

# The evaluation of modified productivity index method on the transitional volcanic-tropical landscape

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**Abstract.** Soil erosion may accelerate the impact of climate change by releasing carbon, productivity loss, and harm the food production securities. Losing of soil productivity may lead to another land and forest clearing to support the agriculture activities. The Modified Productivity Index (MPI) is a new method to assess the effects of soil erosion on soil productivity. This research aimed to evaluate the application of MPI on the tropical volcanic landscape in Indonesia. It is important because having a good quantitative judgment on land evaluations will have a great impact to reduce climate change due to land mismanagement. The research area was at Bompon Watershed, Magelang Regency, Central Java, Indonesia. The method used MPI to estimate the soil productivity potency. The parameters observed were clay content, soil organic matter, soil pH, soil available water, and soil weight. The results found that PI was considered low, despite the actual condition of Bompon watershed which densely covered by vegetation. Turns out, there are some limitations of the method that needs to be corrected before widely applied in the tropical and multi-vegetation area such as Indonesia.

## 1. Introduction

Natural processes accelerated by the errors and inaccurate processing in management can threaten soil productivity against the production of food commodities so that in the long run it can threaten land productivity and food security[1]. Land productivity can be assessed by several methods, for example, the Productivity Index method[2], the Productivity Index Modification in Mungelera Version[3], and Productivity Index Modification[4]. Productivity index values can help in land use planning to evaluate land use and management.

Productivity index is a value to determine the level of soil productivity in agricultural commodities[2][4][5][6] according to the physical and chemical parameters it has. Productivity index has a range of values between 0 (unproductive) to 1 (very productive). Calculation of productivity index values can be done using the Modified Productivity Index (MPI) method[4]. The MPI method is a method developed by Duan[4] in China. This method is a modification of the Productivity Index (PI) method by Pierce[2] in America. This method is developed in areas that have sub-tropical climates and continental landscapes by utilizing plots planted with corn and soybean commodity.

MPI is still rarely used in Indonesia's tropical climate that dominated by volcanic landscapes. Characteristics of volcanic soil in tropical areas have specific soil morphological and chemical properties, namely superdeep soil (more than 2 meters depth), high clay content, and intensive erosion and landslide processes. The transitional volcanic zone is the border area between Tertiary volcanic landforms and Quaternary volcanic landforms. The specific characteristic of the transition zone is that



it has relatively thick soil, which is more than two meters deep. The extreme thickness characteristics of the soil are generated by the formation of soil originating from ash from the Quaternary era, riding on the Tertiary volcanic rocks that are altered due to the magmatic intrusion process. Abundant soil reserves and fertile material produced by the volcanic process become human pulling factors for activities in the transition volcanic zone. Considering physical characteristics and human activity, the transitional volcanic zone is very suitable for testing the MPI method.

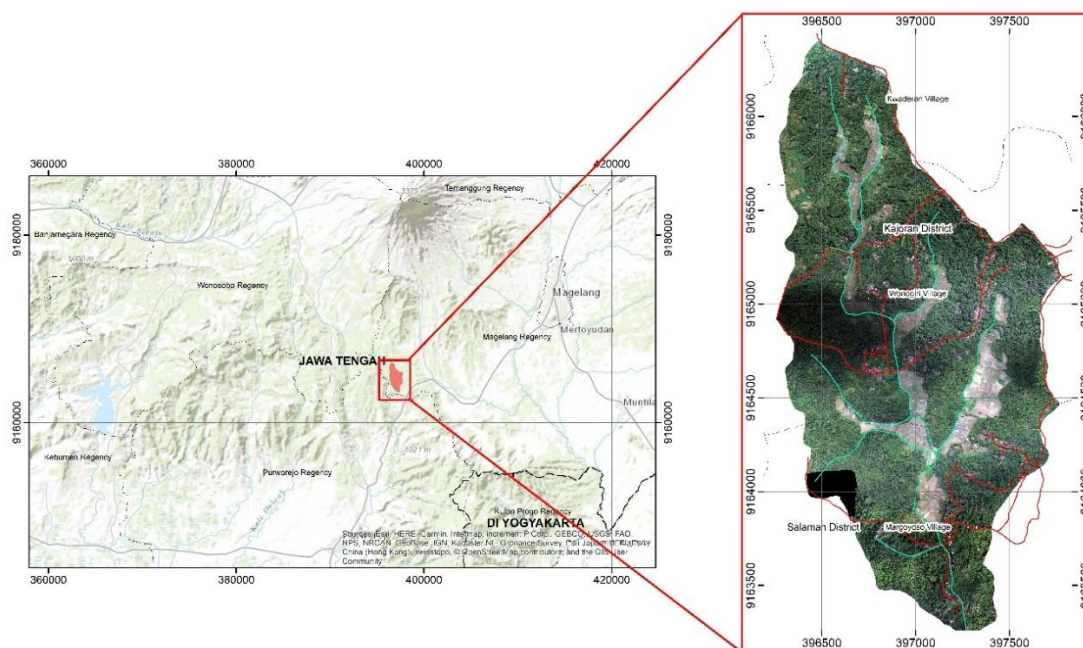
Soil resource research methods that are currently widely used are still qualitative and without considering the soil characteristics[7]. Applying the method of the productivity index modification can be a renewal of methods for quantitative research. The soil physical and chemical characteristics such as organic matter, soil pH, water capacity, clay content, and soil weighting factors are used in the modification of productivity index method. Renewal methods that have quantitative properties have the potential for wider application and can bridge the gap between the realm of science and society in general. But, before this method can widely be applied, it needs to be evaluated first to understand the strengths and weaknesses, and it can be used as a reference for further research development.

## 2. Research method

### 2.1. Study area

Bompon Watershed is an area in the transition volcanic zone. The watershed, which has an area of 300 ha, has land use that varies in the results of human cultivation and management process. Physical characteristics of Bompon Watershed soil are similar to other transitional volcanic areas, which have superdeep soils resulting from volcanic ash weathering. The presence of alteration material, gives Bompon Watershed an aspect of observation and other uniqueness, namely the quite dominant process of soil mass or landslide movement, both active and dormant.

Human activity is quite dominant in the Bompon Watershed. Almost the entire watershed area of Bompon has been cultivated with high to low intensity. Commodities developed include cassava, bamboo, coconut, and sengan. In addition, there are salak, coffee, and spices plants, although not dominant. Part of the Bompon Watershed, especially in Wonogiri Village, has been designated as a Food Independent Village by the district government of Magelang. Bompon watershed is also being developed to become a natural laboratory for a variety of earth and social studies.



**Figure 1.** Research study area

## 2. 2. Methods

**2.2.1. Modified productivity index method.** Calculation of soil productivity index value (PI) is carried out with five main parameters, namely water capacity in soil (A), organic matter content (O), amount degree of acidity (D), clay content (CL) and soil weighting factor (WF). Referring to Duan et al. (2009)[4], the calculation of the productivity index is done by formula 1.  $i$  is the first soil layer and is predicted to erode after the land use period is exhausted ( $t$  value).

$$PI = \sum_{i=t}^n A_i \times CL_i \times O_i \times D_i \times WF_i \quad (1)$$

The value of each parameter has a conversion formula to obtain index values that can be used to calculate the PI value with the MPI method. Referring to Duan et al (2009)[4], the conversion formula for each parameter is as follows.

A {	0 .....	AWC $\leq$ 0.03
	5 x AWC .....	0.03 < AWC $\leq$ 0.2
	1 .....	AWC > 0.2
D {	0 .....	pH $\leq$ 2.9
	-1.31 + 0.446 x pH .....	2.9 < pH $\leq$ 5.0
	0.12 + 0.16 x pH .....	5.0 < pH $\leq$ 5.5
	1 .....	5.5 < pH $\leq$ 6.5
	2.086-0.167 x pH .....	6.5 < pH $\leq$ 8.0
	0.75 .....	pH > 8.0
O {	OM / 4 .....	0% $\leq$ OM < 4%
	1 .....	4% $\leq$ OM
CL {	1 .....	20% $\leq$ Clay $\leq$ 40%
	CL / 20 .....	0 < clay , 20%
	(100-CL) / 60 .....	40% < clay < 100%
	0 .....	Clay = 0 or clay = 100%
WF	$0.35 - 0.152 \times \text{Log} (\text{depth} + (\text{depth}^2 + 6.45)^{-2})$	

(2)

**2.2.2. Defining the mapping unit for soil sampling and data analysis.** Different from the original method, this research doesn't use the soil classifications, instead, we use combinations of landform and vegetation covers to determine the sampling location. The research area, Bompon Watershed is consist of different landform and vegetation cover. Landforms can draw the natural border and conditions of the soil properties because it forms in the long period with complex processes[8]. Vegetation covers are man-made, it affects the soil processes from the detail part such as rooting, tree form, canopy density, and impact to the water and nutrient absorbment[9][10].

Vegetation covers on the research area are heterogene, it consists of many types of the crop from spices, salak, until coconuts. To simplify it, we used some commodities which consider profitable by the local people. Interview for a key person was conducted to inventory the vegetation. The economic approach was used because if we want to apply this research to the people, it will be more understandable. From the interview, we got cassava, coconut, albasia, bamboo, spices, salak, and coffee as profitable commodities.

**2.2.3. Field Observation.** Based on maps of landform units that have been compiled, and the results of vegetation inventories that are considered valuable by the community then obtained 19 points of observation and sampling of soil (Table 1). Observations related to land cover conditions were carried out at 19 sample points and several areas that had similar characteristics. The purpose of land cover observation is as a qualitative consideration of the compatibility between the results of the calculation of the productivity index value with the MPI method and the actual conditions.

**Table 1.** Soil sample points data

Sample Number	Land Unit		Sample Number	Land Unit	
	Landform	Vegetation		Landform	Vegetation
1	Interfluvial	Cassava	13	Middle Slope	Bamboo
2	Upper Slope	Cassava	14	Upper Slope	Coconut
3	Middle Slope	Cassava	15	Upper Slope	Bamboo
4	-	Coffee	16	Upper Slope	Sengon
5	Colluvial Plains	Coconut	17	Bottom Slope	Coconut
7	Bottom Slope	Cassava	18	Bottom Slope	Bamboo / Sengon
8	Interfluvial	Coconut	19	-	Empon-Empon
9	Interfluvial	Sengon	20	-	Salak
11	Middle Slope	Coconut	21	-	Landslide
12	Middle Slope	Sengon			

Duan et al.[4] describe soil samples for MPI calculations taken at a maximum depth of 100 cm. This principle is based on the explanation of Pierce et al.[2] assuming 100 cm is the effective depth of rooting of corn plants. This study modifies soil sampling techniques using a depth of soil as thick as 5 cm from the soil surface to be taken as sample soil. The condition of the multi-layer vegetation and the variety of commodities that planted into consideration the use of 5 cm thickness as an effective thickness that can be utilized by all plants.

### 3. Results and discussion

According to Pierce et al.[2] and Duan et al.[4], the value of the productivity index is in the range of 0 to 1, where the value 0 represents unproductive land and value 1 represents very high productivity. Based on the results of the calculations as shown in Table 2, the productivity index value in the Bompon Watershed is classified as low categories. The highest productivity index value in Bompon Watershed of 0.769 and the lowest is 0.057. If observed at a more detailed level, from 19 sample points, there are only two sample points that have a PI value of more than 0,4 while the rest are in the range of values below it. This condition is very contrasted if you see the real condition of Bompon Watershed which has a high density of land cover vegetation and agricultural activities by the community.

Put aside the WF value or depth factor which is the constant set by Pierce[2] and Duan et al.[4], the lowest index is shown in the value of organic matter. The value of organic matter in the Bompon Watershed is in the range of 0.52 percent to 3.2 percent. This value is low for the MPI method, where based on the conversion factor, the value of the organic material can support maximum productivity if more than 4 percent. The conversion factor resulted in no area in Bompon Watershed which has a value range above 0.800. The low organic content in the soil in Bompon Watershed has various factors, including land-cultivated activities, and soil factors. Bompon Watershed area which has the lowest value of organic matters and organic index at the sample point 1. Physical characteristics in this area are on

the summit or ridge of Bompon Watershed by cultivated land in the form of cassava trees with a high rate of cultivating.

**Table 2.** Productivity index values on surface soil ( $d=5\text{cm}$ )

Sample Number	Land Unit		Parameter					PI
	Morphology	Vegetation	AWC	CL	OM	WF	pH	
1	Interfluve	Cassava	0.428	0.633	0.168	1	0.728	0.066
2	Upper Slope	Cassava	0.360	0.933	0.253	1	0.630	0.107
3	Middle Slope	Cassava	0.388	0.609	0.278	1	0.438	0.057
4	-	Coffee	0.604	0.600	0.443	1	0.960	0.308
5	Colluvial Plains	Coconut	0.564	0.536	0.520	1	0.965	0.291
7	Bottom Slope	Cassava	0.652	0.850	0.235	1	0.920	0.240
8	Interfluve	Coconut	0.652	0.412	0.385	1	0.957	0.198
9	Interfluve	Sengon	0.536	0.831	0.445	1	0.968	0.384
11	Middle Slope	Coconut	0.484	0.700	0.323	1	0.916	0.200
12	Middle Slope	Sengon	0.324	0.731	0.243	1	0.893	0.103
13	Middle Slope	Bamboo	0.456	0.895	0.540	1	0.768	0.314
14	Upper Slope	Coconut	0.524	0.505	0.253	1	0.942	0.126
15	Upper Slope	Bamboo	0.824	0.964	0.778	1	0.968	0.769
16	Upper Slope	Sengon	0.532	0.896	0.225	1	0.989	0.212
17	Bottom Slope	Coconut	0.520	0.570	0.600	1	0.923	0.274
18	Bottom Slope	Bamboo / Sengon	0.552	0.463	0.243	1	0.952	0.118
19	-	Empon-Empon	0.416	0.409	0.350	1	0.831	0.099
20	-	Salak	0.456	0.942	0.513	1	0.938	0.403
21	-	Landslide	0.300	0.469	0.345	1	0.804	0.078

AWC : index of available water content

CL : index for clay percentage

OM : index for organic matter percentage

WF : weight factor value of soil

pH : index for soil acidity



**Figure 2.** Soil conditions on cassava field [12]

Open land, as well as homogeneous and clean land cover from litter, are characteristics of cassava land in Bompon Watershed (figure 2). Open land cultivating and management techniques have an impact

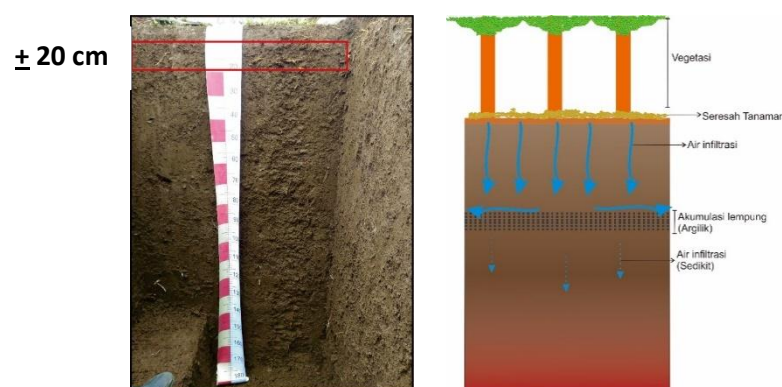
on the high rate of erosion that occurs, where the measurement results show a rate of 85 mm year<sup>-1</sup>. This erosion rate factor will decrease the value of organic matters at a low point[11]. Another factor that affects the low and uneven content of organic matters is the high content of clay.

The soil in Bompon watershed has a fairly high clay content. The results of soil testing in Bompon Watershed showed that from the 19 sample points tested, the majority had values above 40 percent, so it's texture was classified as clay[10]. According to the MPI method, the value of clay content is considered to be able to support maximum productivity if it is in the range of 20 percent to 40 percent, while the value of clay content in Bompon Watershed is above 40 percent and some reaches 60 percent, which mean the soil inability to support maximum productivity (table 3.).

**Table 3.** Clay content on Bompon Watershed

Sample Points	Clay Content	Sample Points	Clay Content
1	62.00	13	46.28
2	44.00	14	69.69
3	63.46	15	42.16
4	12.00	16	46.26
5	67.86	17	65.79
7	49.01	18	72.22
8	8.24	19	75.44
9	50.14	20	43.47
11	14.00	21	71.85
12	56.15		

Another factor that influences due to high clay content is the formation of argillic layers. The argillic layer is generally on the surface precisely at the A and B horizons, but due to the erosion process, it will gradually be exposed to the surface[10]. The presence of argillic layer can inhibit the distribution of nutrients into the soil, this argillic factor which is likely to play a significant role in the low and disproportionate of organic matters in the soil in Bompon Watershed (figure 3.).



**Figure 3.** Argillic horizon on soil profile [12]

The highest and consistent MPI parameter value is the WF or Weight Factor value. The WF value is a constant determined by Pierce[2] assuming a soil thickness of 1 meter. The high WF value in Bompon Watershed is due to the thick soil reserves, which can be cultivated. The thickness of the soil reaching more than 2 meters makes the WF has the maximum value. The assumptions developed in this MPI

method are the thicker the soils, then the soils can provide high productivity and sustain the sustainability.

The low productivity index value in Bompon Watershed can also be influenced by the MPI method itself. The development of a PI method by Pierce and modification of the PI method to MPI by Duan was based on the environmental conditions of America and China. Both use test areas with non-volcanic characteristics. Vegetation used as a reference for calculating productivity values and productivity indices is corn and soybean crops[2][4][6]. These factors have the potential to increase the errors when applied to areas with heterogeneous vegetation.

The application of the MPI method for tropical volcanic regions, especially in transitional areas that have unique characteristics still cannot be done, however, this method has the potential to be further developed. From the description of the MPI method, the vegetation factor takes precedence than the physical factors of the soil. Soy and corn vegetation are the two plants used for the development of this method, so this method can be used to make land use planning with corn, soybean or similar vegetation. The making of MPI modifications locally for other vegetation characteristics in Indonesia such as Cassava, Salak, and Coffee is very possible. Further development for adjustments to the physical condition of the land can also be done, but more especially for the vegetation side first.

#### 4. Conclusion

The results of the MPI method testing show that there is an incompatibility of results with the original conditions in the field. The calculation shows a low productivity index value but in the field conditions shows a thick vegetation cover. The MPI method factor developed for corn and soybean plants in non-volcanic regions is the main cause of the discrepancy. Nevertheless, MPI has the potential to be developed into an appropriate method for the tropics. Development can be done and felt quite strategic because the MPI method is based on actual values in the field, making it easier to understand and understood by decision-makers and land processors in Indonesia. This MPI method can also be used to calculate erosion threshold values, the values that are quite important for conducting a land evaluation and land management. Having a better quantitative method in land use evaluation can reduce illegal and unplanned forest clearance for agriculture purpose, so as to reduce the rate of climate change.

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