class 2 because they have higher ecological functions than bare land and agricultural land (51). Furthermore, dense vegetation cover minimizes soil loss and surface runoff (52), therefore mixed gardens classes and similar land uses are classified as class 3. Forests are classified as class 4 due to their ecologically ideal functions (18).

4.2. Land Capability Classification

A statistical summary of the results of artificial neural networks as a tool for analysing land capability (table 6) consists of MSE (mean squared error) and regression values. Overall the MSE in the study got a number below 9.0e-11, while the regression value of the training set, validation set, and test set got a value close to 1 indicating a strong relationship between the results of the classification with the input. Network architecture is an important factor in neural network processing, some studies have shown that the right architecture selection can optimize time and network performance (22,45). Based on several trials during the testing phase, architecture 10-8-1 (figure 6) can complete the learning process with quite high results. The best MSE performance obtained is classified as very high / close to 0 (1.4552e-11).
05) in the 687 iteration. In this study, the iteration stopped because validation increased from max\_fail, this condition appears to avoid overtraining (53).

There are 6 classes of land capability (class II-VII) in the Bendo river basin that were successfully mapped. Classes with medium arable function (II) have an area of 8.70% of the total area in the middle to downstream area. The limited arable function (III) is class domination spread over the downstream and upper middle slope areas with a total area of 40.23% of the watershed area. The function of intensive grazing land (IV) has an area of 19.74% spread upstream to downstream of the watershed. Land with limited grazing function (V) covering an area of 5.90% spread over the upstream and middle watersheds with steep slope, while limited production forest (VI) with an area of 5.29% and protected forest (VII) with an area of 20.14% is in the upper watershed. The spatial distribution of land capability is presented in Figure 7a.

Based on various characteristics of the Bendo watershed, the dominant limiting factors are erosion potential, coarse fragment, surface fragment, outcrops, soil depth, and soil drainage in upstream areas. Regarding the erosion potential of water, it is directly proportional to the magnitude of the slope (4,54). In addition, the diversity of geological material and rock outcrops in the upstream of Bendo Watershed causes the thin layer of soil and rough fragments on the surface and within the soil. The middle area of the Bendo watershed to the downstream has a fairly thick layer of soil, a limiting factor in this area is surface rock, rough material, and the discovery of rock outcrops in a small area. Towards the downstream, erosion potential decreases but the potential for flooding is widely spread, as a center of occupancy and concentration of built-up land increases the potential and impact of flood hazards (55). Soil salinity throughout the Bendo watershed has a low concentration and can be ignored.

Land conflict analysis uses land capability as a comparison. To facilitate identification, the land capability classes has been simplified into 4 classes according to the analysis used (figure 7b). Class 1 is an area that functions as agriculture, including class II and class III at the research location. Class 2 consists of classes IV and V which function as pastures or grazing areas. Class 3 is a grazing class and / forest which is a production forest (VI), while class 4 is a protected forest classified as an ability class (VII).

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**Table 6. Statistic summary of neural network analysis**

| Samples       | MSE        | R           |
|---------------|------------|-------------|
| Training data | 7.54169e-11| 9.99999e-01|
| Validation data | 7.91931e-11| 9.99999e-01|
| Test data     | 8.22028e-11| 9.99999e-01|

*Figure 6. Network architecture 10-8-1*
4.3. Land Conflict Analysis
Land capability is a recommendation for a land to be utilized, while land use is a condition of land that has been used. Land use that is not in accordance with its capabilities will have a negative impact on land, especially degradation (2–4). The difference between land capability and land use is a step to identify land degradation (1,12,47,48). Identification of land problems in the Bendo watershed produces 3 hierarchical classes regarding the level of land degradation (figures 7, 8) which is then called land use conflict.

Figure 7. (a) Land capability of Bendo Watershed, (b) Land capability classes base on conflict analysis

Figure 8. Land use conflict
An area of 79.54% of the area in the Bendo river basin is classified according to its use, while as many as 20.46% experience land use conflicts that have the potential to cause degradation. Consisting of 19.07% of the area affected by class 1 conflict, 0.34% of the area affected by class 2 conflict, and 1.05% of the area affected by class 3 conflict. Spatially, class 1 land conflicts occurred in the whole Bendo watershed with a centralized in the upstream and middle of the watershed, while class 2 and 3 land conflicts are only centered on upstream areas.

The impact of land degradation on upstream areas will easily spread to other areas in a watershed ecosystem. Upstream watersheds have both land and water conservation functions (9,10,18), degradation as a result of changes in land use, especially in upstream areas can reduce water potential and damage to land (56). Land conflicts in the upstream of Bendo watershed occur because protected forest areas function as shrubs and bare land in the Ijen Crater Tourism Area and Mount Rante. Landslides often occur in the upper reaches of the Bendo watershed as a result of land degradation (figure 9 a-c). Eruption material in bare land with steep slope conditions has a rough texture, with a high weight of soil volume and low water holding capacity so that the potential for landslides (54,57).

Erosion in the middle to downstream areas is not as effective as in the upstream area. The expansion of agricultural land occurs on the Middle slope of Mount Ijen. Transfer of agricultural land functions that do not consider the ability of land to be a source of environmental degradation (2,4,47,48). Plantation land on sloped areas was converted into intensive agriculture resulting in mud floods on surrounding area as an indication of degradation that occurred in the middle Bendo Watershed (28,29), the area identified in this study as a class 1 conflict zone.

Degraded land must be managed more carefully in an effort to prevent negative degradation impacts, especially in the upstream areas of the watershed. Several studies offer sustainable development efforts and rehabilitation in areas affected by degradation (6,10,58). In addition, watershed management planning needs to be conceptualized comprehensively as an effort of sustainable development and optimal land use (5,9).

5. Conclusion

Land degradation is a serious threat to watershed both directly and indirectly. Land capability identification can be a solution to minimize land degradation issues in the study area. The result showed that area of 1963.87 ha (48.93%) in the Bendo watershed falls in the suitable for medium class and limited scale agriculture, 1029.15 ha (25.64%) suitable for grazing, 212.13 ha (5.29) suitable for grazing and forests, while the rest (20.14%) functioned as conservation areas and protected forests.

Furthermore, according to land degradation mapping, 46% of the Bendo Watershed has the potential to be degraded with ranges of grades 1-3, while the majority of land (79.54%) is utilized according to its potential.

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