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INTEGRATION OF BIOPHYSICAL AND SOCIO-ECONOMIC FACTORS TO ASSESS SOIL EROSION HAZARD IN THE UPPER KALIGARANG WATERSHED, INDONESIA

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ABSTRACT

Soil erosion is one form of land degradation, which is caused by the interacting effects of numerous factors such as biophysical characteristics and socio-economic condition of a particular watershed. Previous erosion studies focused on the use of soil erosion models (e.g. USLE, EUROSEM, SLEMSA etc.), which have been developed under local conditions (e.g. United States, Europe, Africa, etc) and mostly use only biophysical factors as inputs to the models. In this study, a methodology that integrates both biophysical and socio-economic aspects into a framework for soil erosion hazard assessment using principal component analysis (PCA) is described. The analysis is done at the land unit level. With the particular conditions of the study area that is characterized by Inceptisols and Alfisols soil types, nine different land uses with mixed vegetation and forest area dominant in the steep slope, high annual rainfall (>2500 mm), high population with mostly low income and low education, were considered. These were used in formulating a soil erosion hazard index (EHI) equation which relates a number of key factors consisting of biophysical and socio-economic variables, namely soil texture, slope steepness, land cover, soil conservation practices, income and farmers' knowledge. Weighting and scoring of these key factors were used to develop the EHI equation and to calculate an index value of erosion hazard for every land unit. Results indicate that more than 60% of the area has erosion hazard ranging from moderate to very severe, and most of the land units with high erosion hazard were found at the mountain areas. It was also found that erosion hazard was severe in areas with high silt content, followed by high rainfall and steep slope, low crop cover without any soil conservation practices coupled with lack of awareness on soil erosion and low income. The key factors identified and level of erosion hazard obtained can be used to formulate conservation measures in critical areas which are prone to soil erosion. Copyright © 2007 John Wiley & Sons, Ltd.

KEY WORDS: biophysical; socio-economic; erosion hazard assessment; key factors; EHI; Indonesia

INTRODUCTION

Soil erosion by water has been identified as a major problem for sustainable agriculture in sloping areas, especially in tropical countries such as Indonesia, where rainfall intensities are very high and soils are generally less fertile. It causes severe on- and off-site environmental, economic and social impacts. On the other hand, increasing demand of natural resources due to population growth and economic development, including extensive agricultural development, has had serious impact on land resource quality (Suwardjo and Neneng, 1994). To ensure sustainable land resource development and reduce environmental degradation, better land use and land management policies are required. However, this requires information which critical areas are susceptible to erosion and needs immediate conservation, as well as improved understanding of the spatial and temporal patterns of soil erosion.

The study area, the Upper Kaligarang Watershed, was identified as the first priority for watershed management for Central Java Province (LRSSC Jratunseluna, 1991; Sudanti, 2001). The main problems identified were high soil erosion mainly in upland cultivation and inappropriate land use, which damaged natural resources for a long period.

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Since then, both local and central government have been striving to solve these problems through many development projects. To be able to curb the worst effect of soil erosion in the future, this failure should be recognized and past approaches on catchment management research should be re-examined using an integrated and interdisciplinary approach (Agus *et al*., 1998). It should be also pointed out that reliable data and information on the extent and the severity of soil erosion hazard, and knowledge of the causal factors affecting erosion is a vital pre-requirement in improving planning policies and executing an effective and holistic approach to address the problem of soil erosion.

Soil erosion hazard, one of the conservation parameters, is a measure of the susceptibility of an area of land to prevailing agents of erosion (Houghton and Charman, 1986). It is determined by climate, topography, soil erodibility and land use. Each specific land use has its own erosion hazard. With regard to land use, any human activity which entails the removal of the protective vegetation cover (forest, shrubs, grass etc.) and improper measures such as ploughing along slopes enhance erosion (Holy, 1980). The severity of erosion depends upon the quantity of material supplied by detachment and the capacity of the eroding agents to transport it (Morgan, 1995). The assessment of erosion hazard is a specialized form of land resource evaluation, the objective of which is to identify those areas of land where the maximum sustained productivity from a given land use is threatened by excessive soil loss.

Many methods have been used in previous studies for assessing soil erosion hazard. One approach is the use of erosion intensity as erosion hazard index (EHI; e.g. Morgan, 1995), where two indexes of erosion intensity to assess erosion risk in Peninsular Malaysia, were used. Stocking and Elwell (1976) presented a generalized picture of erosion risk in Zimbabwe, based on mean annual erosivity values, while Morgan (1974) used KE >25 index, and rainfall aggressiveness p^2/P was used by Fournier (1960, cited in Morgan, 1995). Al-Sheriadeh and Al-Hamdan (1999) used tree erosion indices, namely drainage texture, rainfall erosion index (R) and the ratio p^2/P. Factor scoring was devised by Stocking and Elwell (1973); Vrieling *et al.*, (2001) applied a Qualitative Erosion Risk Mapping (QUERIM) that uses decision trees to assign ratings to the erosion-controlling factors.

Furthermore, United States Soil Conservation Service (Klingebiel and Montgomery, 1961) developed land capability classification as a method of assessing the extent to which prevailing conditions as erosion risk, soil depth, wetness and climate, hinder the agricultural use that can be made of the land. However, soil erosion hazard is most widely assessed using soil erosion models such as Universal Soil Loss Equation (USLE) used by Gregersen *et al*. (2003) and Saha and Pande (1993), and Revised USLE (RUSLE) used by Bartsch *et al*. (2002). The Agricultural non-Point Source Pollution Model (AgPNS) and RUSLE were used by Renschiler and Diekkruger (1999), while Shi *et al*. (2002) integrated RUSLE and GIS to quantify erosion risk in the middle and lower reaches of Hanjiang River. In a surface/sub-surface transport model by Clemente *et al*. (1993, 1998) USLE was modified to evaluate chemical transport and partitioning in runoff and erosion in a cultivated field in Canada. However, only climatic and biophysical variables were used as inputs in the simulation. While in Indonesia, studies on erosion hazard mostly based on USLE model and National Watershed Management and Conservation Project (NWMCP) of Ministry of Forestry of Indonesia recommended the use of aerial photograph and USLE model to produce soil erosion hazard map as a basic resource for formulating middle term planning of land rehabilitation and soil conservation programme.

It can be seen that most of previous studies only used biophysical factors as a basis for soil erosion hazard assessment. In addition, existing soil erosion models have been developed under local conditions (e.g. United State, Europe and Africa) whose climate, topography, and soil properties may be different compared to tropical area like Indonesia.

In view of the above limitations, it is necessary to develop a methodology for assessing erosion hazard that incorporates both biophysical and socio-economic factors. This is the main objective of this study where detailed information of key factors that affect erosion hazard, and predicts the extent of variation of soil erosion hazard in study area, will be investigated. The methodological approach can be utilized for other areas, which have unique biophysical characteristics and socio-economic conditions. Furthermore, the findings of this study will also be useful for policy makers and organizations working on the prevention of soil erosion and land degradation since they can direct their efforts more effectively.

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MATERIALS AND METHODS

Profile of the Study Area

The research site (i.e. catchment area) was selected based on its priority for watershed management by Central Java government for the following reasons: it is a representative of its land use, topography, social and economic condition of the region, accessibility, and possible collaboration with existing research institutions. In addition, the suitability of the site for hydrologic monitoring was also set as a criterion.

The study area, the Upper Kaligarang Watershed, is one of the important sub-watershed of Kaligarang watershed in the northern part of Central Java, Indonesia. It is located at longitude 111° 20′ 6″ to 110° 26′ 28·8″ East and latitude 07° 18′ 18″ to 07° 45′ 28·8″ South (Figure 1). The total area of this sub watershed is 7081 ha. The highlands of Kaligarang Watershed have slopes ranging from 15 to 40 per cent, becoming steeper as it approaches closer to the summit of Mount Ungaran. Forest still covers the steepest slopes, but annual food crops and various estate crops (such as coffee, cloves, nutmeg and tea) predominates at the area with 400–1000 m elevation. The intermediate plateau, with elevation between 50 and 400 m, is covered by a mosaic of agro-forestry gardens, villages, and lowland rice fields. Soil types in the study area include Andosols, Alfisols, Ultisols and Inceptisols. Soil map acquired is for 1995, with scale 1:50 000 based on soil series and association of two or more soil groups. The climate in the area is characterized by two seasons, i.e. wet season from November to April and dry season from May to October. Seasonal change is controlled by the difference in atmospheric pressure between the western and eastern Pacific zones.

Research Materials

The materials used in this study are as follows: (1) Topographic map (1:25 000) acquired in 1998 by Bakosurtanal (National Coordinator for Survey and Mapping Agency, Indonesia). This map was used for generating watershed boundary, village boundary, drainage pattern, road network, contour map, elevation map and slop map; (2) Soil map (1:50 000) acquired in 1995 by Indonesian Soil and Agro-climate Research Center (ISARC) for generating soil type boundary. Sixty four soil samples were collected for the estimation of soil properties; (3) Landsat TM Image (2002) from LAPAN for generating land cover/land use map; (4) Rainfall data (6 min data from 1993 to 2002) for calculating annual rainfall, maximum 30-min intensity (I_{30}), kinetic energy (EI_{30}) and runoff. (5) Socio economic data that was gathered through the household survey for descriptive statistical data (frequency, means and weight index) and product of multivariate analysis (coefficient matrix, variance and correlation)

Research Methods

The overall methodology involves the use of a principal component analysis (PCA) and Geographic Information System (GIS), with data obtained from weather stations, soil map, topographic maps, satellite image, land use map and field surveys. The details of the flow of activities are described below.

Identification of Biophysical and Socio-economic Factors

Identification of biophysical and socio economic factors that affect soil erosion is aimed to decide which variables will be gathered in the study. The steps of activity are: (1) Reviewing biophysical and socio economic factors that affect soil erosion; (2) Identification of biophysical and socio economic variables for the study area as a basis in data collection and for in-depth interview.

Biophysical Data Collection and Preparation

Rainfall erosivity and runoff

This study investigates the seasonal pattern of rainfall intensity and runoff using 6 min data from six stations (Banyumanik, Ungaran, Nyatnyono, Keji, Sidorejo and Pagersari), for which autographic records are available. Six min rainfall data from six stations in the study area covering 1993–2002 were compiled as point database for analysis. Calculation of daily, monthly and annual rainfall means, maximum 30-min intensity (I_{30}) and kinetic

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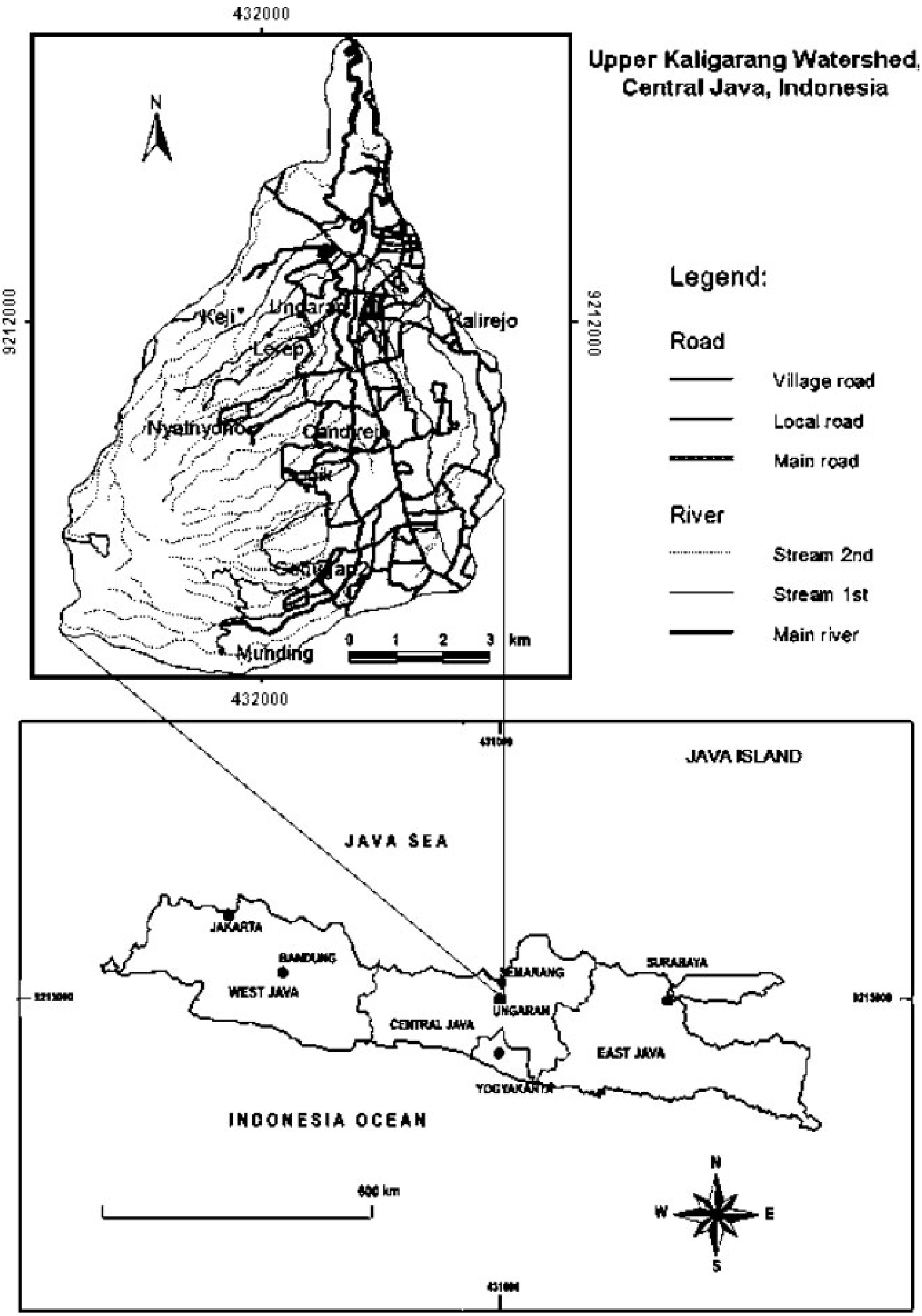

Figure 1. The study area in Upper Kaligarang Watershed, Central Java, Indonesia.

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energy (EI_{30}) were made at each station. Grid interpolation method was performed to establish spatial mean annual rainfall, I_{30} and EI_{30} across the entire study area to create the Isohyet line under ArcView system.

Slope map

Digital topographic data for the Upper Kaligarang was obtained by digitizing four sheets of topographic maps of scale 1:25 000. The contours and the drainage system were digitized separately and used to build up the Digital Elevation Model (DEM) of the watershed. The contour interval used is 12·5 m. The result of DEM is used to determine the slope gradient (S) and slope length (L) in Arc/Info GRID.

Land use map

Landsat–TM image in a digital format was acquired on May 2002 for Path/Row- 120/65 that obtained from LAPAN and used to characterize and identify land use class. The Image processing was performed by using ENVI version 3·4, NT Arc/Info version 3·2 (Grid), and ArcView version 3·2a.

Crop cover and land management value

This study examined the relationship of soil erosion hazard under different land use. In order to get the percentage of crop cover, it is necessary to get information about crop calendar especially for each type of annual crop that are available at the study area. This information was collected from field survey to develop crop calendar. Field observations data integrated with crop calendar were used for estimating the average crop cover for every land use. Meanwhile, information on land management practices was gathered by using field observation/interview during the field survey. The crop cover and land management practices values were determined based on land use map, field survey data, C-index and P-Index based on '**Pedoman Penyusunan Rencana Teknik Lapangan**' (Field Engineering Design), Ministry of Forestry, Republic of Indonesia (RKLT, 1998).

Soil map and land unit map

The soil type map of the Upper Kaligarang was prepared by digitizing the Soil Map of **Kabupaten Semarang** acquired in 1995 (**Puslittanak**) and clip with the Upper Kaligarang Watershed boundary using ArcView/GIS technique. This map was overlayed with land use map and slope map that was produced in previous work to generate land unit map. Every land unit map has unique characteristic that is the combination of land use/land cover, soil type and slope degree.

Soil characteristics

Sixty four soil samples were collected to represent all land units, both disturbed and undisturbed soil samples, using the following guidelines: (1) The sample needs to be representative of all of the soil in the grid, not just the location at the centre of the grid cell, (2) Each sample was made up of sub-samples. GPS was used to locate the approximate centre of the target cell/polygon. Then, partial samples were gathered by going a few metres in several directions from the centre and the samples are mixed together in one bag to represent the overall sample for that grid cell. Undisturbed soil samples were used for soil physical analysis and disturbed soil samples were used for soil chemical analysis. The soil characteristics used in this study include texture (sand, silt and clay content), permeability, bulk density, water aggregate stability, water holding capacity and organic matter content.

Socio Economic Data Collection and Preparation

In order to get representative information of socio-economic condition of the study area, ecological units were delineated into 'lowland' and 'upland' areas based on natural drainage, elevation data indicated in topographic map and terrain relief of the study area. For lowland areas two villages were selected based on land use (e.g. irrigated and rainfed paddy field), and seven villages in upland areas, which represent annual crops (two villages), estate crop (two villages), mixed vegetation (two villages) and vegetable (one village). The two villages in the lowland area are: Candirejo and Kalirejo, while the seven villages in the upland area are: Keji, Kalisidi, Lerep, Gogik, Nyatnyono, Gebugan and Munding.

Socio economic survey

The socio-economic component of the study involved both qualitative and quantitative analysis of data on population, education, age structure, household size, occupation, conservation, technology adoption, farmer perception on soil conservation, problems on soil conservation application, accessibility to capital, agro-input supply and information sources, crops production, farm income, off farm income, gross income, crop production input, crop yield and benefit cost ratio. The selection of above variables was based on literatures (e.g. Blum, 2001; Enters, 1998; Mamicpic *et al*., 1996; Thapa, 1988), which identified them as the important socio-economic drivers of soil erosion and soil conservation measures.

The study area has about 4223 farm households, out of which 150 farm households were sampled purposefully both and lowland and upland areas using the standard formula (Yamane, 1967) of deciding the sample size. Further, the samples were proportionally distributed in upland (114 households) and lowland (36 households).

To collect the above information, household survey was conducted using participatory approach and structured questionnaire. The interviews concerning conservation problems and programmes in the villages were also held involving Head of the Villages and Chairman of Farmer Groups. Secondary data such as geographic, demographic, agricultural and economic statistics, erosion problem etc. were taken from reports and publications on conservation programme. Specifically, the supporting data which are related to soil conservation problem and activities were collected from village, local government, forestry and agricultural offices at district and provincial levels.

Data Integration

Define Sample Unit Area: Sample unit area is the area obtained by overlaying land unit map and socio-economic unit map that are produced from previous work. The socio economic data was calculated for each land unit. The overlapping areas of two or more socio-economic boundaries were used weighting technique to obtain new values. The integrated data provides unique combination of all biophysical and socio economic values.

Statistical Analysis

Determining erosion hazard key factors

Principal component analysis (PCA) was used to identify erosion hazard key factors. The analysis involved a sequence of logical steps, starting with the initial selection of potential erosion hazard factors to the determination of key factors that best represented the biophysical and socio-economic function. The sequence of main steps is as follows:

1) Selection of a set of biophysical and socio-economic indicators for the study area. The initial set consisted of 18 biophysical and 9 socio-economic indicators.
2) To standardize data, *F*-test was used in order to test normality of data distributional characteristics and data transformations to correct violations of statistical assumptions and provide a mean of modified variables.
3) To determine of the dominant factors, the PCA was performed to find out the principal components (PCs) or subsets from a large data set. It was assumed that PCs with high variance (eigenvalues) best represent system indicators. Therefore, only PCs with eigenvalues ≥ 1 were used for further analysis (Andrews *et al*., 2002; Brejda *et al*., 2000). Eigenvalues are the amount of variance explained by each factor, i.e. in this case 'biophysical and socio-economic indicators/attributes'.

PCs were then used to group the initially identified factors into statistical factors based on their correlation structure. The correlation structure was analysed using bivariate analysis.

Each variable (i.e. soil and socio-economic attribute) in the PCs received a weight or factor loading (eigenvectors) that represented its contribution to the PC. Retained variables, which have high factor loading for each selected PC, were identified. As suggested by Andrews *et al*. (2002), only the highly weighted variables from each PC were retained in the data set. Highly weighted variables were defined as those within 10 per cent of the highest factor loading. When more than one variable was retained within a PC, their correlation significance was observed. If the weighted variables were not correlated (i.e. $r < 0{\cdot}60$), then each was considered important and was retained in the PCs. If the variables were significantly correlated, one of the variables could be considered redundant and, therefore, eliminated from the PC. Among the significantly correlated variables within a PC, the variable with

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the highest sum of correlation coefficients was chosen for the PC (Andrews *et al*., 2002). The selected variables are then defined as the erosion hazard key factors.

Developing EHI

To develop EHI, the variables (e.g. $X_1, X_2, \ldots, X_p$) were analysed using PCA and combined linearly after multiplying with respective weights of PCs to come up with indices. In conjunction with this analysis, EHI can be formulated as a function of a set of mutually exclusive component, in which each component consisted of a set of retained variables. Conceptually, EHI is a function of all PCs that can be expressed as follows:

$$\mathrm{EHI} = f(\mathrm{PC}_1,\ \mathrm{PC}_2, \ldots, \mathrm{PC}_n) \quad (1)$$

EHI were then developed using all key factors (retained variables), which were identified earlier. The weighting factor W (i.e. the weight of each PC) was determined by the percentage of variance in the PC divided by the total percentage of variance for all PCs, which have eigenvalues ≥ 1. Using the modified soil quality index formula described by Andrews *et al*. (2002), the EHI was constructed as follows:

$$\mathrm{EHI} = \sum_{I=1}^{n} W_i * X_i \quad (2)$$

where: W = PC weighting factor X = Key factor score

Generating Erosion Hazard Map

The aim of generating erosion hazard map is to find out the locations of the areas, which have certain level of erosion hazard. For this purpose, mapping technique was used. The steps for generating erosion hazard map are as follows:

1) Definition of the key factor. Depending of the direction of influence of the biophysical and socio-economic characteristics (i.e. positive or negative) where greater the score, the higher the contribution to erosion hazard (e.g. the higher slope steepness, the higher its contribution to erosion hazard) or the less the score, the higher the contribution to erosion hazard (e.g. the less the soil aggregate stability, the higher its contribution to erosion hazard).
2) Scoring and conversion of erosion hazard key factors into a 0 to 1 scale using the modified two equations proposed by Diack and Stott (2001). The equations are:

$$y = (x - s)/(1 \cdot 1t - s) \quad (3)$$

for 'more is higher contribution to erosion hazard'

$$y' = 1 - y = 1 - \{(x - s)/1 \cdot 1t - s)\} \quad (4)$$

for 'less is higher contribution to erosion hazard' where, y is the score key factor; x is the value of key factor converted into 0 to 1 scale value; s is the lowest possible value of key factor (i.e. s = 0); and t is the highest value for that key factor.

3) Calculating EHI using equation (2) for all land units.
4) Assigning EHI for each land unit on the map using GIS technique.
5) Classification of EHI into five classes using equal class interval approach.

RESULTS AND DISCUSSION

Slope Map

The land slope of the study area varied from 0 to >100 per cent. Slope map was reclassified into six major classes as follows: 0–3 per cent, 3–8 per cent, 8–15 per cent, 15–25 per cent, 25–45 per cent and >45 per cent based on

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Indonesian standard (RKLT, 1998). The percentage areas covered by each category were as follows: 23·98, 12·58, 10·71, 9·13, 14·18 and 29·11 per cent, which can be translated to 1697, 891, 758, 637, 1003 and 2061 ha, respectively. From this classification, it was found that more than 50 per cent of the study area is inside steep slope (i.e. more than 15 per cent slope steepness).

Land Use Map

The land use map 2002 produced consisted nine categories of land use in the study area, i.e. industrial area (0·67 per cent), tea (1·42 per cent), nutmeg (1·80 per cent), coffee (6·59 per cent), annual crops (7·43 per cent), residential area (8·26 per cent), forest (18·03 per cent), paddy field (21·66 per cent) and mixed vegetation (34·14 per cent). Paddy field, residential and industrial area are mostly located at the lowland area with the slope degree less than 15 per cent, while forest, estate crops, and mixed vegetation occupy the upland area (Figure 2).

The average canopy for every type land use are 80, 70, 70, 80, 50, 70, 95, 95 and 75 per cent, respectively and the C-factor values range from 0·001 for forest area and 0·588 for annual crops.

Soil Map and Soil Characteristics

Soil Map: It was generated from Soil Map of **Kabupaten** Semarang acquired in 1995 (**Puslittanak**, 1995). The soil types (Groups) were found on the study area include: Dystropeptst (Dt), Dystopepts and Eutropepts Association (DtEt), Dystropepts, Hapludalfs and Eutropepts Association (DtHuEt), Hapludands (Han), Haludalfs and Dystopepts Association (HuDt), Dystopepts, Paleudults and Kanhapludalfs complex (DtPuKu), Miscellaneous (MCL), and Tropaquepts (Ta) with area 3·06, 30·85, 6·35, 22·18, 2·53, 8·56, 14·17 and 12·29 per cent, respectively

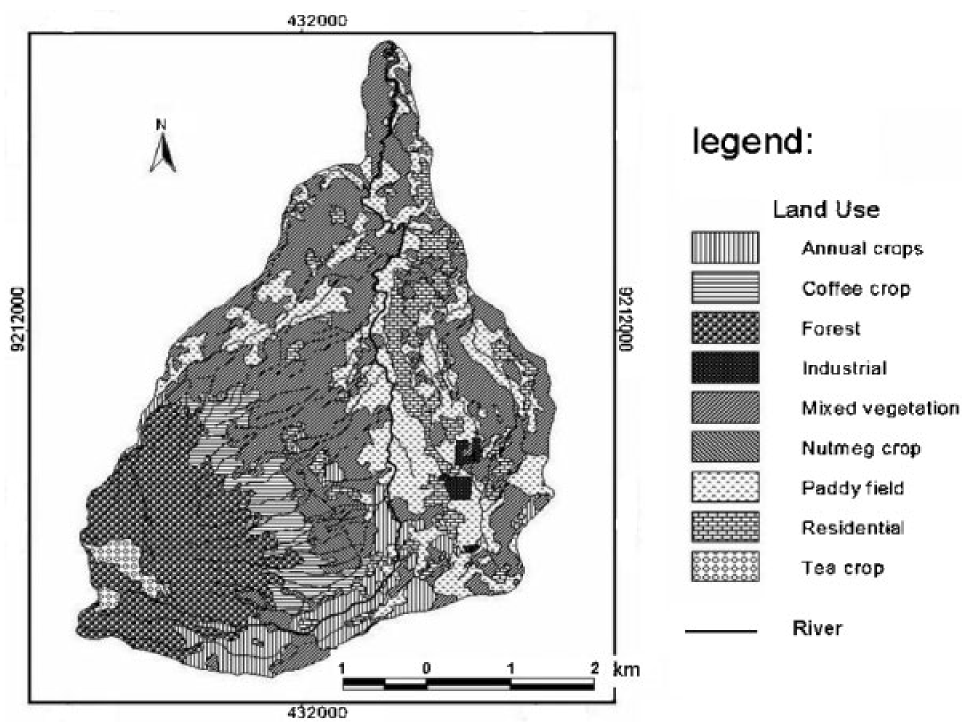

Figure 2. Land use map of Upper Kaligarang Watershed.

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Land Unit Map (Overlapping of Land Use Map, Soil Map and Slope Map)

There are 98 land units found in the study area. These land units were used as a basis for unit observation of biophysical characteristic of the study area considering that every land unit has a unique characteristics which is the combination of land uses (nine land use types), soil type (eight classes) and slope degree (six classes) as shown in Figure 3.

Based on soil analysis, six soil texture classes were obtained, namely: clay (25·98 per cent), silty clay (9·33 per cent), silt (7·58 per cent), loam (13·71 per cent), clay loam (12·79 per cent), silty clay loam (13·71 per cent). Clay texture class was dominant at lowland and flat area, while loamy and silty texture class was found at high land. Texture class has good agreement with soil type where on the highland, inceptisols and andisols types of soils were observed. Soil organic matter content varied from low to very high. The highest organic matter content is in the forest area, and as expected, this area also exhibited lowest bulk density (0·79 g cc^{-1}) and rapid permeability. The highest bulk density (1·24 g cc^{-1}) is in the lowland area with highest clay content and low permeability. Aggregate stability is lower on the forest area, even though with higher organic matter content, but low in clay content.

Rainfall Erosivity and Runoff

Data calculation and interpolation were conducted in order to get annual rainfall (mm), I_{30} (maximum rainfall intensity in mm h^{-1}), EI_{30} (Kinetic energy in J mm m^{-2} h^{-1}), and runoff (cm h^{-1}). These data were used as erosivity factor index to evaluate their effects on erosion hazard and have been displayed on Isohyetal Map of annual rainfall, I_{30} and EI_{30}. This area has high rainfall with average between 2400 and 3500 mm y^{-1}. The highest is found in Nyatnyono, and the lowest is

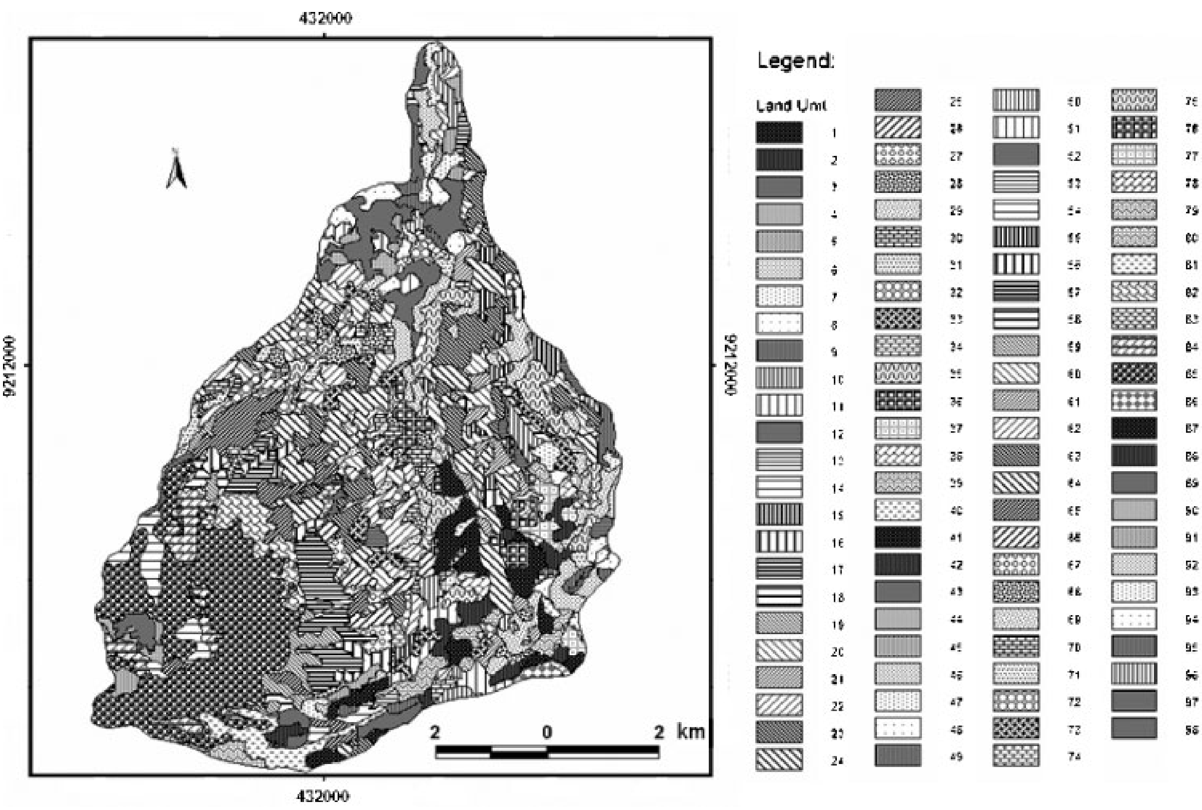

Figure 3. Land unit map of Upper Kaligarang Watershed.

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Table I. Rainfall data for 2002 of Upper Kaligarang Watershed

No.	Weather station	Annual rainfall (mm)*	I_{30} (mm h^{-1})	Daily rainfall (mm)	5 days antecedent rainfall (mm)
1	Banyumanik	2950	95·2	58·2	79·6
2	Ungaran	2863	99·2	66·6	80·2
3	Keji	3174	83·2	56·0	53·4
4	Nyatnyono	3547	92·0	53·0	54·6
5	Pagersari	2445	88·0	70·6	47·4
6	Sidorejo	2836	71·6	76·0	91·8

Note:
*Average 1993 to 2002.

in Pagersari (Table I). The monthly distribution of rainfall on the study area for every station illustrated in Figure 4. In 2002, the highest monthly rainfall is in February while the lowest was in August.

Socio Economic Condition of the Study Area

Data analysis was conducted in order to get descriptive information of the socio-economic condition of the study area. These data were integrated with biophysical data for principal component analysis.

Population density of the study area varied from 723 to 1496 people km^{-2}. The highest was in Candirejo (lowland area) and the lowest was in Gogik (upland area). On the other hand, Gogik had the highest population growth, i.e. 1·59, while the lowest was in Keji, 0·83 per cent y^{-1} (Table II).

The average farmer's education attainment at Munding Village was the lowest and the highest level was in Gogik. While the average age at Kalirejo was the highest and the lowest at Gogik. Kalirejo is at lowland area where mostly young people were work in government offices, factories, trading companies or went to the capital cities instead of working on farm, while in upland area most of family members were involved in farming activities.

The highest average income was found in Munding with main source coming from vegetables cultivation. Growing these crops give higher benefit to farmers compared to growing rice or other annual crops. Land holding

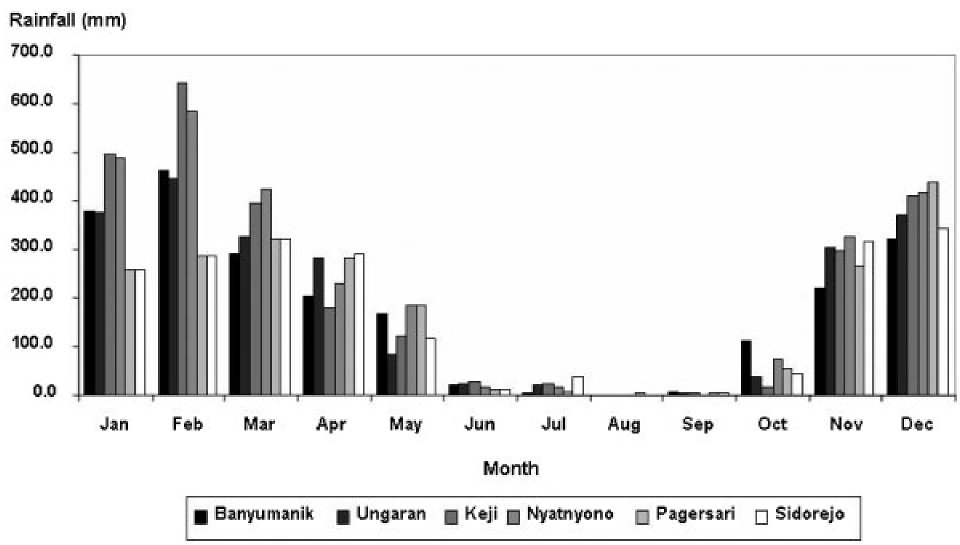

Figure 4. Monthly rainfall for 2002.

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Table II. Population density and growth rate, 2003

Population	Lowland			Upland							
	Candirejo	Kalirejo	Average	Keji	Kalisidi	Lerep	Gogik	Nyatnyono	Gebugan	Munding	Average
Total	2843	3075	2959	1989	5120	8324	3226	5461	4549	2746	4774
Density (people km^{-2})	1496	1367	1432	908	862	1071	442	645	757	723	773
Growth rate (% y^{-1})	1·00	1·26	1·13	0·83	0·85	0·89	1·59	0·93	0·83	0·85	0·97

Sources: District and village offices statistical data, 2003.

area at lowland area (mostly for paddy field) was smaller than at upland area with the smallest area was at Kalirejo Village, and the largest area was at Gogik with estate crops or mixed vegetation as the main crop. Slope steepness of farm land at Munding village is the highest because this village is in the mountain area with slope class moderate to very steep and the elevation more than 900 m above sea level. Even though, the people in this area used terracing techniques to reduce the slope steepness.

Based on interview with the farmers, accessibility to capital, agricultural inputs and farm information had similar pattern for each village, where the most accessible was at Keji followed by Lerep. In contrary, Kalisidi and Gebugan villages had lack of accessibility. Farmer's perception on erosion and conservation was very good at Gogik and Kalisidi and the least at Nyatnyono followed by Gebugan and Kalirejo. This condition has high correlation with education level of the respondents, in which about 50 per cent of respondent at Gogik finished their high school and college, while at Nyatnyono, more than 60 per cent of the respondent only experienced elementary education and at Gebugan, beside low level of education, they also lack accessibility to information.

Erosion Hazard Key Factors

PCA was used to group the 18 biophysical and 9 socio-economic variables into statistical factors based on their correlation structure. To select representative variables as erosion hazard key factors, we examined only PCs which have high factor loading with eigenvalue ≥ 1 (Hair *et al*., 1998; Kachigan, 1991; Ehrenberg, 1982). In this PCA, we retained only the variables of high weight from each principal component and the identified variables then defined as erosion hazard key factors.

PCA result indicates that there are seven principal components with significant loading (eigenvalue ≥ 1) with an overall cumulative variance of about 76·46 per cent. The order of significance of these variables was determined by the magnitude of their eigenvalues (Table III). The PCA identified seven factors (five biophysical and two socio-economic variables) contained in seven PCs that have high factor loading (eigenvectors). These seven key factors constitute the erosion hazard key factors for the PCs, which can be used to construct EHI for the different land units.

The higher weighted variables in the PCs relate to the biophysical characteristics of the area, i.e. silt content (representing texture), LS-factor, C-factor, I_{30}, P-factor and socio-economic variables that have higher weighted factors are farmer's perception on erosion (representing farmer knowledge and awareness to soil erosion and conservation), and farmer's income. The different variables considered in the analysis and their factor loadings within their respective PCs are shown Table IV. It can be seen that some factors within a PC have almost similar values of eigenvectors (e.g. 0·94 and 0·95 in PC4 for slope index and LS-factor etc.). However, since coefficient correlation between the highly weighted variables are significant, only the factor with the most highly correlative to the PCs is selected as representative of the group and this is consistent with Andrews *et al*. (2002) and Brejda *et al*. (2000) which also used PCA for soil quality assessment.

Based on the PCA results, the erosion hazard key factors for the study area can be identified as follows:

a. Biophysical key factors: soil texture, rainfall intensity, LS-factor, C-factor and P-factor. These factors have about 65 per cent contribution to erosion hazard.
b. Socio-economic key factors: income and farmer's knowledge on soil erosion and conservation with about 35 per cent contribution to erosion.

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Table III. Principal components (PCs) for biophysical and socio-economic variables

PCs	Eigenvalue	Variance (%)	Cumulative variance (%)	PCs-indicators
1	3·355	14·59	14·59	Farmer's knowledge
2	3·225	14·02	28·61	Farmer's income
3	3·202	13·92	42·53	Soil texture
4	2·403	10·45	52·98	Slope steepness
5	1·908	8·30	61·28	Land/crop cover
6	1·868	8·12	69·40	Rainfall
7	1·623	7·06	76·46	Soil conservation practices

Erosion Hazard Indices

In conjunction with the PCA, an EHI equation was developed using all indicators that are retained within all components with eigenvalue ≥ 1, based on Equation (2). The result of factor analysis indicates that there are seven key factors identified as principal components with high eigenvalue ≥ 1. Weighting value for every component was calculated to construct the equation for EHI with factor weighting values were 0·19 for PC1, 0·18 for PC2, 0·18 for PC3, 0·14 for PC4, 0·11 for PC5, 0·11 for PC6, and 0·09 for PC7. The EHI formula for each land unit is expressed as

Table IV. Results of principal components analysis (rotated component matrix)

Variables	Eigenvectors							Commonalities
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	
Sand (%)	−0·08	−0·02	0·34	0·30	0·18	−0·62	0·08	0·63
Silt (%)	−0·08	−0·10	**0·86**	0·15	0·08	−0·13	−0·01	0·79
Clay (%)	0·09	0·08	**−0·79**	−0·27	−0·15	0·42	−0·04	0·91
SOC (%)	−0·05	0·04	0·34	−0·04	0·11	−0·23	0·53	0·46
WAS (%)	−0·03	−0·07	−0·64	0·09	0·04	−0·11	−0·43	0·62
WHC (%)	−0·04	0·07	−0·22	0·16	0·20	−0·44	0·46	0·52
Permeability (cm h^{-1})	−0·11	0·17	0·71	0·13	−0·11	0·15	−0·02	0·60
LS-factor	−0·14	−0·02	0·13	**0·95**	0·03	−0·06	0·06	0·82
Slope Index	−0·14	−0·05	0·17	**0·94**	0·09	−0·07	0·07	0·86
Canopy (%)	−0·01	0·02	0·12	−0·03	**−0·84**	0·03	−0·32	0·77
C-factor	−0·04	0·04	0·11	0·08	**0·91**	−0·04	−0·12	0·95
P-factor	−0·03	−0·04	0·06	0·09	−0·01	0·03	**0·87**	0·94
I_{30} (mm/hour)	0·44	0·27	−0·13	−0·03	−0·03	**0·69**	0·13	0·77
Kinetic Energy (J mm m^{-2} h^{-1})	0·49	0·32	−0·17	−0·15	0·07	**0·63**	0·05	0·79
Runoff (mm)	0·06	−0·03	0·12	0·20	0·33	0·54	−0·12	0·47
Population density (pop km^{-2})	0·17	0·33	−0·24	−0·36	−0·29	0·49	0·15	0·67
Population growth (% y^{-1})	−0·11	0·77	0·02	0·04	−0·09	−0·14	−0·02	0·64
Income (Rp. $capita^{-1}$ y^{-1})	−0·14	**−0·91**	−0·13	−0·01	−0·06	0·07	0·03	0·88
Farmer perception on erosion	**−0·92**	−0·07	0·03	0·06	0·13	−0·16	−0·07	0·90
Farmer perception on conservation	**−0·91**	0·23	−0·08	−0·17	−0·10	0·14	−0·01	0·94
Conservation techniques adopted	−0·89	−0·12	0·15	0·16	0·05	−0·12	0·03	0·87
Problem on soil conservation application	0·76	0·52	−0·05	−0·20	−0·07	0·13	−0·01	0·91
Fuelwood gathering (m^3)	0·17	**0·89**	0·07	−0·09	0·06	0·07	−0·00	0·85

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
SOC, soil organic carbon; WAS, water aggregate stability; WHC, water holding capacity.
Bold factor loadings correspond to highly correlated factors included in the PCs.
Factor loadings in underlined are considered highly weighted (key factor).

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follows:

$$EHI = 0{\cdot}18\ S_{(y)} + 0{\cdot}14\ LS_{(y)} + 0{\cdot}11\ C_{(y)} + 0{\cdot}11\ I_{30(y)} + 0{\cdot}09\ P_{(y)} + 0{\cdot}19\ FPE_{(1-y)} + 0{\cdot}18\ In_{(1-y)} \quad (5)$$

where: EHI = EHI; S = Silt (per cent); LS = LS-factor; C = C-Factor; P = P-factor; I_{30} = Maximum 30-min rainfall intensity; FPE = Farmer's perception on erosion; In = Income; $y = (x-s)/(1{\cdot}1t-s)$, a 0 to 1 score of key factor with the more value means higher contribution to erosion hazard, and $(1-y) = 1-\{(x-s)/1{\cdot}1t-s)\}$, a 0 to 1 score of key factor with the less value means the higher contribution to erosion hazard (Equation 3 and 4).

The most important biophysical factor that influences erosion hazard in the study area is soil texture. Results indicate that the higher silt content the higher erosion hazard. This is consistent with the properties of soil; when silt particle (eroded particle) is high, clay content is low. It means that if the soil has low cementing agent resulting in low aggregate stability, then it will be more erodible. In this study area, clay content has high correlation with water aggregate stability. Therefore, the area that has high silt content (low clay content) has higher hazard than the area with high clay. According to Schwab *et al*. (1993), the groups or category of the factors that influence the rate of soil erosion are resistance, energy and protection measures. Fundamental to the resistance group is the erodibility of the soil that depends upon soil texture, aggregate stability, shear strength, infiltration capacity and organic content and chemical properties of the soil. Yu *et al*. (2003), on the other hand, found that soil texture has large particles that are resistant to transport because of the greater force required to entrain them and that fine particles are resistant to detachment because of their cohesiveness. The least resistant particles are silts and fine sands. Furthermore, study of Wakindiki and Ben-Hur (2002) indicated that the high aggregate stability and low dispersivity of clayey kaolinitic soils can minimize soil detachment, and due to its low runoff, its transport capacity is also minimized, thus reducing soil loss. On the other hand, sandy loam montmorillonitic soils have low aggregate stability and high runoff potential, which can contribute to high soil loss.

In this study, soil organic content has negative correlation with water aggregate stability. It means that aggregate stability depends on the amount and type of cementing agent factors such as clay content, calcium, organic matter and other cementing agents. This study also revealed that the aggregate stability was mostly influenced by clay content due to the differences in soil types.

The second biophysical key factor that influences EHI is rainfall erosivity factor, which consists of kinetic energy and maximum rainfall intensity. These two factors have high correlation with erosion, that is the higher the I_{30} the higher kinetic energy, and so with the erosion hazard. This result can be explained by the relationship that increase kinetic energy of raindrops can also increase the detachment process which can enhance the fragmentation of soil aggregate to the small size and then becomes easier to transport. The energy group includes the potential ability of rainfall, run off and wind (erosivity) to cause erosion. Hudson (1981) stated that precipitation is the most important climatic factor affecting erosion with intensity of rainfall as the basic driving force.

A slope factor is the third biophysical factor that influence erosion hazard in this study area. The result indicates that the higher slope steepness, the higher the erosion hazard. Morgan (1995) stated that the rate at which water erodes soil is related to both the land's length and its steepness. Erosion increases with the increasing of degree and length of slope. Moreover, the effect of slope is stronger at tropical conditions where the rainfall is more intense.

Land cover (C-factor) was also found to be a key factor that affect erosion hazard in the study area. The result shows that the higher C factors the higher erosion hazard. C factor values depend on the type of land/crop cover. Land without cover has the highest value (equal to 1). In this study, land/crop cover has negative correlation with the percentage of canopy. It indicates that high C factor value (low covered land) reflects low protection of aggregates resulting in destruction by raindrops on the surface soil. Morgan (1995) and Schwab *et al*. (1993) said that vegetation provide protective cover on the land and prevent soil erosion for the following reasons: slow down water as it flows over the land (runoff); plant roots contribute to mechanical strength of the soil by holding the soil in position and preventing it from being washed away; break the impact of a raindrop before it hits the soil, thus reducing its erosivity. Jansson (1982) noted that any man-induced change in vegetation cover has effects on the erosion process. According to Elwell and Stocking (1976), for adequate protection, at least 70 per cent of the ground surface must be covered, but reasonable protection can be achieved with 40 per cent cover. Meanwhile,

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Wu and Tiessen (2002) found out that land use (grassland) degradation and cultivation cause a severe soil erosion and fertility decline.

The fifth biophysical key factor of soil erosion hazard is soil conservation practices factor (P-factor). The highest P-factor value is 1 when the land has no soil conservation practices. The results indicate that the higher the P-factor, the higher contribution on index value, and the higher erosion hazard on the area. Soil conservation practices will reduce the amount and rate of water runoff and thus reduce the amount of erosion. The most commonly used supporting cropland practices are cross slope cultivation, contour farming and strip cropping (Morgan, 1995). The importance of organic manures and mulching as means increasing the moisture retention capacity of the soil and in improving its structure is well recognized. Crop rotation or multiple cropping is another important feature in soil conservation. These provide good ground cover, help maintain or even improve the organic status of the soil, thereby contributing to soil fertility and enable a more stable aggregate structure to develop the soil.

The other major factor considered in the analysis is the effect of socio economic factors on erosion. The factors that have high contribution on erosion hazard at study area include farmer perception on soil erosion and soil conservation and farmer's income as indicated at the first and the second PCs.

Farmer's perception on soil erosion has the highest eigenvector in PC 1. This factor was found as the first socio economic key factor of soil erosion hazard at the study area. Farmer's perception on soil erosion is in line with their perception on soil conservation, and has negative correlation with the adopted soil conservation techniques. The higher the farmer's perception on soil erosion, the better their understanding and adoption of soil conservation techniques. This result has a good agreement with the interview result with the farmers and the village leaders that most problems in implementation of soil conservation is lack of capital and human resource, followed by low farmer's knowledge and lack of accessibility to information. Daba (2003) has found out that perception about the danger of gully erosion is significantly correlated to severity of water scarcity, location of farm within the landscape, and literacy of farmers.

In PC 2, that is income factor, there are three socio economic factors that are dominant which influence erosion hazard, i.e. income, fuelwood gathering and population growth. Correlation analysis indicates that farmer's income has significant negative correlation with volume of fuelwood gathering by the farmers and population growth. Referring to key factor definition above, if retained variable in every component has a value more than 1 and has significant negative correlation among them, the factor with highest eigenvector is defined as key factor.

This result shows that the use of fuelwood increases when farmer's income is low. According to Adhikary (1988), fuelwood is used as the major source of energy in developing countries due to problems of lack of money and unavailability of non-farm employment opportunities, and increasing demand for energy where rural people are forced to cut trees to fulfill their needs. The other reason of large-scale consumption of fuelwood is related to poverty.

High population growth especially in developing countries has resulted in increasing pressure on land mainly for settlement and agricultural production. Process of expansion of settlement and agricultural lands by destruction of natural vegetation led to the disappearance of considerable expanses of forests that may increase the chances of rapid mass movements of soil and ultimately increasing the volume and rate of soil erosion (Cook, 1988; Ovuka, 2000). This increase is attributed to the accelerated growth rate of population and concurrent deteriorating economic conditions.

Erosion Hazard Map

Using the EHI equation derived from this study, EHI for all land units was calculated. After weighting, the attributes of each principal component were scored using Equations (3) and (4). Equation (3) was used for the 'more is higher contribution to erosion hazard' scoring function, for total Silt, LS-factor, C-factor, P-factor and I_{30} because of their positive effect on erosion hazard. Equation (4) was used for the 'less is higher contribution to erosion hazard' scoring function, for farmer's perception on erosion and farmer's income. The results indicate that the lowest EHI at study area is 0·33 and the highest is 0·72, and it was classified into five classes using equal class interval as presented in Table V.

The result indicates that more than 60 per cent of the area has high erosion hazard (moderate to very severe), where most of areas with severe erosion hazard (class 4 and 5) were found at the mountain area. Furthermore, the

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Table V. Erosion hazard class of Upper Kaligarang Watershed

No.	Classification and Index Interval	Area	
		ha	%
1	Very low (<0·41)	1354·6	19·13
2	Low (0·41–0·48)	1333·8	18·84
3	Moderate (0·48–0·56)	962·7	13·60
4	Severe (0·56–0·63)	1663·0	23·49
5	Very severe (>0·63)	1766·7	24·95
	Total	7080·8	100·00

area with high index (severe and very severe erosion hazard) was caused by high weight of soil texture (expressed in term of silt content), followed by high rainfall intensity (I_{30}), steep slope, low crop cover without any soil management practices plus the socio-economic factors such as low income and low perception on soil erosion and conservation (Figure 5).

The extent of the level of erosion hazard has good agreement with potential erosion of the study area. The result of comparison between them using paired-samples t-test indicates that its correlation is highly significant (coefficient $= 0{\cdot}65$, t-test value $= 127{\cdot}93$ at $p < 0{\cdot}01$).

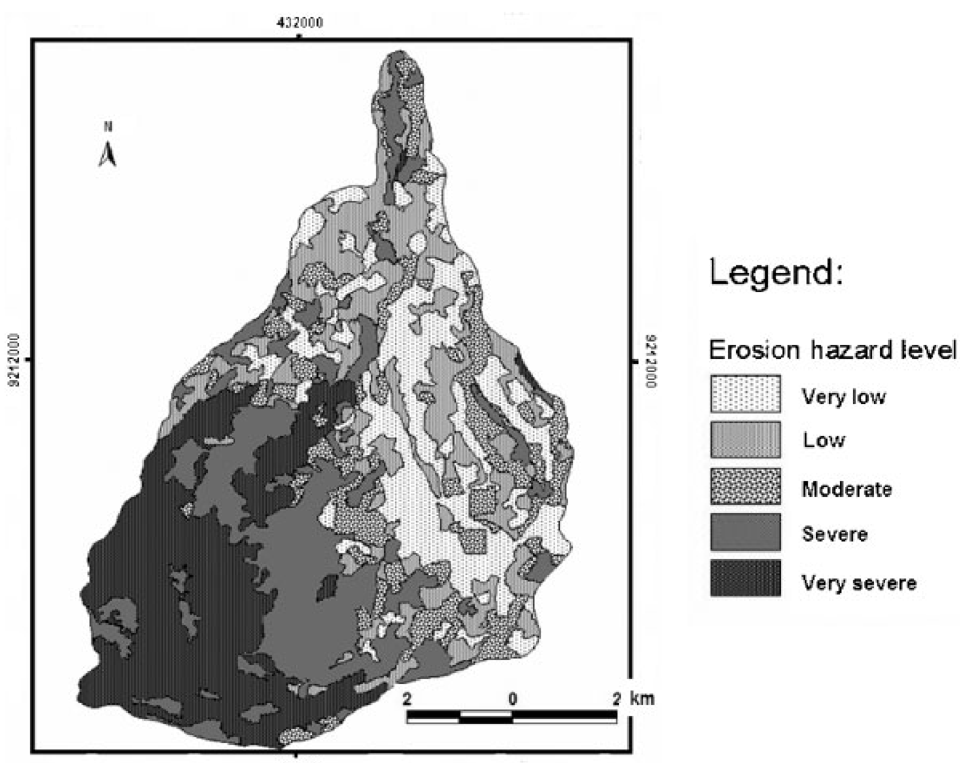

Figure 5. Erosion hazard map of Upper Kaligarang Watershed.

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CONCLUSION

By integrating biophysical and socio-economic factors in assessing erosion hazard, it was found that seven erosion hazard key factors in Upper Kaligarang Watershed, namely five biophysical factors, i.e. soil texture (silt content), maximum rainfall erosivity (I_{30}), slope (LS-factor), land cover (C-factor), soil conservation practices (P-factor) and two socio-economic factors (i.e. farmer's perception on erosion and income) affect erosion. Biophysical factors have about 65 per cent contribution to erosion hazard and socio-economic factors account for about 35 per cent. Contribution (weight) of each factor is 0·18, 0·14, 0·11, 0·11, 0·09, 0·19 and 0·18, which correspond to silt content, LS-factor, I_{30}, C-factor, P-factor, farmer's perception on soil erosion, and farmer's income, respectively.

More than 60 per cent of the area have high erosion hazard (moderate to very severe) with the highest hazards at the mountain area. This is consistent with general conception that high slope contribute to erosion hazard. The areas with high erosion hazard level (severe and very severe) were caused by high silt content followed by high rainfall, steep slope without any soil conservation practices, coupled with low perception on soil erosion and low income which were mostly found at the mountain area.

The key factors and level of erosion hazard found in the study area have identified critical or priority areas, which requires soil conservation measures. Because of high erosion hazard in mountain areas, it is strongly recommended to protect these areas from anthropogenic activities that contribute to land degradation.

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