Spatial modelling of watershed health assessment by using GIS

C Setyawan\textsuperscript{1,2}, S Susanto\textsuperscript{1} and CY Lee\textsuperscript{3}

\textsuperscript{1}Department of Agricultural and Biosystem Engineering, Faculty of Agricultural Technology, Universitas Gadjah Mada, Yogyakarta 55281, Indonesia.
\textsuperscript{2}Department of Tropical Agriculture and International Cooperation, International College, National Pingtung University of Science and Technology, Pingtung 91201, Taiwan, ROC.
\textsuperscript{3}Department of Soil and Water Conservation, College of Engineering, National Pingtung University of Science and Technology, Pingtung 91201, Taiwan, ROC.

E-mail: chandra_tsap@yahoo.com

Abstract. Watershed assessment methods have been developed in many types of approaches and purposes. However, the assessment concepts which are explicitly considering spatial aspects of a watershed remain unclear. The present study performed a spatial modeling for watershed health assessment in a Geographic Information System (GIS). Five indicators presented in GIS raster maps such as annual rainfall, land slope, land use/land cover (LULC) types, soil types and population density were used for the assessment and applied in Progo watershed, Central Java Province, Indonesia. A quantitative scoring was applied to classify indicator value and to categorize the watershed health level in five zones (very poor, poor, moderate, good and very good). The result shows that the study site is covered by three health level zones (poor, moderate and good). About 47.85\% of the watershed area has a moderate health level. While, 39.04\% and 13.11\% of the watershed area are covered by areas with poor and good health level, respectively. Spatially, the area with poor health level is dominated by farmland and steep sloping area. Spatial modeling enables a watershed health assessment with a more specific and understandable result for watershed problems control.

1. Introduction

In a good health condition, a watershed has a good ability to control the balance of water availability during the dry and the wet season. Hence, droughts in the dry season and floods in the wet season can be avoided. Presently, intensive land explorations of watersheds for many purposes without good conservation practices increase land degradation problems significantly [1-3]. This situation endangers the function of the watershed in keeping the system of water balance. The same situation has also occurred in tropical watersheds as happened in the present study. A massive land exploration for farming and the effect of heavy rainfall enhances land degradation particularly in the form of soil erosion and sedimentation [4]. A reliable watershed assessment tool with specific output and result is required for monitoring and evaluation purposes to solve problems in watersheds.
Mostly, watershed assessment is performed to calculate a specific indicator or purpose such as sedimentation, water discharge, erosion and others [5-7]. While, the assessment of watershed health status which considers many aspects of a watershed system including spatial aspect is still limited. In this study, an assessment of watershed health was performed in GIS-based modeling. The main concept of the assessment was considering all important aspect of a watershed system. Data scarcity had become the main obstacle to perform the modeling particularly in determining indicators for the assessment. By considering data availability, the present study was conducted by using five indicators reflecting important aspects of a watershed system. Data of the present study were collected from many sources. The application of GIS in the present study provides better and more specific information for watershed management purposes.

2. Methodology

2.1. Study site
The present study was performed in Upstream Watershed of Progo which is administratively located in Temanggung Regency, Central Java Province, Indonesia (Figure 1). The study site covers about 417.7 km² area and has more than 2,000 mm rainfall in a year with the lowest and highest point are 500 and 1,450 m.a.s.l., respectively. The average daily temperature and relative humidity are 20°C and 74.45%, respectively. Climatically, the study site lies under tropical climate region with average daily sunshine duration is 35.23%. Mostly, the upstream area of the study site is used for tobacco plantation by the local inhabitant.

2.2. Indicators of the study
The present study was performed by using overlaying technique in Arc GIS 10.1. Indicators of the study were presented in raster maps of GIS in 30 m cell size (resolution). A raster calculator (map algebra) of spatial analysis tools was used for total scoring of indicators. Each indicator of the study (annual rainfall, land slope, soil type, LULC type and population density) was scored based on three categories i.e. poor (score= 5), moderate (score= 3) or good (score= 1), where the category of each indicator was determined.
based on standard values from various sources. All related information about the raster map (indicator) was available in the attribute table of the map. The total score is the sum of all indicator’s score.

2.2.1. Annual rainfall and land slope. The category and score for annual rainfall value were determined based on water need for evapotranspiration in the study site (4 mm/day or \( \approx 1,500 \) mm/year). Three categories were proposed for this indicator such as good (score= 1) for annual rainfall >2,000 mm, moderate (score= 3) for annual rainfall 1,500-2,000 mm and poor category (score= 5) for annual rainfall <1,500 mm. Rainfall and evapotranspiration data were collected from four climate stations in Temanggung, Kaloran, Parakan and Jumo (see Figure 1) for the three past years (2016-2018). A low annual rainfall (<1,500 mm) may result in drought and some problems in the watershed. Therefore, annual rainfall data is necessary as one of the primary indicators for watershed health assessment.

For land slope, the data (map) was obtained from Indonesia Topographic Map in 2018. Land slope was classified and categorized in three classes refer to US Soil Conservation Service [8, 9] such as good (score= 1), moderate (score= 3) and poor (score= 5) for areas with land slope class 0-15%, 15-40% and >40% respectively. The land slope has a significant effect on watershed degradation problem, especially soil erosion, hence the score for low slope area was one (1) and for the steep sloping area was five (5). Figure 2 shows rainfall (IDW method) and land slope maps.

![Rainfall and land slope maps](a) (b)

Figure 2. Annual rainfall (a) and land slope (b) maps of the study site.

2.2.2. Soil type. Soil map of the study site was obtained from the Main Office of Serayu Opak Rivers (BBWS.SO), the Ministry of Public Work Indonesia which is issued in 2012. According to soil erodibility studies in java island [10, 11] which consider soil vulnerability for erosion, three categories for groups of soil which are commonly found in Java Island were used in this study such as good, moderate and poor for soil type of Latosol (score= 1), Lithosol/andosol (score= 3) and Regosol/grumusol (score= 5) respectively. Soil map indicates that the study site (watershed area) is covered by latosol soil (score= 1).

2.2.3. Land use/land cover (LULC) and population density. Land use/land cover (LULC) in the study site was identified in six types (exclude the water body) as shown in Figure 3a. For scoring purpose, LULC types were grouped and categorized into three types i.e. good (score= 1) for vegetation type (forest and shrub), moderate (score= 3) for settlement type and poor (score= 5) farming land type (dry farmland, mixed garden and rice field) refer to USLE C factor value for erosion study [11, 12, 13]. Farming land occupies the largest area in the study site (82.4%), followed by settlement (12.8%) and vegetation (4.8%).

Meanwhile, population density data were collected from statistical data of Temanggung, Wonosobo and Semarang Regency (issued by Central Statistical Agency of Indonesia) for the three previous years (2016-2018) and presented in a regency based (Figure 3b). According to watershed monitoring and
evaluation tools standard issued by the BBWS.SO office, the Ministry of Public Works Indonesia in 2010 [14], three categories were proposed such as good (score= 1), moderate (score= 3) and poor (score=5) for population density (people/km$^2$) 0-250, 250-750 and >750 respectively.

![Figure 3. Land use types (a) and population density (people/km$^2$) (b) in the study site](image)

Raster maps of indicators reflect the existing condition in the study site. Though, three categories were used for scoring, substantively some indicators such as annual rainfall, soil types and population density only had less than three types range value (score) as described in Table 1. There is no fixed standard for the range value of indicators. Therefore, some references are used in this study.

**Table 1. Scoring information of attribute table in raster maps of the present study**

| Id | Name of Map/indicator       | ∑ type | Existing value and score of indicators |
|----|-----------------------------|--------|---------------------------------------|
| 1  | Annual rainfall (mm)        | 1      | >2,000 = 1                            |
| 2  | Land slope (%)              | 3      | 0-15= 1, 15-40= 3, >40= 5             |
| 3  | LULC types                  | 3      | Vegetation = 1, Settlement= 3, Farmland= 5 |
| 4  | Soil types                  | 1      | Latosol= 1                            |
| 5  | Population density          | 2      | 250-750= 3, >750=5                    |

2.3. **Criteria for a watershed health condition**

The present status of the watershed health level is determined based on a total score of indicators as described in Table 2. Five categories were proposed and used to describe the present status of watershed health level. The use more categories for leveling watershed condition status provides more specific information about status and problems in the watershed [4, 15].

**Table 2. Watershed health level based on the total score of indicators**

| Total score of indicators | Watershed health level |
|---------------------------|------------------------|
| 0-5                       | Very good              |
| 6-10                      | Good                   |
| 11-15                     | Moderate               |
| 16-20                     | Poor                   |
| 21-25                     | Very poor              |
3. Results and Discussions

Overlaying method in a raster calculator enables addition scores of raster map. The result of spatial modeling for watershed health assessment in a GIS is presented in Figure 4. There are three types of health level zones (area) in the study site (good, moderate and poor) with the lowest and the highest score were six (good category) and sixteen (poor category). Figure 4 indicates three factors (indicators) such as land slope, land use and population density have a dominant effect on the present status of watershed health in the study site due to the value of those indicators are various (more than one type).

Generally, the zone with good health level occupies the eastern part of the study site. This zone has vegetations land cover (forest) with a more moderate sloping area (15-25%) and moderate population density (250-750 people/km²). The zone with moderate health level covers west and middle-east part of the study site. This zone is dominated by farmland type with a few vegetation land cover (shrub) and settlement in the west part. The land slope in the middle-east is low (0-15%), whereas in the west part is covered by various type of land slope from 0% to >40%. The population density is generally moderate (250-750 people/km²) in the middle-east part and poor (>750 people/km²) in the west part. The effect of land slope on watershed health problem especially erosion in the steep sloping area can be reduced by using vegetation cover as reported in previous studies [13, 16]. Good vegetation covers (dense forest with cover plants) are effective to control land degradation problems due to soil erosion, surface runoff or sedimentation. Meanwhile, the zone with poor health level category is largely found in the middle part of the study site. This zone is mostly covered by farmland type (with a few of settlement), low sloping area (0-15%) and poor population density (>750 people/km²).

![Figure 4. Spatial distribution of health level status in the study site](image)

Farmland and population density have a vital role in the forming of a poor health level zone. Those two factors have a strong correlation and indicate a high dependence of local inhabitant on the land. This situation has been also found largely in many developing countries and become one of the main factors causing land degradation problem of watersheds particularly in the form of soil erosion and sedimentation as reported by Merten and Minela [17] and Guerra and Correia [18]. The using of five indicators for the assessment complement some previous studies which are focusing on a single indicator for watershed assessment such as Gebretsadik [5], Fukunaga et al. [6] and Thakkar et al. [7]. Hence, the
The present study provides more reliable information to understand the general condition of watershed health. Meanwhile, the application of spatial modeling enables problems and health level mapping specifically in a watershed scale which is not clearly provided by previous studies (e.g. Setyawan et al. [4]; Susanto and Setyawan [15]).

4. Conclusion
Spatial modeling in a GIS for watershed health assessment is producing a more specific result of health level zonation. The present study reveals that there are three types of health level zones in the study site i.e. good, moderate and poor which are centered in some parts of the watershed area. In general, about 47.85% of the watershed area is covered by a moderate health level zone. While, poor health level zone is also covering a significant area in the watershed (39.04%). This zone is a priority for conservation practices planning in the watershed. More than one indicator with the same category (e.g. poor/score 5 or moderate/score 3) resulting in different patterns in different areas. Development of score range for health level categories as presented in Table 2 for the future study may provide more specific results in health level status zonation.

References
[1] Pramono I B 2014 Mitigation of land degradation at Juana Watershed, Central Java J. Degrade. Min. Land Manage. 2 (1) 235-242.
[2] Niang D, Yacouba H, Doto C V, Karambiri H, Lahmar R 2015 Land Degradation Impact on Water Transfer of Soilplant-Atmosphere Continuum in The Burkinabe Sahel Larhyss J. 24 109-127.
[3] Chalise D, Kumar L, Kristiansen P 2019 Land Degradation by Soil Erosion in Nepal: A Review Soil Syst. 3 12.
[4] Setyawan C, Susanto S, Sukirno 2013 A Quantitative Assessment Model of Land and Water Conservation Measures Case Study at Upper Watershed of Kali Progo Proc. of International Symposium on Agricultural and Biosystem Engineering (Yogyakarta: Dept. of Agricultural and Biosystem Engineering Faculty of Agricultural Technology Universitas Gadjah Mada Indonesia).
[5] Gebretsadik Z M 2014 Watershed degradation and the growing risk of erosion in Hawassa-Zuria District, Southern Ethiopia J. Flood Risk Manag. 7 118-127.
[6] Fukunaga D C, Cecílio R V, Zanetti S S, Oliveira L T, Caiado M A C 2015 Application of the SWAT hydrologic model to a tropical watershed at Brazil Catena 125 206-213.
[7] Thakkar A K, Desai V R, Patel A, Potdar M B 2017 Impact assessment of watershed management programmes on land use/land cover dynamics using remote sensing and GIS Remote Sens. Appl.: Soc. and Environ. 5 1-15.
[8] Soil Conservation Service 1974 Soil surveys of Lehigh/Northampton Counties (USA: Lehigh Valley Planning Commission).
[9] Tang T 2000 Slope profile analysis and classification on limestone residual hills in Guilin, China Middle States Geographer 33 40-53.
[10] Vis M 1987 A Procedure for the Analysis of Soil Erosion and Related Problems in Water and Land Resources Management Studies (Netherland: International Reference Centre for Community Water Supply and Sanitation).
[11] Asdak C 2007 Hidrology and Watershed Management (Yogyakarta: Gadjah Mada University Press, Indonesia).
[12] Andriyanto C, Sudarto, Suprayogo D 2015 Estimation of soil erosion for a sustainable land use planning: RUSLE model validation by remote sensing data utilization in the Kalikonto watershed J. of Degraded and Min. Lands Manag. 3 (1) 459-468.
[13] Cadaret E M, McGwire K C, Nouwakpo S K, Weltz, M A, Saito L 2016. Vegetation canopy cover effects on sediment erosion processes in the Upper Colorado River Basin Mancos Shale formation, Price, Utah, USA Catena 147 334-344.
[14] Main Office of Serayu Opak Rivers 2010. Hand Book for Monitoring and Evaluation of Water Resources Facilities (Yogyakarta: The Main Office of Serayu Opak Rivers the Ministry of Public Works Indonesia).

[15] Susanto S, Setyawan C 2010 Assessment Model of water Resource Conservation Measures Case Study at Upper Watershed of Sempor and Wadaslintang Dam, Proc. of International Seminar of ICID (Yogyakarta: ICID).

[16] Zhou P, Luukkanen O, Tokola T, Nieminen J 2008 Effect of vegetation cover on soil erosion in a mountainous watershed Catena 75 319-325.

[17] Merten G H, Minella J P G 2013 The expansion of Brazilian agriculture: Soil erosion scenarios Int. Soil and Water Conserv. Res. 1 (3) 37-48.

[18] Guerra C A, Correia P T 2016 Linking farm management and ecosystem service provision: Challenges and opportunities for soil erosion prevention in Mediterranean silvo-pastoral systems Land Use Policy 51 54-65.