Quick Mapping of Soil Erosion Risks by Remote Sensing and GIS in East Java, Indonesia

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Abstract

This study demonstrated the use of Remote Sensing techniques and Geographic Information System (GIS) for assessing and mapping of soil erosion risk in East Java Province, Indonesia. A digital elevation model (DEM) derived from elevation contours combined with digital data on shuttle Radar Topographic Mapping-SRTM were used to calculate terrain parameters, such as slope and relief. The Landsat Thematic Mapper data were analysed to identify the existing landuse characteristics. The data of soil erosion factors such as soil erodibility, rainfall erosivity, slope steepness, type of landuse and management practices were scored and ranked according to their contribution to soil erosion risk. By means of GIS approach, a "weighted–summation" analyses of multiple input was performed to generate soil erosion risk map. The degree of soil erosion risk of certain areas was indicated by the total score resulting from summation of all soil erosion parameters. To verify the result of analyses, the ground truth and field data collection within representative sample areas were conducted. The results show that the degree of erosion risk was strongly related to the degree of rainfall erosivity, soil erodibility and slope steepness. It was found that about 43.1 % of the total areas were susceptible to erosion, ranging from moderate to high, and that 48, 6% of the intensive cultivated land were threatened by soil erosion. Agricultural production sustainability of sloping lands is strongly depended on the farm level management practices, such as by applied terracing, contour ploughing, strip cropping, etc.

1. Introduction

Soil erosion by water is the main degradation process of agricultural lands in Indonesia, including in the East Java province. A number of field trials, using USLE (Universal Soil Loss Equation, Wischmeier et al., 1978) method have been used to measure the soil erosion rates (Suwardjo, 1981 and Abdurachman et al., 1985) of some food crops areas, resulting in the soil erosion data of 300 – 2500 ton/ha/year. It is evident that the severe erosion processes have been degrading some large agricultural lands, and resulting in the decrease of land productivity. For this reason, to control such soil erosion is a must, in order to maintain and increase the agricultural production level. Some supporting data are needed, including the soil erosion risk data, preferably in the form of spatial data or map, i.e. the Soil Erosion Risk map. The severe erosion processes of the agricultural areas of Indonesia are the results of the combination of several erosion factors, i.e. rainfall erosivity (R), soil erodibility (K), slope length and gradient (LS), vegetation cover or landuse (C), and management (P = soil conservation practices). The values of each erosion factor can be collected using certain field trials, and then the soil loss to be computed following the Universal Soil Loss Equation (USLE): A= R.K.L.S.C.P (Wischmeier and Smith, 1978). However, the field method is costly and time consuming, hence, a quick and simplified method is needed, although the accuracy of the data might be somewhat less. Such quick method is possible to obtain, by using the GIS and Remote Sensing Techniques, to produce a simplified soil erosion risks map

2. General Description of the Study Area

2.1 Site Location and Soil Characteristics

The study area is the whole province of East Java, Indonesia, covering about 4,632,800 hectares, located between 7° 12′ South Latitude to 8° 48′ South Latitude and 111° 0′ East Longitude to 114°4′ East Longitude (Figure1). According to the classification of Schmidt and Ferguson (1951), the province has 6 climatic areas: A, B, C, D, E, and F climate types. However, almost 52% of the province area falls into D climate and 30% falls into C climate (Oldeman, 1975).

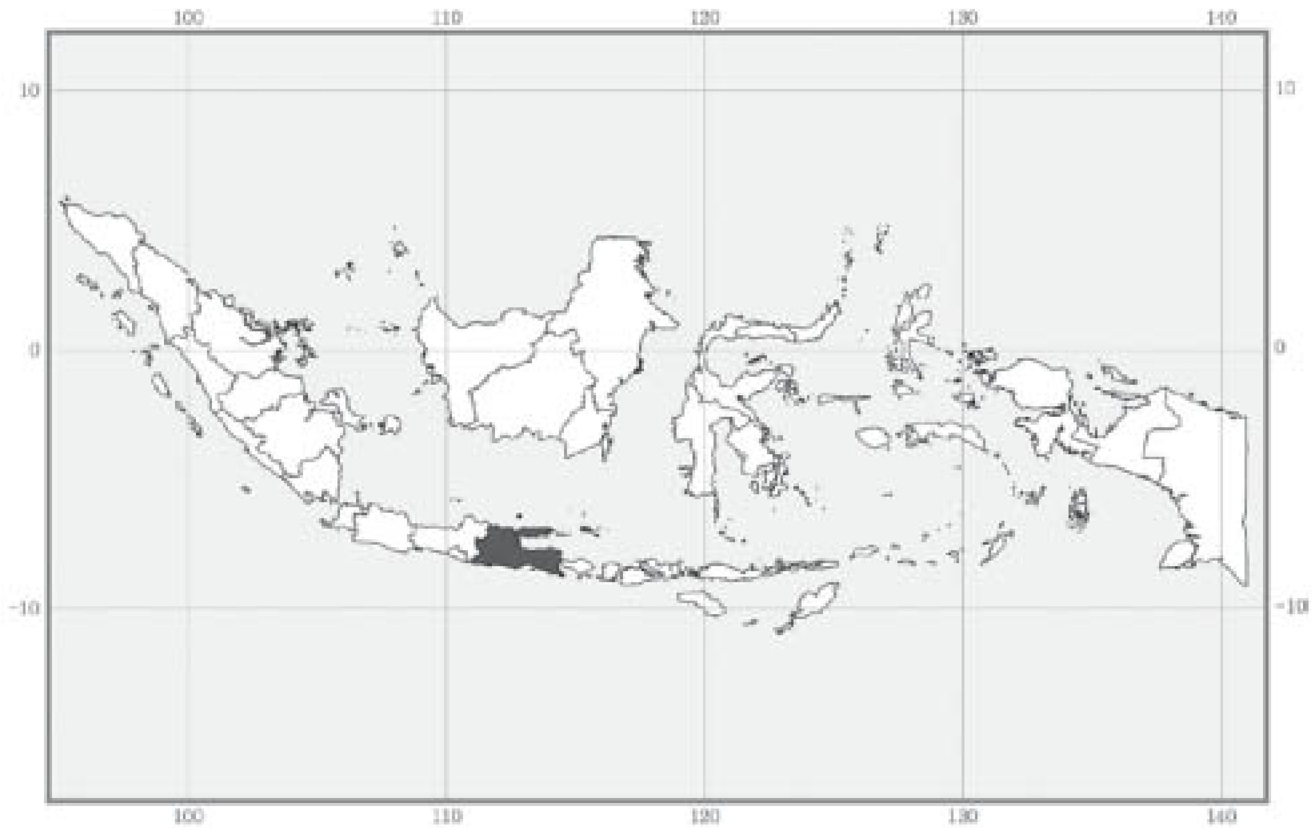
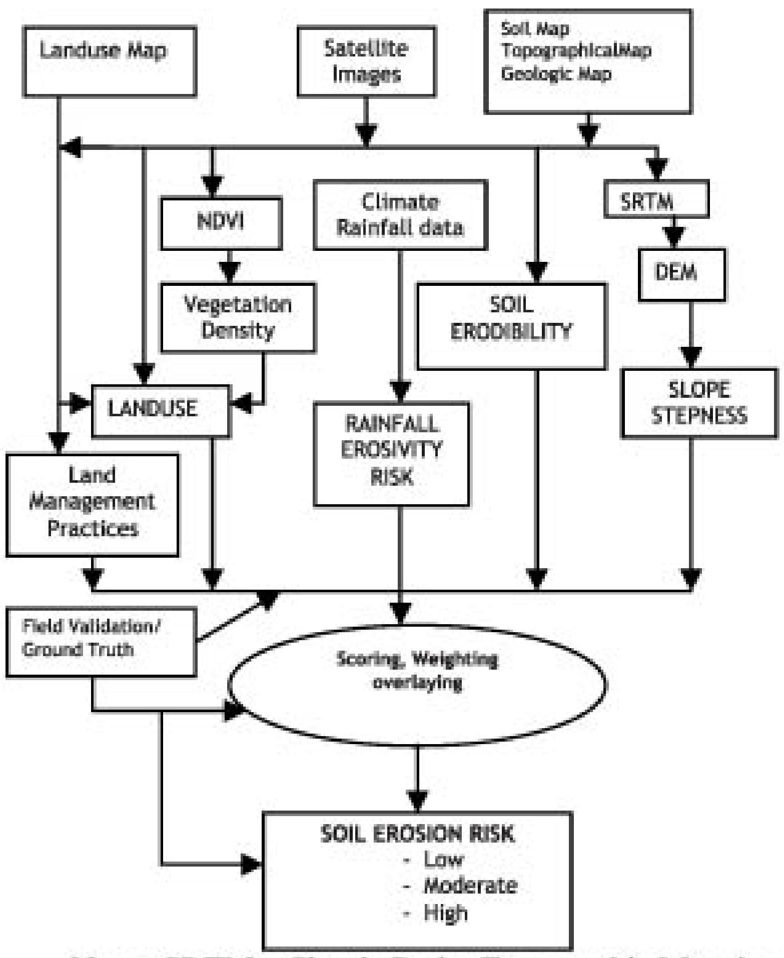


Figure 1: East Java study site location map



Note : SRTM = Shuttle Radar Topographic Mapping
DEM = Digital Elevation Model

Figure 2: Flow chart of the soil erosion risk assessment method

In this study, most of the soil data were derived from the published soil maps at the scale of 1:100,000 to 1:250,000 (Indonesian Centre for Soil Research, 1985). The soils in the study areas are dominated by six soil orders, i.e.: Entisols, Inceptisols, Andisols, Mollisols, Alfisols and Ultisols (according to the Soil Taxonomy Classification, Soil Survey Staff, 1999). The soil erosion processes have degraded the soils, resulting in the decrease of the land productivity and capability for agriculture.

2.2 Landuse and Landcover

In the areas surrounding the big cities (e.g. Surabaya, Malang), the land-use pattern was generally complicated, because some landuse types are mixed. For examples: rice fields are often mixed with built up areas, or with rural housing, or mixed gardens, etc. Due to this particular condition, the mapping of land-use types by means of automatic classification of digital satellite images was complicated, therefore the combine method of automatic classification and visual/ on screen digitizing method was choosen, supported with additional data/map from National Land Agency.

3. Materials and Method

3.1. Materials and Methods

The images and maps of East Java were obtained from various sources, included: (1) Satellite images of Landsat Thematic Mapper (TM)-5 and Landsat-7 taken in 2006 to 2007 (2) Digital Topographic maps, published by Bakosurtanal (1981-1990} at 1:250.000 scale (3) Soil Maps of East Java at 1:250,000 scale (Soepraptohardjo et al., 1961), (4) Geological Map of East Java at scale of 1:250,000, published by Directorate of Geology and Mines in 1986 – 1992. This study consisted of four activities: (1) desk study to explore the information from

Landsat TM images and others source satellite data, having relation with the problems of soil erosion. (2) ground truth and field data collection and (3) evaluate the soil erosion factors, (4) Generate soil erosion susceptibility risk map, and erosion factors evaluation related to their contribution to soil erosion risk. The desk studies includes the reviewing and analyzing all existing soil and climate/ rainfall data, geological, topographical, as well as information from previous studies including journal and maps. The Steps of Soil Erosion Risk Mapping, schematically depicted in Figure 2 the rain-fall erosivity index, calculated from the rain-fall series data. The others were collected by digitizing spatial relevant data combined with the satellite imageries, and geo-referencing the topographic maps. To verify the results, then some ground truth and field data collection of physical parameters within the representative key areas were carried out. The main erosion factors, investigated in this study were: (1) rainfall erosivity, (2) slope steepness, (3) soil erodibility, (4) type of landuse, and (5) land management practices. Rainfall erosivity was estimated based on the assumption that different erosion factors have different impacts on the erosion rate, then they were weighted according to their contribution. For example, the slope steepness and rainfall erosivity were considered to have strongest influence on soil erosion, therefore to be weighted as 25, while the conservation practice was considered less contribution, then to be weighted as 10. The parameters were scored into 2-5 points, depended on their susceptibility to soil erosion. For example mixed garden and tree plantation were considered less susceptible to erosion, therefore the score were 2-4 (depended on the vegetation density), while the score of bare land was 5. By means of GIS module, a weighted - summation analysis of mutiple input was performed. The erosion factors (soil erodibility, rainfall erosivity, slope steepness, landuse/ land cover, and conservation practices), were recorded according to their contribution to soil erosion risk (Table 1). The degree of soil erosion risk of certain areas is indicated by the total score resulting from summation of all erosion parameters. It consisted of 3 groups: (1) low risk, (2) moderate risk, and (3) high risk.

Table 1: Weighted summation analysis for the soil erosion risk mapping

Erosion Factors	Major Types	Weighting Factor	Rating/ Scoring value	Composite Score
Soil Erodibility		20		
	Low Erodibility		2	20
	Moderate Erodibility		3	60
	High Erodibility		4	80
Rainfall Erosivity (RE)		25		
	< 50 (very low)		1	25
	50 – 100 (low)		2	50
	101 – 200 (moderate)		3	75
	201 – 300 (high)		4	100
	>300 (very high)		5	125
Slope Gradient		25		
	<8% (flat – undulating/flattish)		1	25
	8-15% (rolling/ gentle sloping)		2	50
	15-25% (hilly/ somewhat steep)		3	75
	25-40% (hilly- mountaineous/ steep)		4	100
	>40% (mountaineous/ very steep slope		5	125
Landuse (type and crop cover density)		20		
	- bare land		5	100
	- Shrubs and bushes – dense crop cover		3	60
	- Shrubs and bushes – rare crop cover		4	80
	- Wetland – annual crops		1	20
	- dry land – annual crops		4	80
	- mixed garden/ tree crops – dense crop cover		2	40
	- mixed garden/ tree crops – moderate crop cover		3	60
	- mixed garden/ tree crops – rare crop cover		4	80
	- Plantation – dense crop cover		2	40
	Plantation- moderate crop cover		3	60
	Plantation –rare crop cover		4	80
	- Dense forest		1	20
	Moderate dense forest		2	40
	Rare forest		3	60
	- Settlements, city, Industries		-	-
	- Water body, lake, river, swamp		-	-
Land Management Practices	Available management practices	10	1	10
	No management practices		4	40

Note : vegetation covered density : dense = >50%; moderate = 25 – 50%; rare = <25%

4. Results and Discussion

4.1 Rainfall Erosivity

The rainfall erosivity index is related to the rainfall amount, rainfall intensity and distribution. It is related to total rainfall over the year (More 1978, Hudson, 1981and Kassam et al., 1992). Several equations of erosivity index have been established by various authors e.g: Bergsma, 1980 and Mouwen, 1990. Unfortunately most of these equations require certain rainfall data which are mostly unavailable in the study area. Therefore, the rainfall erosivity was determined using the modified Fournier Index equation (Arnoldus, 1980 and Kassam et al., 1992), i.e. $RE = \sum (MR)^2 / AR) / 12$, where MR and AR are monthly and annual millimeters of rainfall respectively. The rates of rainfall erosivity in the study area, ranging from 106 to 370. About 71, 1% of the study area fall into the high rainfall erosivity index; 18, 4 % moderate, and 10, 5 % very high.

4.2 Soil Erodibility

The degree of soil erodibility is depended mainly on soil properties, which are reflected in the inherent soil types. It can be grouped in to 3 (three) classes, as follows: (following the soil classification of Soil Survey Staffs, 1999)

a. Class 1 (Low erodible soils): Aquents, Arents, Fluvents, Aquepts, Aqualfs, Aquults, Aquox, Aquods, Aquerts, Aquolls, Histosols, Udepts

b. Class 2 (Moderate erodible soils): Ustepts, Xerepts, Antrepts, Albolls, Xerolls, Ustolls, Udolls, Ustals, Xeralfs, Udalfs

c. Class 3 (High erodible soils): Torrands, Xerands, Vitrands, Ustands, Udands, Torrox, Ustox, Perox, Udox, Xererts, Torrerts, Ustersts, Uderts, Humods, Orthods, Humults, Udults, Ustults, Xerults, Psamments, Orthents, Rendolls

4.3 Slope Factor

The slope gradient data were derived from the Digital Elevation Model (DEM). The source of the DEM was the topographical map at scale of 1:50,000, with contour interval of 25 meters and digital data of Shuttle Radar Topographic mapping-SRTM. The slope data from DEM were obtained by applying slope formula in GIS module. Slope Gradient (%) was calculated, and then classified into six classes, based on FAO guidelines (1994). Generalization was also done by using a majority filter. Based on the slope steepness and relief, the areas of East Java province could be splitted up into 6 classess, as shown on Table 2.

Table 2: Slope classes of the areas of East Java province

Slope class	Gradient (%)	Area (ha)	Area (%)
1	0 - <3	2,082,080	44.94
2	3 - <8	1,006,336	21.72
3	8 - <15	599,808	12.95
4	15 - <25	447,646	9.66
5	25 - <40	361,083	7.79
6	>40	135,847	2.93
	Total	4,632,800	100.00

4.4. Crop (Landcover) Factor

The land use type was analyzed from the satellite imagery. The bare lands can be distinguishable from the covered lands, using the combination of band 5, 4, dan 3, of the TM-7, and can be clearly delineated. Furthermore, the vegetation covered areas (%) can be calculated using the formula "Normalized Different Vegetation Index-NDVI" program. There was an indication that the lower value of the vegetation greeness, the less density of the vegetation. The lower greeness also indicated the less density of the tree canopies, and furthermore indicated bush, grass, imperata, and bare lands. In the severe eroded lands and bare lands, the erosion factors such as land management, percentage of vegetative land cover, and slope gradient, can be identified somewhat clearly, using satellite images supported by other relevan map/data. Furthermore, the parameters of the erosion factors can be scored for assessing the erosion risk level. While in the forest land or covered by dense vegetation, the erosion parameters were more dificult to assess. Crop cover is the covering proportion of the ground surface over a given area against the impact of rain. Natural vegetation in the humid tropics including in East Java, especially natural evergreen forest, has tremendous effect on soil formation. Even on very steep slopes and under highly erosive rainfall soil losses are minimal, and deep soil are found (Gark and Harrison, 1992, FAO, 1994).

4.5Management (Soil Conservation Practice) Factor

During ground truth and field data collection, some soil conservation practices were found, including: crop management, cultivation system, land management and small construction works for controling soil erosion. In some areas, where annual crops can be combined with woods growing, usually the agroforestry techniques applied. The other types of management, such as: crop rotations and stubble mulching, were randomly applied by the farmers, however, they were undetectable on satellite images.

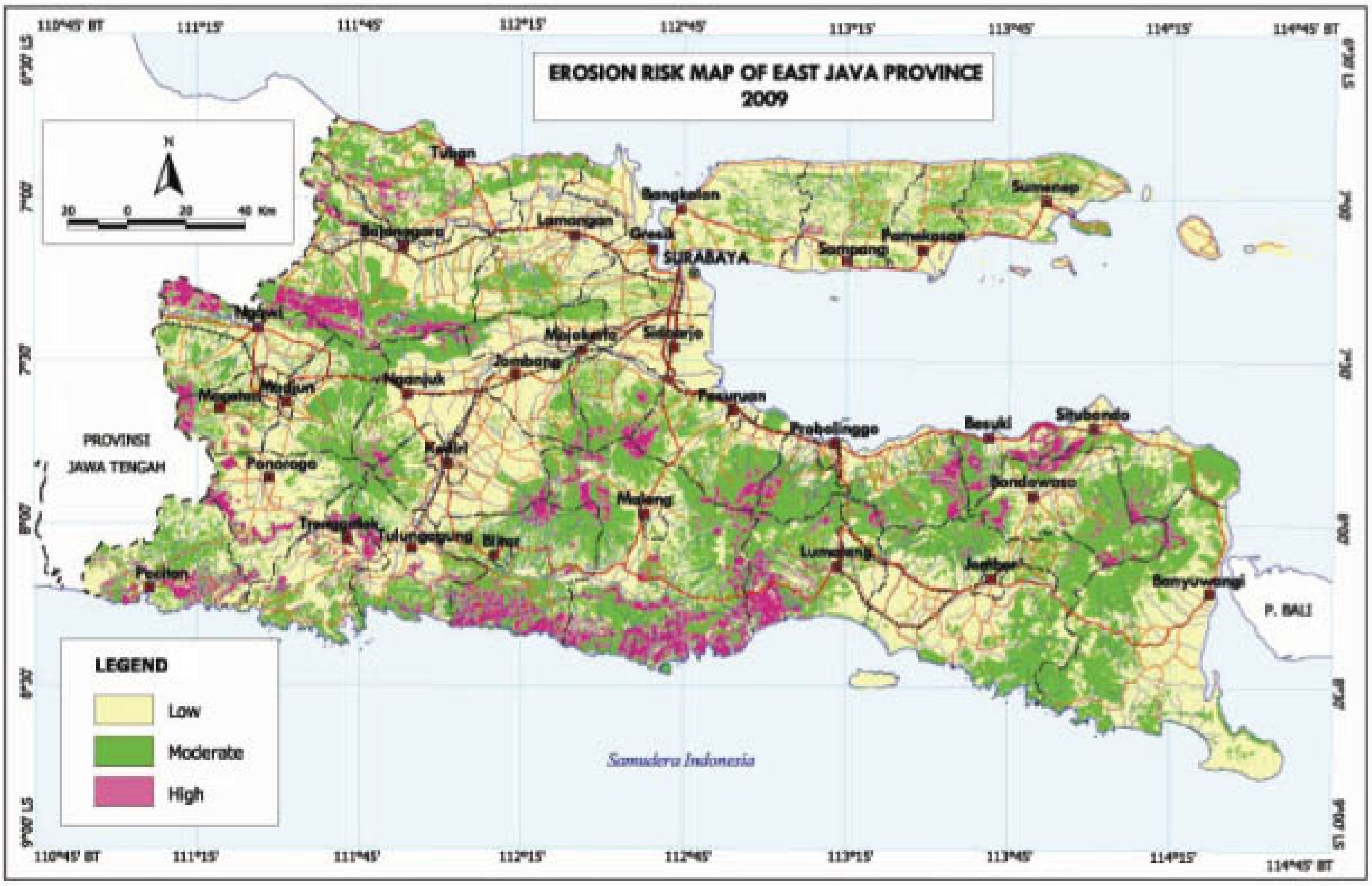


Figure 3: Soil erosion risk map for East Java province, Indonesia

Some other types of land management practices, such as contour tillage, contour strip cropping, terraces and gully filling, could be recognized on air photo or big scale of remote sensing imagery. Unfortunately, Landsat TM satellite images, could not provide information on such management practices throughout the year, hence, it was assumed to be "no management practice at all".

4.6 Soil Erosion Risk Map

The results of soil erosion risk mapping by means of a weighted summation analyses of multiple input for East Java Province can be seen in Figure 3. The areas could be splitted up into 3 classes: (1) low risk, covering about 2.588.830 ha (55,9%), (2) moderate risk, about 1.652.711 ha (35,7%) and (3) high risk about 391.258 ha (8,4%). The high and moderate erosion risk areas were generally indicated by steep slopes, high soil erodibility, and lack of vegetation cover. The spatial distribution in detail is presented in Table 3. There were 6 Regencies in East Java, having areas susceptible to erosion of more than 30.000 ha, i.e. Malang (77.341 ha), Banyuwangi (34,047 ha), Blitar (39,368 ha), Lumajang (34.416 ha), Bojonegoro (30,326 ha), and Blitar 39.368 ha. It was found that about 43.1 % of the East Java province was susceptible to soil erosion, ranging from moderate to high, and that 48,6% of the intensive cultivated land with annual crops are threatened by these risks.

5. Conclusions

1. The development of Remote Sensing techniques and GIS has been successfully facilitating the assessment of soil erosion risk of a regional scale. The identification and quantification of erosion factors is required in order to select appropriate conservation measures and land management strategies.
2. The Digital Landsat TM Satellite images can be used to collect the information of relief, slope characteristics, and major landuse types. Therefore, the mapping of the erosion risk areas can be done faster, compared to conventional method. However, on Landsat TM satellite images, the soil erosion features, indicating the actual soil erosion conditions and soil management practices could not be detected clearly.
3. There were three groups of areas in the East Java, i. e.: (1) Low erosion risk areas, covering 2.588.830 ha (55, 9%), (2) Moderate erosion risk areas, 1.652.711 ha (35,7%), and (3) High erosion risk areas, 391.258 ha (8,4%). It is a warning for the local governments and relevan

people, to be aware of the threat, in the form of soil erosion, landslides, flood and drought.

4. The soil erosion risk on annual crops areas with slope <15% falls into low to moderate degree, and annual crops with slope >15% generally have moderate to high degree. The annual crops on sloping areas, should be provided with propper conservation practices, such as crop and land management practices.

Table 3: Soil erosion risk of East Java province areas

No.	District	Soil Erosion Risk Area (Ha)			Total Area (ha)
		1 (Low)	2 (Moderate)	3 (High)	
1	Bangkalan	104,571	21,185	244	126,000
2	Banyuwangi	428,736	145,517	4,047	578,300
3	Blitar	37,363	82,169	39,368	158,900
4	Bojonegoro	126,369	74,005	30,326	230,700
5	Bondowoso	60,447	75,573	19,980	156,000
6	Gresik	106,876	12,224	0	119,100
7	Jember	98,032	145,520	4,248	247,800
8	Jombang	67,058	20,893	2,449	90,400
9	Kediri	104,867	29,260	4,473	138,600
10	Kota Batu	2,896	3,185	3,219	9,300
11	Kota Blitar	1,091	2,209	0	3,300
12	Kota Kediri	5,804	189	307	6,300
13	Kota Madiun	3,154	146	0	3,300
14	Kota Mojokerto	1,552	48	0	1,600
15	Kota Pasuruan	3,452	48	0	3,500
16	Kota Probolinggo	5,384	316	0	5,700
17	Kota Surabaya	29,093	3,507	0	32,600
18	Lamongan	119,924	46,847	229	167,000
19	Lumajang	56,014	88,670	34,416	179,100
20	Madiun	43,758	56,846	496	101,100
21	Magetan	42,223	19,838	6,839	68,900
22	Malang	107,556	114,003	77,341	298,900
23	Mojokerto	33,674	30,571	4,955	69,200
24	Nganjuk	80,093	37,110	5,197	122,400
25	Ngawi	71,952	39,119	18,529	129,600
26	Pacitan	53,324	55,429	25,447	134,200
27	Pamekasan	43,645	35,555	0	79,200
28	Pasuruan	49,909	52,150	13,041	115,100
29	Ponorogo	91,685	28,756	16,759	137,200
30	Probolinggo	62,021	78,555	19,324	159,900
31	Sampang	82,574	39,376	1,350	123,300
32	Sidoardjo	63,020	380	0	63,400
33	Situbondo	60,038	82,896	20,966	163,900
34	Sumenep	127,814	71,025	1,061	199,900
35	Trenggalek	63,017	41,522	15,961	120,500
36	Tuban	98,948	73,082	11,970	184,000
37	Tulungagung	50,896	44,987	8,717	104,600
	Total (ha)	**2,588,830**	**1,652,711**	**391,259**	**4,632,800**
	Total (%)	55.9	35.7	8.4	100.0

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