SPATIAL MODELING FOR ECOSYSTEM DISTURBANCE DISTRIBUTION IN "HUTAN PENDIDIKAN WANAGAMA I"

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Abstract. Hutan Pendidikan Wanagama I (HPW I) gives a lot of benefits for the local community, indicated by the rapid increasing of cultivation land within the area. However, human activities can be a threat for forest ecosystem within HPW I area. Therefore, it is necessary to determine forest ecosystem disturbance experienced by HPW I. The balance of stands' ecosystem can be quantified using stand basal area. The objectives of this study are to: (1) Determine the stand basal area in HPW I; (2) Develop spatial model for ecosystem disturbance due to human activities in HPW I. Worldview-2 satellite imagery was classified to obtain land cover and forest strata maps which then used to locate the basal area sampling point. Accuracy on the classification results were quantified using kappa statistic. Stand basal area was measured using Bitterlich's method. Disturbance distribution in HPW I was modelled using spatial analysis with Geographic Information System (GIS) with five disturbance parameters approach; i.e.: distance to rural road, distance to macadam road, distance to settlement, slope and entropy value. The results showed that average stands basal area of HPW I was 17,2 m^2/ha. Spatial analysis on five disturbance parameters showed that HPW I can be classified into three areas: the high disturbed area 178,7 ha (stand basal area 0 – 13,6 m^2/ha) the moderate disturbed area 246,7 ha (stand basal area 13,7 – 19,1 m^2/ha) and the less disturbed area 189,2 ha (stand basal area 19,2 m^2/ha up).

1. Introduction

In 1960s Gunungkidul area known as a barren region as an impact from natural resources exploitation policy carried out by the colonial era (Wardhana 2015)so was Hutan Pendidikan Wanagama I (HPW I) area as well. Facing how miserable the environment was, then Gadjah Mada's forester made a break through to initiate the land rehabilitation program in Gunungkidul, one through HPW I forest development effort. Over time, HPW I has become the face of successful land rehabilitation program in Gunungkidul (Pramoedibyo et al. 2004).

The HPW I dominated by local communities whose livelihoods depend mostly on taking fuel wood, animal grazing and cultivating agriculture land inside HPW I. Frequent human intervention in taking fuelwood, other forest products and grazing habitat could causing the change of many species' resistance (Pandey and Shukla 2004), change of species composition and change of forest structure that leads to forest degradation (Smiet 1992). Forest degradation due to human intervention that could led to fluctuations in the ecosystem then defined as ecosystem disturbance (Pickett and White 1985). There's remain unknown how far the disturbance occur in HPW I as the impact of human intervention in HPW I. There has been no quantitative explanation to show how disturbed an ecosystem was. Prior to forest management operation, some quantitative approach that can be used is by knowing the basal area value (Pandey and Shukla 2004) and other anthropological factors: distance to road, distance to settlement, slope and entropy index.

There is a correlation between human interventions with basal area where the higher basal area value is, the smaller disturbance occurs. On contrary, the smaller basal area value is, the higher disturbance occurs. In montane forest in Gunung Kawi, a very disturbed forest ecosystem has smaller basal area value than the undisturbed forest (Smiet 1992). Similarly, in dry tropical forests in India the more disturbed plots has a smaller basal area value than undisturbed plots (Pandey and Shukla 2004). Road is the main factor that causes the change of forest land cover to non-forest as a corridor that connects forest area with human activities (Kuncoro 2015). The closer distance a forest area to a settlement the more chance for human to depend their livelihood to the forest resources (Brinkmann et al. 2014). Slope is one of geophysical factors that will affect in land cover pattern in a forest area (Muller and Zeller 2002). Human intervention in HPW I can be approached from the heterogeneity of land use pattern which showed by an entropy index (Adityawan 2015). However, understanding ecosystem disturbance distribution caused by human intervention in HPW I remains a challenge. Therefore, a detailed study of ecosystem disturbance distribution on HPW I is needed to know how far the disturbance occurs. The objective of this study was to understand: (i) the distribution of basal area value in HPW I (ii) the spatial model of ecosystem disturbance in HPW I.

2. Material and methods

2.1 Study area

The 600 hectares Hutan Pendidikan Wanagama I (HPW I) area is located in Gunungkidul District about 40 kilometers far to south east from Yogyakarta Capital City. Gunungkidul District is dominated by karst land landscape and divided into three rock formation zones: Batur Agung Valley, Gunung Sewu and Wonosari Valley (Wardhana 2015). HPW I included into Wonosari rock formation zone which has a typical hilly relief and layered rock structure that led to the formation of caves or underground river. This phenomenon potentially forming many springs underground so the below layer is rich of water but the topsoil rapidly lose water because of the inability to hold the water, and that making the land known as an arid land (Pramoedibyo et al. 2004). HPW I surrounded by human settlement whose livelihoods depend mostly on HPW I area (Figure 1).

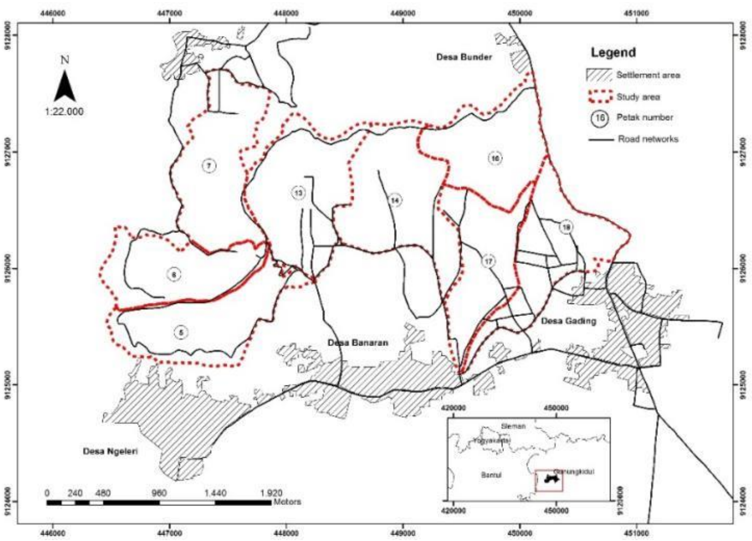


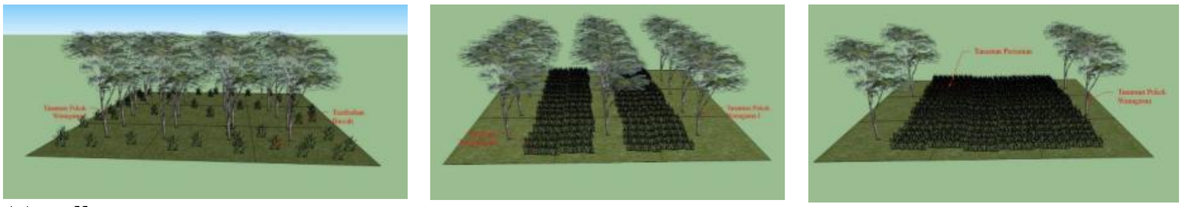
Figure 1. Study area

Recently there are 496 total people from three village around whose responsible for agricultural land use in all *compartment* in HPW I (Adityawan 2015) (Table 1). Compartment is a term used refers to the compartment area in HPW I to ease the management. There are 8 compartment in HPW I that every one of them has its own character so that it affect surrounding people's activities and motivation in taking benefit of HPW I.

Table 1. Number of farmer in HPW I area

Village/Compartment	Banaran	Gading	Bunder	Total
Compartment 5	4	0	0	4
Compartment 7	4	0	6	10
Compartment 6	0	0	0	0
Compartment 13	133	0	0	133
Compartment 14	57	0	0	57
Compartment 16	16	0	0	16
Total				496

Overtime, human intervention inside of HPW I slowly create specific land uses pattern which then become trending. There are three dominated land use pattern that exists inside HPW I area: full trees, alley cropping and trees along border (Figure 2). Full trees indicates low human intervention, meanwhile alley cropping an trees along border indicates a high intervention (Adityawan 2015).



(a) Full trees (b) Alley cropping (c) Trees along border

Figure 2. Land use pattern in HPW I

HPW I area is defined as type C in Schmidt-Ferguson Climate Classification, characterized by moderate humidity (78-88%) with two zone of seasons: wet season and dry season with average rainfall 1900mm/year (Pramoedibyo et al. 2004). The dry season usually lasts 2-6 months, but mostly last longer than the wet season in a year. HPW I dominated by man-made forest with many tropical tree species developed, but mostly dominated by leguminosae family.

2.2Satellite imagery segmentation

Worldview-2 satellite imagery of HPW I area was already corrected radiometrically and geographically then segmented using ENVI software to get the land cover and crown strata classification. Land cover data was defined and classified using Badan Standarisasi Nasional Indonesia (BSNI) land cover and land use classification rule, for a 1:25.000 map scale. According to field observations, various land use classes were detected in the study area explained below (Table 2)

Table 2. Land use classification

No	Land use class name	Ground object
1	Water	Open bodies of water, lake, river,
2	Dry forest	Exploited forest area, usually marked by a visual roads or another exploitation marks
3	Manmade forest	Established plantation forest in order to increase the potential and quality of forest resources
4	Shrub land	An open dry land dominated by low or rare trees
5	Cropland	Agricultural land and productive grass land
6	Built-up land	A permanent water resistant substituted natural land use for human activities

Crown strata was classified using ArcGIS following the David Paine template (Figure 3 and table 3) to measure crown cover (%) and crown diameter (meters) (Paine 1981). The classified crown strata in HPW area then used to place the basal area sampling point. Statistically, there is a correlation between basal area and crown strata (Sumarna 2008) since crown cover was the most used parameter in representing stand's characteristic (Laar and Akca 2007).

Table 3. Crown cover classification

Crown cover range (%)	Code	Crown diameter range (meters)	Code	Density level
10 – 40 %	C1	< 10	D1	Low
41 – 70 %	C2	10 – 20	D2	Moderate
>70 %	C3	> 20	D3	Dense

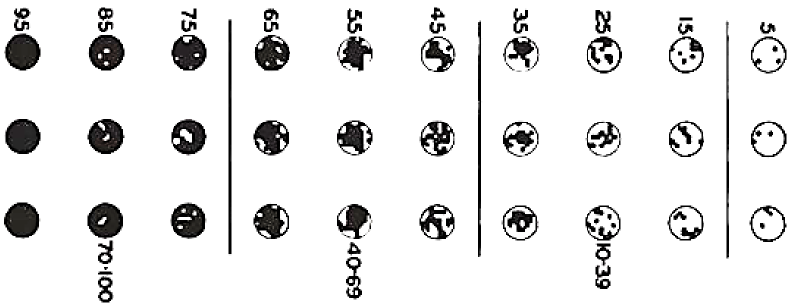


Figure 3. Crown closure template (Paine 1981)

2.3 Accuracy assessment

Land cover data accuracy was conducted by using 659 validation plots scattered randomly to all of the land cover class. We use kappa statistic evaluate the quality of land cover data obtained from Worldview-2 imagery with this following formula (Stehman 1996)

$$K = \frac{N \sum_{i=1}^{q} pii - \sum_{i=1}^{q} p_{i+}p_{+i}}{1 - \sum_{i=1}^{q} p_{i+}p_{+i}} \quad (1)$$

Where pii = Nii/N, pi+ = Ni/N, and p+i = Mi/N. Suppose a remote sensing image of N pixels is classified into q categories. Given a census of all N pixels and the true classification of each pixel, the population error matrix is (Table 4). A perfect data would equal to a kappa of 1 and a poor data would equal to a kappa of 0. Kappa value interpretation visualized in table 5 below (Viera and Garrett 2005).

Table 4. Error matrix for kappa statistic

		Reference				Row Total
		1	2	...	Q	
Image (stratum)	1	N_{11}	N_{12}	...	N_{1q}	N_1
	2	N_{21}	N_{22}	...	N_{2q}	N_2
	:	:	:	...	:	:
	q	N_{q1}	N_{q2}	...	N_{qq}	N_q
Col. Tot		M_1	M_2	...	M_q	N

Table 5. Kappa statistic interpretation

Kappa value	Fairness interpretation
0,01 to 0,20	Slight
0,21 to 0,40	Fair
0,41 to 0,60	Moderate
0,61 to 0,80	Substantial
0,81 to 0,99	Almost perfect

Meanwhile, crown cover data accuracy assessment was conducted by using 468 validation plots scattered equally to all of the crown cover class. We use manual measurement in each plot measuring crown diameter per tree in 4 directions (north, east, south, and west). Plot size determined by critical radius obtained from Bitterlich's stick that we use to estimate stand basal area value.

2.4Basal area sampling

Stand basal area was obtained using point sampling method with Bitterlich's stick (Figure 4). Every sample has an expansion factor that expands the sample estimates to the population level. In point sampling the expansion factor is related to the plot size and tells how many trees per hectare are represented by each tree included in the sample (Ordewald 1990). We use Bitterlich's stick with three expansion factor (Simon 2007) which shortly we call basal area factor (BAF) to help specify sample tree and border tree in each plot. To determine the sample size, we choose 40% of coefficient variation with 5% desired precision (Marty 1999). We got 64 sampling plots which then were placed randomly but equal to the crown cover distribution. To get basal area value distribution in HPW I, then sample data per plot were generalized spatially using Inverse Distance Weighted (IDW) geostatistical interpolation with ArcGIS. IDW determines unknown values using a linearly weighted combination based on a set of known sample points as a function of inverse distance (Geach et al.2014). The method assumes that the influence of a known sample point decreases with distance as defined by a mathematical power parameter. A higher power parameter places more emphasis on the closest known values (Geach et al.2014).

Figure 4. Bitterlich's stick with three BAF

2.5Disturbance parameters data analysis.

The impact of disturbance on every land cover class was then defined with a set of parameters which all used to represent either a symptom or a cause of disturbance in the forest area. Digital maps of five chosen disturbance parameters: road networks (macadam and rural road), settlement, slope and entropy index were produced from Worldview-2 satellite imagery and updated by field surveys based on GPS measurements. Road networks and settlement data were used to measure accessibility variables by calculating the Euclidean distance to roads, distance to settlement from HPW I area border using ArcGIS (Brinkmann et al. 2014). Slope and entropy index data were used to spatially locate potential disturbance area inside HPW I (Adityawan 2015). These five parameters then combined spatially using scoring method (Sagar, Raghubanshi, and Singh 2003) before finally compared with basal area value data to show the disturbance distribution in HPW I area.

3. Results

3.1. Land cover and crown cover trend

Imagery segmentation showed that HPW I area is dominated by dry forest about 54,5 % from total HPW I area followed by cropland area about 22,4 % from total HPW I area (Table 6). Land cover data here is used as the basic data to determine crown cover and also used as one of the additional information to describe the disturbance distribution. Meanwhile, crown cover data then used to determine BAF in each plot and mostly the dominated crown cover is dense cover (C3) but with low diameter (D1) about 23 % from total HPW I area (Table 7).

We see that understand the disturbance distribution in all of HPW I area without any compartment was way too wide and complex. So we simplify the way we understand disturbance distribution using *compartment* approach. We have to know those eight compartment condition and vulnerability in HPW I to experience the disturbance, quantitatively from their land cover domination, basal area value and disturbance parameters' trends. Based on its trending land cover area, HPW I divided into two part: the dry forest part and the cropland part. Mostly dry forest area was clustered along a group of four compartment: compartment 5, compartment 6, compartment 7 and compartment 13. Otherwise, cropland area was clustered along in compartment 14, 17, 18 and 16. Another land cover such as shrub land, built-up land and water were spread associated among dry forest and cropland area (Figure 8). Similar to the land cover trend, crown cover trend also dividing HPW I into two part: a dense crown with low crown diameter (C3D1) and both low density and low crown diameter (C1D1) (Figure 9). Mostly C3D1 clustered in compartment 5 and compartment 7 where on that compartment generally dominated by dry forest and C1D1 clustered in compartment 13 and compartment 14 where generally dominated by cropland.

Table 6. Land cover distribution in HPW I

No	Land cover class	Area (hectares)	Area (%)
1	Dry forest (Df)	334,9	54,5
2	Shrub land (Sb)	136,4	22,2
3	Cropland (Cr)	137,6	22,4
4	Built-up land (Bl)	1,5	0,2
5	Water (W)	4,5	0,7
Total		614,6	100

Table 7. Crown strata distribution in HPW I

No	Crown cover and diameter	Area (hectares)	Area (%)
1	C1D1	76,9	23
2	C1D2	4,9	1,5
3	C2D1	67,3	20,1
4	C2D2	48,8	14,6
5	C3D1	77,2	23
6	C3D2	59,9	17,9
Total		334,9	100

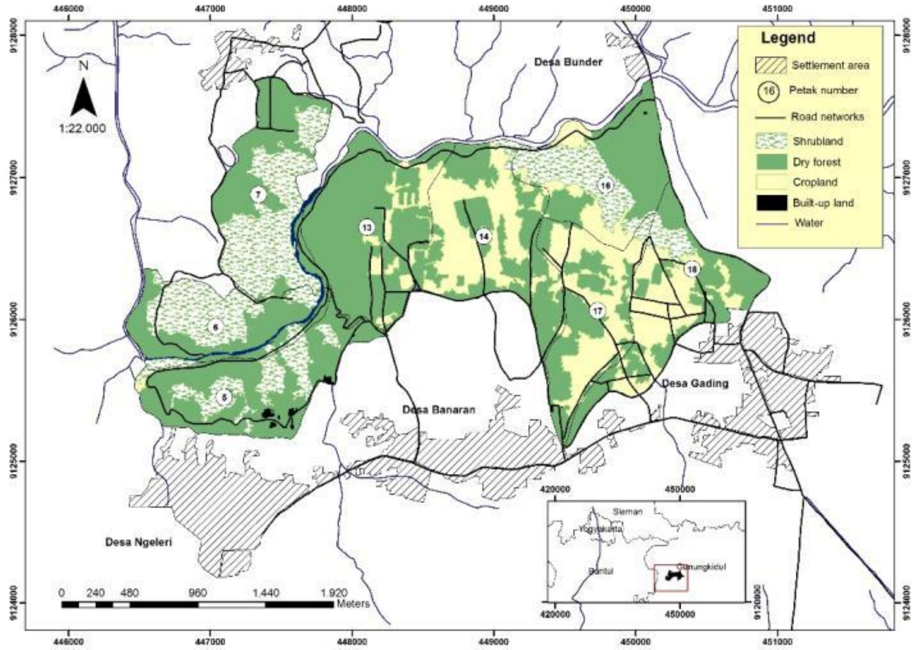


Figure 5. Land cover trends in HPW I

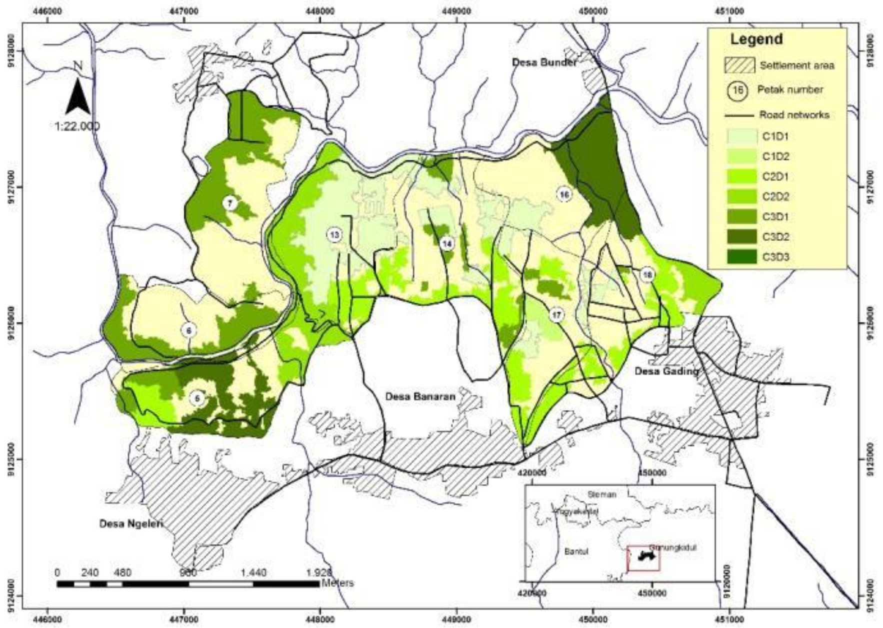


Figure 6. Crown strata trends in HPW I

3.2. Accuracy assessment

The Worldview-2 satellite imagery was recorded in 2012 and ground check was conducted in 2015 so there is 3 years gap where both land cover and crown strata data clearly would have some difference compared to the ground object. Differences won't be a problem if we define the minimal value for kappa statistic is above 0,61, since the image has a high resolution (Viera and Garrett 2005) The overall accuracy of the land cover classification is 0,82 which is mean that the classification result was almost perfect. The highest difference occurred in dry forest land cover class with 54 unmatched plots where mostly changed to cropland area (Table 8). The overall accuracy of crown strata classification is 0,79 which is mean that the classification result was substantial. The highest difference occurred in C3D1 and C2D2 class with 22 unmatched plots where mostly changed to higher crown strata (Table 9).

Table 8. Summary of accuracy assessment of land cover data

Image	Ground object						Producer accuracy
	Df	Sb	Cr	W	Bl	Total	
Df	305	33	15	2	4	359	0,55
Sb	7	125	9	3	2	146	0,22
Cr	6	4	134	1	2	147	0,22
W	0	0	0	2	0	2	0,00
Bl	0	0	0	0	5	5	0,01
Total	318	23	15	8	13	659	
User accuracy	0,48	0,03	0,02	0,01	0,02		

Df: Dry forest Sb: Shrub land Cr: Cropland W: Water Bl: Built-up land

Table 9. Summary of accuracy assessment of crown strata data

Image	Ground object						Total	Producer accuracy
	C1D1	C1D2	C2D1	C2D2	C3D1	C3D2		
C1D1	95	10	3	0	0	0	108	0,23
C1D2	3	4	0	0	0	0	7	0,01
C2D1	5	9	80	0	0	0	94	0,20
C2D2	0	0	0	47	17	4	68	0,15
C3D1	0	0	0	7	87	14	108	0,23
C3D2	0	0	0	0	6	77	83	0,18
Total	103	23	83	54	110	95	468	
User accuracy	0,22	0,05	0,18	0,12	0,24	0,20		

3.3. Basal area distribution

The measured basal area in the sampling plots then analyzed using descriptive statistic (Table 10). The basal area value ranged from 0 – 54 m^2/ha with 16,9 m^2/ha of average. The value of SEM was 1,7 m^2/ha, about 10% from the average value. The data was close to the average population if SEM value at least 30% from the average value (Banyard 1975) so that the basal area data was close to the average population. The value of skewness was 0,97 which is mean that mostly the data distribute below the average (Table 10). Basal area population value in HPW I area was estimated using geostatistical interpolation and showed a close number to the sample. The basal area value ranged from 0 – 53, 94 m^2/ha and the average value was 17,2 m^2/ha (Table 11). Mostly the data clustered below the average from 0,02 – 14,82 m^2/ha with the largest area of 282,56 hectares spread in compartment 13, compartment 14 and compartment 17 (Figure 10).

Table 10. Descriptive statistic of basal area sample

Parameters	Value
Minimum	0 m^2/ha
Maximum	54 m^2/ha
Average	16,9 m^2/ha
Standard deviation	13,89 m^2/ha
Standard error of the mean (SEM)	1,7 m^2/ha
Skewness	0,97
Sample size	64 plots

Table 11. Estimated basal area value in HPW I

Categories	Estimated value (m^2/ha)		Average (m^2/ha)	Standard deviation (m^2/ha)	Area (ha)
	Low	Up			
Low	0,02	14,82			282,56
Moderate	14,83	22,22	17,2	9,6	164,4
High	22,23	53,94			167,63

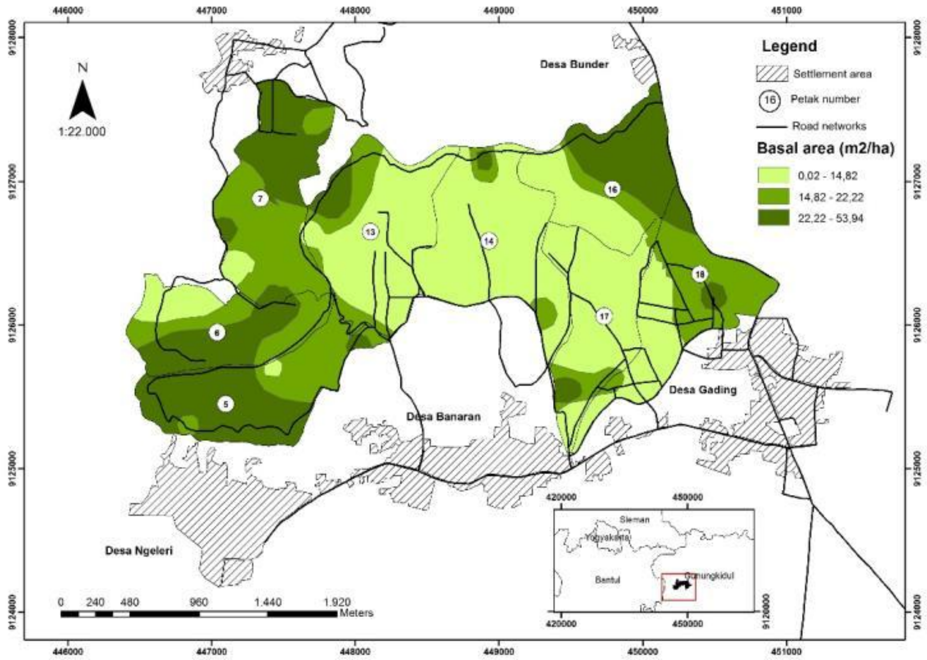


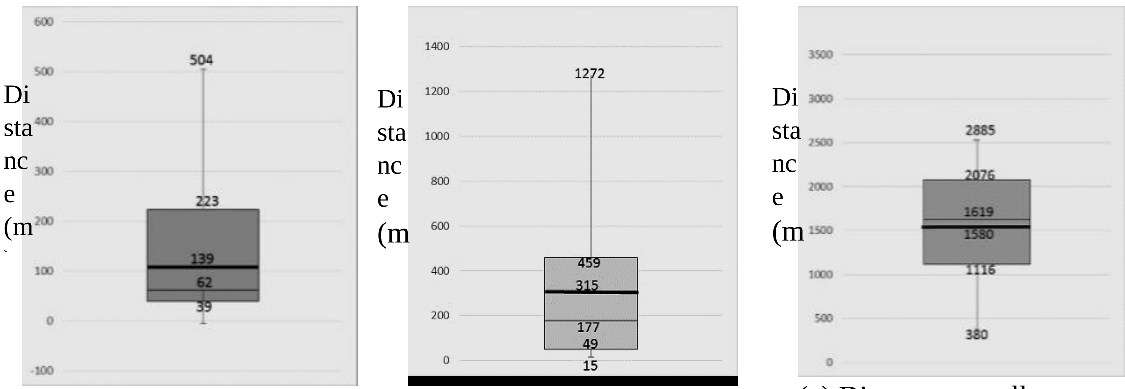
Figure 7. Basal area distribution in HPW I

3.4. Disturbance parameters distribution

Each parameter has different impact in causing disturbance occurrence in HPW I so that we have to know each one of their characteristic by grouping and classing their impact based on their attribute data (Figure 11). The closest settlement to sampling plots was 380 meter far and the furthest was 2885 meter. This is a close distance for human accessing the forest since there were already has an accessible road networks both rural and macadam road over each compartment in HPW I area. It is difficult to measure how close sampling plots to the rural road because it could be measured from all directions. So we quantify the distance from one possible direction that mostly accessed by human. The closest rural road to sampling plots was 39 meter far and the furthest was 504 meter. Meanwhile distance to macadam road from sampling plots was easier to assess because there was only one network for this kind of road. The closest macadam road to sampling plots 15 meter far and the furthest was 1272 meter. The other parameters: slope and entropy index was measured based on the digital data. In HPW I there is a specific pattern from the people in cultivating the land that they only cultivate in a land below 25% level of slope (Adityawan 2015). Mostly HPW I dominated by a hilly topography with 0 – 15 % slope that lied down in 303,7 hectares area (Table 11). Entropy index shows us land use pattern variation in HPW I in each compartment (Figure 12). The range of entropy value is 0 to 1 where 0 means that there is no land use variation otherwise closer to 1 shows that the higher variation of land use. In HPW I the highest index lied down on compartment 18 and compartment 14 (0,46 from 1) and the lowest index lied down in compartment 6 (0,01 from 1). It means compartment 14 and compartment 18 has a high variety of land use pattern compared to another compartment. All of the data attribute explained above showed us its quantitative value so that we can do statistical analyze to see the distribution value of each parameter in giving impact on disturbance occurrence. We group the impact based on the ranged value in three classes: low impact, moderate impact, high impact (Table 12).

Table 11. Slope class in HPW I

No	Slope (%)	Class	Area (ha)
1	0 – 15	Sloping	303,7
2	15 - 25	Strongly sloping	178,4
3	> 25	Steep	132,5



(a)Distance to rural road (b) Distance to macadam road (c) Distance to setllement

Figure 8. Disturbance parameters data distribution

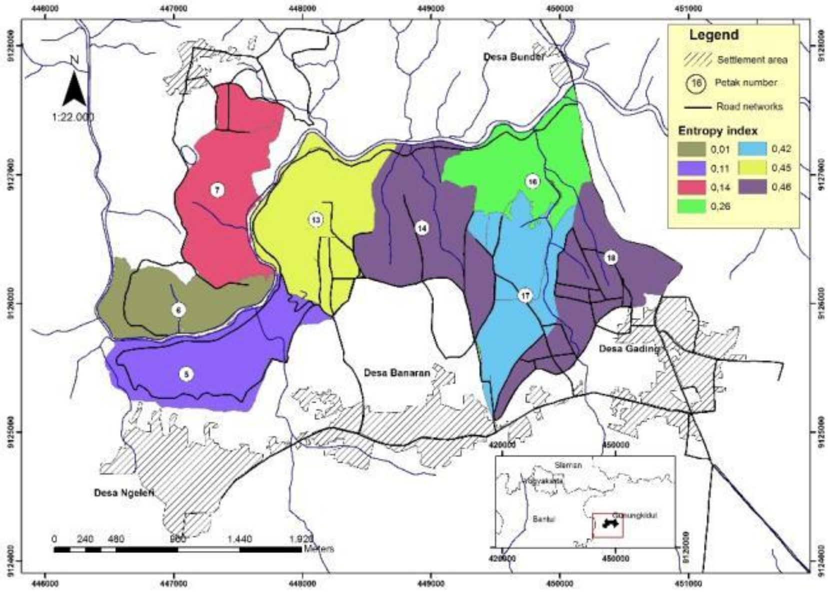


Figure 9. Entropy index in each compartment in HPW I

Table 12. Parameters and disturbance impact class

Parameter	Disturbance impact class		
	High	**Moderate**	**Low**
Distance from settlement	>1900 m	1100 m – 1900 m	0 – 1000 m
Distance from rural road	>200 m	100 – 200 m	0 – 100 m
Distance from macadam road	>800 m	400 – 800 m	0 – 400 m
Slope	>25%	15 – 25 %	0 – 15 %
Entropy index	0,42 - 0,46	0,14 - 0,42	0,01 - 0,14

3.5. Spatial modeling of disturbance distribution

Scoring analysis was done to see the disturbance range as the result of the data attribute quantitative analysis from disturbance parameters. The disturbance was scored in three classes: 1 for the lowest, 2 for moderate and 3 for the highest disturbance (Table 13). Analysis showed us that the score was ranged from 5 to 14 where the higher the score is, the higher the disturbance as it explained on Table 13. We use spatial analysis with ArcGIS to show the disturbance distribution based on the score result as it showed on Figure 12. The result showed us that HPW I area is dominated by moderately disturbed disturbance class with 246,7 hectares area and 13,7 m^2/ha to 19,1 m^2/ha of the range basal area value. It spread in all over of the compartment in HPW I but mostly it lied down on compartment 17 (Figure 13).

Table 13. Disturbance distribution based on scoring result

No	Score range	Disturbance class	Area (ha)	Basal area range (m^2/ha)
1	5-7	Low	189,2	19,2 up
2	8-10	Moderate	246,7	13,7 – 19,1
3	11-14	High	178,7	0 – 13,6

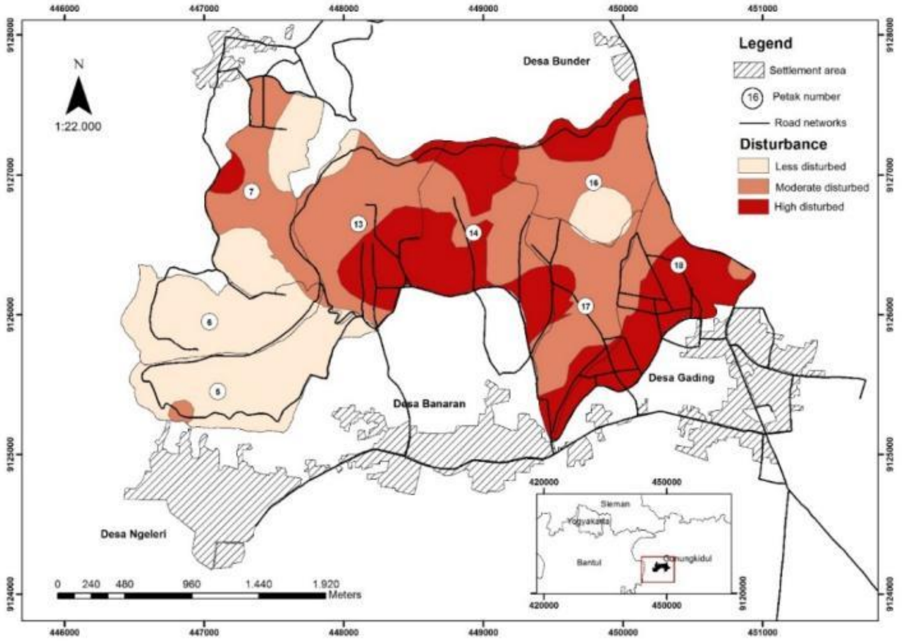


Figure 10. Disturbance distribution in HPW I

4. Discussion

Land use changes due to human activity in HPW I identified as ecosystem disturbance that can quantitatively be assessed from stand's basal area value. Compared to other parameters such as stand density, basal area is the most appropriate quantitative parameter to indicate ecosystem disturbance due to land use activities in the forest (Smiet 1992). There are many techniques to obtain and estimating basal area value but in this study, plotless sampling method using Bitterlich's stick was chosen instead of plot sampling method because of its simplicity yet accurate to obtain population basal area value. Plotless sampling could estimating population value 2,7 times more precise than the sampling plots (Estreguil and Lambin 1996).

There are a lot of methods and applications that can be used to map the distribution and pattern of ecosystem disturbance. Spatial analysis and specific software methods were mostly used considering their effectiveness and accuracy in understanding disturbance occurrence in forest area. Satellite imagery and spatial analysis based Geographic Information System (GIS) application can be used to map the distribution of anthropogenic ecosystem disturbance and its effect on vegetation cover(Keating 1997) and (Potter, Tan, and Kumar 2005).This study combine between satellite imagery and GIS to develop a spatial model to see the disturbance distribution in HPW I.

Basal area value was not quite able to explain the distribution of ecosystem disturbance as a single factor so that it is necessary to indicates any other possible factors to understand the disturbance occurrence more accurate. Mostly anthropological factors such as accessibility, surrounding settlement, altitude, and slope (Smiet 1992) and (Klein, Suzanne, and Manon 2002) were described as the most possible factors and then were analyzed as disturbance parameter. The disturbance distribution in HPW I is clear to see spatially above in Figure 12 but there are some findings in this study that indicates a symptom of disorder and the disturbance can't be explained simply by looking at the spatial distribution. To be specific in there were some area in HPW I such as at the eastern part on compartment 7 and the northern part of compartment 16, there is actually no cultivated land and has a high value of basal area, but are spatially close to the settlement so that those area was classified as moderate disturbed. In addition, condition such as topographic slope in field has a major impact on the human perception in cultivating the land, even if it spatially is close to the settlement (Brinkman et al. 2014) and (Adityawan 2015).Furthermore, the ecosystem in compartment 6 and compartment 7 is dominated by shrub land and it was indeed used as a conserved shrub ecosystem. This also supported by the steep slope on those area and has no accessible road networks. Shrub land has a low basal area value because of the shrub species small size stem diameter. We can conclude that we have to combine between the disturbance parameter with the basal area value to understand much more the ecosystem condition and vulnerability.

HPW I was built indeed to represent a successful rehabilitation program in Gunungkidul both in ecology and social economy. So at that time foresters were involving the local communities to play role in planting the seed, taking care of the nursery, securing the forest area and as the return they could taking advantages with a few area of land to cultivate. The mistake was no written record or formal agreement between local communities with HPW I stakeholder (Adityawan 2015)and until now that condition built a perception that HPW I area is open to local communities to access. It is also argued by some several research before that every year, cropland is increasing about 4 hectares spreading in HPW I area (Kuncoro 2015). However, based on the spatial view, the HPW I ecosystem is still not at risk but has a potential to experience further disturbance if human intervention is not restricted immediately and recorded periodically.

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