Geospatial-Interface Water Erosion Prediction Project (GeoWEPP) application for the planning of Bompon Watershed conservation-prioritized area, Magelang, Central Java, Indonesia

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Abstract. Bompon watershed is located in the Quaternary Volcano (Mt. Sumbing) and tertiary (Mt. Menoreh) transition zones. The implication is that the soil material is well developed with super thick characteristic and is sensitive to erosion. The existence of land processing interventions by the locals supports the increasingly high rate of erosion. The use of the GeoWEPP model facilitates the rapid calculation of erosion rates and evaluation of conservation applications. The aim of the study was to calculate the erosion rate and determine the priority areas with the GeoWEPP erosion model. The GeoWEPP application was chosen because of its ability to show the spatial distribution of erosion and sedimentation. Evaluation of prioritized areas is carried out with the erosion rate criteria of the model and the important value of the land. The results of the Bompon watershed erosion model show variations in erosion and sedimentation. High erosion is in hilly morphology (slope of > 25%) with agricultural land annual crops (moor) and mixed gardens. High sedimentation is on the colluvial plains with moorland and rice fields land use. The existence of agricultural areas with cassava, corn and rice commodities has important value for villagers. Agriculture is the main livelihood of the community so that it has priority in handling conservation to maintain the productivity of the agricultural land. The assessment criteria for rate erosion and important value of the land produce priority sub-watershed that location covering 2 locations with an erosion rate of 441 tons/ha and 438.2 tons/ha.

1. Introduction
Bompon watershed, which is located in the transition zone, especially the Quaternary volcano (Mt. Sumbing) and tertiary (Mt. Menoreh), describes the character of a micro-watershed in Indonesia. Bompon watershed has a complex topographic characteristic that is gentle to steep hills with relief amplitude of ± 60 m. Soil material develops well with super thick soil layers (> 2 m in depth) and is sensitive to erosion. The land in the study area is managed into agricultural land with the main commodities of cassava and corn [1]. Land management that is not in accordance with the principles of conservation causes a decrease in the quality of land which is characterized by high erosion rates [2]. The activities have an impact on the opening of the soil layer. The presence of rain in the open
land area also causes the infiltration rate to decrease and increases runoff. The increased runoff will increase erosion intensity and sediment distribution in the downslope area [3]. Intensive erosion problems in Bompon watershed are urging conservation activities to control the erosion[1, 4-5].

Conservation efforts within the watershed start from assessing soil vulnerability to erosion. Data limitations become obstacles in these activities. The application of the model in the calculation of erosion can be carried out to solve the limitations. One of the erosion calculation models is GeoWEEP (Geospatial-Interface Water Erosion Prediction Project). GeoWEPP is an erosion model from the previous model development, namely WEPP (Water Erosion Prediction Project) [6]. The GeoWEPP model has several data inputs; climate, soil, topography, and land management data. These parameters are sensitive parameters to analyze the formation of erosion and sedimentation processes [7]. This model is able to represent the watershed area with the characteristics of micro size, topographic complexity, and intensive agricultural areas [8]. The results of the model produce the distribution of spatial erosion variations in the form of maps. Quantitative results of erosion values are presented in each hillslope unit.

The purpose of this study was to calculate erosion and determine priority areas for conservation in the Bompon watershed. Erosion calculations with the GeoWEPP model have values on every single hillslope[6]. The hillslope on the sides and on the upper part of the stream composes a sub-watershed analysis unit. The erosion prediction in the Sub-watershed unit is useful as initial information on the assessment of conservation priority areas. The priority area is determined based on the relationship between erosion value and the importance of the land in the sub-watershed analysis unit. Areas with high erosion and the existence of high economic value land for the community are references in determining priority conservation areas.

Priority areas assist in recommending conservation technique plans. Conservation recommendations from research by Setiawan, et al 2018. is a JALAPA technique (Coconut Mesh), wood sediment trap and polybag planting system [1]. The conservation method aims to increase the percentage of soil surface cover to protect the detachment process when it rains and runoff occurs. The conservation concept can be modeled through the regulation of land management data in GeoWEPP. Several studies indicate that GeoWEPP is able to evaluate the effectiveness of management practices, actions, and conservation of the amount of runoff and soil loss [9-14].

2. Methods
2.1. Study location
The location of the study is shown in Figure 1. Bompon watershed is one part of the upper watershed of the upper Bogowonto watershed system. Bompon watershed has an area of 295 ha. This watershed is administratively located in Kajoran and Salaman sub-districts, Magelang regency, Central Java. Bompon watershed is located in a transitional area between units of Sumbing Volcanoes with pyroclastic (volcanic) material and Menoreh Hills with andesitic breccia, tuff, and sandstone material that has been altered into the clay. The fertile and potential land of the area attracts local people to utilize the land, especially for agriculture and plantations.
2.2. GeoWEPP model process

GeoWEPP model integrates the GIS, TOPAZ and TOP WEPP processes. The function of the GIS process has the results of the map or visualization output of erosion distribution and sediment deposition [6]. TOPAZ function (TOPography Parameterization) is to process DEM and topographic data. TOPAZ allows the processing of DEM and topographic data input to carry out the classification process of segment configuration of river channels (permanent and non-permanent) and the length of the river channel [14] [15]. TOP WEPP is a tool for connecting between GeoWEPP and WEPP. Data input in GeoWEPP such as slope, land, land cover and land use data are integrated with the WEPP device database [6]. The operation structure of GeoWEPP is shown in Figure 2.
2.3. Data collection

The data includes 4 main inputs in the operation of the GeoWEPP model; climate, topography, land and land management. Climate data is processed with CLIGEN software (Climate Generator). CLIGEN functions to generate existing climate data to be modeled in a 100-year period with the matching of WEPP database through EPIC [16] and SWRRB [17]. Climate data that will be generated including climate data from the Kalisari Station in Bompon watershed is from the records of January 2015 - June 2017. The WEPP climate station, namely Alabama region, has proximity to the characteristics of the study area. The parameterization analysis compares climatic data of St. Kalisari and Alabama with the assumption of the proximity of the rain value and the pattern in a year. Another data is topographic Digital Elevation Model (DEM) generated from Terrasar data processing with ci 9 m. DEM processing is done automatically from the TOPAZ. The results of TOPAZ processing, including the catchment boundary of the watershed, river channel and hillslope are shown in Figure 3.

Subsequent data collections are soil and land management practice data. The sampling technique used in these primary data in the field was purposive sampling. Sampling on the soil was done using a landform unit approach. Stratified sampling was used with the assumption of a soil sample in a landform that was able to represent the overall landform conditions within the same characteristics. Land data which is the result of an inventory of Translucent data is shown in Table 1. Parameterization is needed in the aspect of land management due to the GeoWEPP database which did not represent the complexity of land management in Indonesia. Parameterization was carried out at the field survey stage, with an inventory of existing land practice patterns in the field. The inventory was carried out by comparing the land cover data of the GeoWEPP database with Indonesian standard land cover. The result of the parameterization of land management characteristics is shown in Table 2.
Figure 3. Results of TOPAZ River Channel and Hillslope Unit

Table 1. Soil data

| Landform                          | Layer | Texture (%) | Organic matter (%) | Bulk density | Albedo | CEC | Saturation |
|----------------------------------|-------|-------------|--------------------|--------------|--------|-----|------------|
| Colluvial plain                  | 1     | 20.99       | 11.15              | 67.86        | 2.08   | 1.14| 0.11       | 38          | 70     |
|                                  | 2     | 12.35       | 33.78              | 53.87        | 1.15   | 1.14| 0.11       | 39          | 70     |
| Colluvial footslope             | 1     | 11.29       | 32.56              | 56.15        | 0.97   | 1.04| 0.18       | 30          | 70     |
|                                  | 2     | 11.10       | 31.46              | 57.44        | 0.94   | 1.04| 0.18       | 35          | 70     |
| Lowerramp with alteration of breccia (Menoreh Mt) | 1     | 8.23        | 19.55              | 72.22        | 0.97   | 1.2 | 0.18       | 38          | 70     |
|                                  | 2     | 8.38        | 18.88              | 72.73        | 0.88   | 1.2 | 0.18       | 37          | 70     |
| Upperlepp with alteration of breccia (Menoreh Mt) | 1     | 8.59        | 46.84              | 46.26        | 0.9    | 0.88| 0.18       | 25          | 70     |
|                                  | 2     | 9.99        | 28.94              | 61.40        | 0.66   | 0.88| 0.32       | 45          | 70     |
| Upperlepp with alteration of breccia | 1     | 8.92        | 21.80              | 69.69        | 1.01   | 1.18| 0.18       | 37          | 70     |
|                                  | 2     | 6.24        | 5.84               | 87.82        | 0.65   | 1.18| 0.32       | 27          | 70     |

Table 2. Land management data

| NO | Landcover               | Land management in WEPP                  | NO | Landcover               | Land management in WEPP                  |
|----|-------------------------|------------------------------------------|----|-------------------------|------------------------------------------|
| 1  | Bamboo                  | Tree 5 Yr - Forest Disturbed             | 9  | Coffee                  | Tree 5 Yr - Forest Disturbed             |
| 2  | Durian                  | Tree 5 Yr - Forest Disturbed             | 10 | Snackfruit              | Tree 5 Yr - Forest Disturbed             |
| 3  | Coconut                 | Tree 5 Yr - Forest Disturbed             | 11 | Taro                    | Tree 5 Yr - Forest Disturbed             |
| 4  | Mahogany                | Tree 5 Yr - Forest Disturbed             | 12 | Empor-empon             | Tree 5 Yr - Forest Disturbed             |
| 5  | Melinjo (I. Spinosa Linn.) | Tree 5 Yr - Forest Disturbed              | 13 | Corn                    | Agriculture                              |
| 6  | Jackfruit               | Tree 5 Yr - Forest Disturbed             | 14 | Cassava                 | Agriculture                              |
| 7  | Silk tree (A. Chinosi)   | Tree 5 Yr - Forest Disturbed             | 15 | Paddyfield              | Agriculture                              |
| 8  | Beach Hibiscus          | Tree 5 Yr - Forest Disturbed             | 16 | Road WEPP-Hillslope     | Road WEPP-cut slope                      |
| 17 | Area of landslide       | Road WEPP-Hillslope                      |    |                         |                                          |
2.4. Validation
The results of the GeoWEPP model including the prediction of erosion is predictive data. Validation aims to determine the effectiveness of the GeoWEPP model in the ability to represent the results and processes of erosion in Bompon watershed. Validation was done by comparing the model data with the observation data. Quantitative evaluation model refers to Nearing (2000). The concept of validation is calculating the value of the erosion model interval by calculating the Rdiff upper and Rdiff limits. The erosion value is accepted if the value is in range according to the graphic illustration of the results of the erosion plot data (Figure 4)[18].

![Figure 4](image.png)

Figure 4. Relative Difference Graph of Measurement of Land Loss between Replicated Plots (Rdiff) with the Observed Soil Loss Value (kg / m2)

3. Results and Discussion
3.1. Output Model Erosi GeoWEPP
The erosion simulation using GeoWEPP was planned for 1 whole year period. The results were spatial erosion distribution and erosion value onsite on the hillslope units. Spatial erosion results of Bompon Watershed are shown in Figure 5. The tabulation results of the area coverage of the erosion and sedimentation class are shown in Table 3. The results from the table above show that the average soil loss each year is 17.956, 2 tonne/year. If it is converted to unit area, the rate is 68, 1 tonne/ha or 6.8 mm/year. The erosion rate is considered high considering the formation of land in Indonesia is around 2 mm / year [19].
3.2. GeoWEPP performance evaluation

GeoWEPP performance evaluation was done by comparing erosion model data with actual erosion data of Bompon watershed [4]. The results show that from 11 observation points, 8 entry points in the Rdiff included in the 95% interval range. Validated observation points with a percentage of 72% show that the erosion model is acceptable. The erosion model at 3 validation points outside the range was spread on the sample form of hilltop land on sengon (Albizia Chinensis) vegetation, the upper slope on sengon vegetation, and lower slope on coconut vegetation. The three samples had in common, that was in the vegetation of wood plants, namely sengon and coconut. However, for samples in sengon and other coconut vegetation, they had been in range as a condition of the model being accepted. The values outside the range of values could be caused by uncertainty from the model when replicating conditions in nature. This is considered normal because of the complexity of the watershed conditions. Model validation calculations by calculating Rdiff are shown in Table 4.

Table 3. Classes and the width of erosion

| Erosion Class (tonne/yr) | Area (ha) | Percentage (%) | Information     |
|-------------------------|-----------|----------------|-----------------|
| > - 500                 | 2.2       | 0.8%           | Sedimentation   |
| - 500 - 0               | 17.0      | 6.5%           | Sedimentation   |
| 0 - 15                  | 31.5      | 11.9%          | Erosion         |
| 16 - 60                 | 155.8     | 59.2%          | Erosion         |
| 60 - 180                | 30.5      | 11.6%          | Erosion         |
| 180 - 480               | 14.2      | 5.4%           | Erosion         |
| >480                    | 12.2      | 4.0%           | Erosion         |
|                         | 263.3     | 100.0%         |                 |

Average of Soil Loose: 17956.2 tonne/yr; 68.1 tonne/ha
Table 4. Validation of erosion and observation models

| Sample                      | Soil Loose (Observation) | Soil Loose (Prediction) | Rdiff | R diff (limit) | R diff (upper) |
|-----------------------------|--------------------------|-------------------------|-------|----------------|----------------|
| Hilltop (Coconut)           | 140                      | 14                      | 13.5  | -0.02          | -0.37          | 0.03          |
| Hilltop (Sengon)            | 377.5                    | 37.75                   | 19.0  | -0.33          | -0.27          | 0.01          |
| Upperslope (Coconut)        | 165.4                    | 16.54                   | 117.1 | -0.17          | -0.35          | 0.05          |
| Upperslope (Bambu)          | 187.2                    | 18.72                   | 97.7  | -0.21          | -0.34          | 0.06          |
| Upperslope (Sengon)         | 260.9                    | 26.09                   | 125   | -0.25          | -0.31          | 0.04          |
| Middleslope of hill (Coconut)| 205.5                   | 20.55                   | 111.9 | -0.29          | -0.33          | 0.05          |
| Middleslope of hill (Bambu) | 163                      | 16.3                    | 169.4 | 0.02           | -0.15          | 0.02          |
| Middleslope of hill (Sengon)| 265                      | 26.5                    | 143.5 | 0.20           | -0.31          | 0.03          |
| Lowerslope of hill (Coconut)| 131.1                   | 13.11                   | 265.1 | 0.34           | -0.38          | 0.02          |
| Lowerslope (Sengon)         | 236.4                    | 23.04                   | 236.8 | 0.06           | -0.32          | 0.01          |
| Lowerslope (Cassava)        | 451.3                    | 45.13                   | 357.6 | -0.12          | -0.25          | -0.04         |

3.3. Analysis of Erosion Pattern

Erosion events have a distribution pattern that is in the foot-slope, lower-slope and upper-slope landform which have a slope of> 25%. The landform of the colluvial plains has the characteristics of sedimentation greater than other regions. Several factors supporting intensive erosion are the physical condition of land and land use. Bompon watershed has well-developed and sensitive soil for erosion. The high content of clay in the watershed soils also affects the erodibility rate of the soils. Soils with clay content are easily saturated when rain occurs and surface runoff is easily formed. Hills morphology with variations in gentle to steep slopes increase surface runoff energy and be able to support the detachment process of surface material.

High erosion in the study area was prone to occur on land with high tillage intensity. The village in the agricultural land would be more intensive than in other land-use or cover characteristics such as in sengon, coconut, mahogany, and others. The high processing intensity of soil (near 100%) using hoes or heavy equipment caused soil aggregates to be easily destroyed so that the soil loses its binding capacity. Hoe implements had an average depth of soil processing of 10 cm with the aggregation of damaged soil aggregate material with a diameter of 1-3 cm. High erosion characteristics were generally found in cassava and corn areas (Figure 6). The location of agriculture in the area of hilly morphology with a slope of> 25% causes increasing erosion.

Figure 6. Agricultural land conditions (A) Corn and (B) Cassava with high erosion characteristic

The rate of erosion in corn and cassava plants had a difference. Cassava farming had higher erosion due to the morphology of canopy cover with low-density cassava plants. Surface material conditions in cassava farming were managed more intensively with low leaf litter cover. Different conditions in
maize were denser and longer plant canopy. The part of the land surface was covered more by leaf litter and grass so that it could reduce the rate of erosion. Indicator erosion in cassava farming area is shown in Figure 7.

![Pedestal Erosion](image1.png) ![Pedestal and Rill Erosion](image2.png)

Figure 7. Indicators of soil erosion in cassava agricultural land (A) Pedestal erosion on land surface (B) Pedestal and rill erosion

3.4. Evaluation of prioritized areas

Prioritized areas were determined by criteria including (1) Quantitative results of the GeoWEPP erosion model and (2) Important value of land. The GeoWEPP analysis unit produced erosion values in hillslope units. Hillslope was a part of the slope that composes a Micro Sub-Watershed. The basis of the second analysis was the importance of land-based on aspects of land use and land status in the planned area as prioritized areas. Land use that had important value in Bompon watershed was agriculture from rice, cassava, and corn. Areas with agricultural land use were prioritized for conservation so that agricultural activities in Bompon watershed were carried out sustainably to support local food security. Land status also influenced decision making. The status of “Tanah Bengkok” or village land had a special role in land use policy. "Tanah Bengkok” is managed for agriculture activities and regulated by village government.

Figure 8 shows the results of the analysis of priority areas generated in hill slope from the Sub-Watershed unit. The results of the prioritized area analysis resulted in 2 hillslope regions from Sub-watershed units. The biggest proportion of the assessment was based on high erosion value in hillslope units. Hillslope is a slope wing unit in the Sub-watershed area. Generally, there is 3 hillslopes which makes up the sub-watershed area, namely hillslope 1 on the upper slope wing, hillslope 2 on the right slope wing and hillslope 3 on the left slope wing.

The analysis showed that high erosion rate was in hillslope unit code 172 with erosion 438.2 tons/ha in the area coverage of 1.5 ha and hillslope with code 103 with erosion of 441 tons/ha in 2.6 ha area coverage. The next assessment of priority criteria was the importance of land. Both hillslopes were areas of agricultural land use, especially cassava and rice which were the main commodities of farmers in the watershed. The land had high economic value which had an impact on the lives of the people. The land in hillslope code 171 was officially owned by the village "Tanah Bengkok”. This land was managed by the village as an intensive agricultural land. This land had important value to be used as a prioritized conservation area because it had an impact on the welfare of the village. The condition of the Prioritized Sub-watershed is shown in Figure 8, while the details of the erosion rate for each hillslope in Sub-watersheds are shown in Table 5.
3.5. Conservation planning of prioritized areas

The priority area includes 2 sub-watersheds with the characteristic of hills with a dominance of slopes > 25 % and seasonal agricultural land uses (cassava and corn). Recommendations for the application of conservation techniques, especially on agricultural land, require information about the local knowledge of the community. This knowledge includes information from farmers' perceptions in managing agricultural land. There are conservation recommendations that can be applied to control erosion in the Bompon watershed.
The conservation technique includes JALAPA (coconut mesh), wood sediment trap and polybag farming system. The JALAPA technique effectively reduces erosion rates up to 43%, wood sediment trap with 22%, and agricultural polybag systems reduce 22%. [1] The conservation technique aims to increase the percentage of soil surface cover to protect the detachment process when it rains and runoff occurs. The conservation concept can be modeled quantitatively through GeoWEPP processing. The input settings for land management characteristics in the GeoWEPP feature include adding a percentage of surface cover with 50% percentage. Evaluation can be done by comparing the existing erosion value and post-conservation data input.

4. Conclusions
GeoWEPP erosion models applied in Bompon watershed can help in planning prioritized areas. Evaluation of prioritized areas at the watershed level begins with an analysis of the erosion distribution pattern of the GeoWEPP model. The goal is to recognize erosion problems including the distribution, patterns and causes and effects of erosion. The next assessment criteria are the identification of important values of land. The important value of land is characterized by agricultural activities that play an economic role in people's lives. Prioritized areas produce 2 sub-watersheds with high erosion characteristics and the presence of agriculture with maize and cassava commodities.

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References
[1] Setiawan M A et al 2018 Sustainability of Three modified Soil Conservation Methods in Agriculture Area. IOP Conf. Series: Earth and Environmental Science 148 (2018) 012018
[2] Singh R Panda R Satapathy K. and Ngachan S 2011 Simulation Of Runoff And Sediment Yield From A Hilly Watershed In The Eastern Himalaya, India Using The WEPP Model. Journal of Hydrology : 261-276.
[3] Morgan R C P 2005 Soil Erosion and Conservation. Third. ed. (Victoria, Australiia : Blackwell Publishing Ltd)
[4] Rokhmaningtyas R 2017 Estimasi Kehilangan Tanah Aktual terkait Pengaruh Vegetasi di DAS Bompon, Kabupaten Magelang. Skripsi. (Yogyakarta: Fakultas Geografi UGM).
[5] Wardhana G M K 2017Efektivitas Teknik Konservasi Dalam Pengendalian Erosi Sebagai Upaya Pengelolaan DAS Dengan Pendekatan Geomorfologi (Kasus DAS Bompon, Kabupaten Jawa Tengah. Thesis. (Yogyakarta: Pascasarjana Fakultas Geografi UGM)
[6] Flanagan D C and Nearing M A 1995 USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation. NSERL Report No. 10.West Lafayette, IN, (USA: USDA-ARS National Soil Erosion Res. Lab).
[7] Flanagan D Frankenberger J R Cochran T A Renschler C S and Elliot W J 2013 Geospatial application of the water erosion prediction project (WEPP) model. Trans. ASABE, Am. Soc. Agric. Biol. Eng 56: 591–601
[8] Mello C R Norton L D Pinto L C Beskow S and Curi N 2016 Agricultural Watershed Modeling: A Review For Hydrology And Soil Erosion Processes. Ciência e Agrotecnologia 40(1):7-25, Jan/Feb. 2016.
[9] Akbari A Sedaei L Naderi Samah A A and Sedaei N 2015 The Application Of The Water Erosion Prediction Project (WEPP) Model For The Estimation Of Runoff And Sediment On A Monthly Time Resolution. Journal Of Environ Earth Sci, 74: 5827–5837.
[10] Embrahimpour M, Balasundram S K, Talib J, Anuar A R, and Memarian H. 2011. Accuracy of the GeoWEPP in estimating sediment load and runoff from a tropical watershed. *Malaysian Journal of Soil Science* 15:25-33.

[11] Flanagan D C, J E Gilley, and T G Franti. 2007. Water erosion prediction project (WEPP): Development history, model capabilities, and future enhancements. *Trans. ASABE* 50(5):1603-1612.

[12] Mello C R, Norton L D, Pinto L C, Beskow S, and Curi N. 2016. Agricultural watershed modeling: A review for hydrology and soil erosion processes. *Ciência e Agrotecnologia* 40(1):7-25, Jan/Feb. 2016.

[13] Meghdadi A R. 2013. Identification of effective best management practices in sediment yield diminution using GeoWEPP: The Kasilian watershed case study. *Environmental Monitoring and Assessment, December 2013* 185:9803-981.

[14] Renschler C S. 2003. Designing Geo-Spatial interfaces to scale process models: The GeoWEPP approach. *Journal Hydrological Processes*, 17(5):1005-1017.

[15] Garbrecht J and Martz L W. 2000. *TOPAZ: An Automated Digital Landscape Analysis Tool for Topographic Evaluation, Drainage Identification, Watershed Segmentation, and Subcatchment Parameterization: Overview*. (US Department of Agriculture, Agricultural Research Service, Durant, Oklahoma) (ARS-NAWQL 95-1).

[16] Williams J R, Jones C A, and Dyke P T. 1984. A modeling approach to determining the relationship between erosion and soil productivity. *Trans. ASAE* 27(1):129-144.

[17] Williams J R, Nicks A D, and Arnold J G. 1985. Simulator for water resources in rural basins. *ASCE Hydraulics J.* 111(6):970-986.

[18] Nearing Mark. 2000. Evaluating soil erosion model using measured plot data: Accounting for variability in the data. *Journal Earth Processes and Landform, 25*: 1035-1043.

[19] Hardjowigeno S and Widiatmaka. 2011. *Evaluasi Kesesuaian Lahan dan Perencanaan Tataguna Lahan*. (Yogyakarta : Gajah Mada University Press).