Soil Erosion Risk Assessment Using GIS and Farmer's Perception: A Case Study in Dry Zone Area of Central Region of Myanmar

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Abstract

Soil erosion is the single most important environmental concern in the developing world. It has been become an ecological, social and economic problem. This study explored the influence of major socioeconomic factors on erosion processes and conservation measures in a Dry Zone farming context for producing Erosion Risk Map of the study area. In order to gain an over view on the erosion status of the study area and to identify potential areas where effective erosion protection measures might be useful, erosion risk assessment was carried out based on both farmers' perception and RS and GIS analysis. The multinomial logit model was chosen to study the identification of major socio-economic and physical factors influencing on soil erosion in the context of individually farmer's specific data on multiple choice. The farmers perceive soil erosion and land degradation mainly by yield variability, changing in soil color and appearance, occurrence of stony and pebbles followed by rill, sheet and gullies formation. And trend of changing number of tillage operation is increasing being top soil has been removed due to erosion. To estimate a spatially-explicit of soil erosion risk in the study area, Digital Elevation Model (DEM), digital geological map and Landsat TM image were used with the ICONA model. The final erosion risk map shows that 76.5 % of the area has low erosive status. These areas are including agricultural land and already eroded area in the past.21.8% of area has medium erosion risk and 1.7% of the area in high erosion risk status. The ICONA erosion risk model is useful for forming erosion risk assessment framework of large areas and farmers' perception may improve estimations and accuracy of the model in the study area.

Keywords: *Soil Erosion Risk; Farmers' Perception; GIS; ICONA; Myanmar*

Introduction

Land degradation is a serious problem in most of the upland agricultural areas of Southeast Asia including Myanmar. Soil erosion is the most widely recognized and most common form of land degradation and, therefore, a major cause of falling productivity (Stocking and Murnaghan, 2001). It is a natural process and generally aggravated by human intervention, and exceeds the rate of soil regeneration.

In Dry Zone Area of Central Region of Myanmar, soil erosion is high, particularly in the form of water erosion during the rainy season. Rills, gullies and rivers full of sediments show that a considerable amount of soil is carried away, mainly during the destructive intense storms which characterize Myanmar dry zone rainfall patterns. In the

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Myanmar Dry Zone, although annual rainfall ranges between 500 mm and 1000 mm, heavy individual storms and destructive showers occurring within a very short period causing flood and severe erosion. In addition, due to deforestation, soil degradation is now taking place particularly in the central dry zone of the country (NCEA, 1997).

Soil erosion is a physical process, but its underlying causes are firmly rooted in the socio-economic, political and cultural environment in which land users operate (Stocking and Murnaghan, 2001). Therefore, the degree of soil erosion in a particular climatic zone with particular soils, land-use and socioeconomic conditions, will always results from a combination of the above factors (De Graff, 1993).

Pallaris (2000) stated that despite the knowledge acquired and the many technological advances, the threat of degradation remains as pertinent as ever and one of the main reasons for this is that high risk areas are not being effectively and efficiently identified by the existing erosion risk models. Existing secondary data related to the environmental, socioeconomic and land use conditions of an area can be used reliably to identify relative soil-erosion risks of a particular area and their spatial distribution.

Objectives

1. To identify major socio-economic and physical drivers that influence on soil erosion risk from farmer's perception.
2. To estimate a spatially-explicit of soil erosion risk in the study area.
3. To compare the farmer's perception on soil erosion risk with the estimated soil erosion.

Research methods

Study site

Magway district in the Dry Zone Area of Central Myanmar was chosen as study site. In this district, biophysical and socio-economic characteristics are typical and representative for the whole area of Dry Zone.

It has an area of 9,592 sq km and is situated between north latitude 19° 36' and 20° 55'and between east longitude 94° 42' and 95° 50' with 402 m average altitude. It includes six townships (sub-districts) namely; Magway, Yenanchaung, Chauk, Natmauk, Myothit and Taungdwingyi. About only 5% of total area is covered by natural forest in 2007. Topography is generally undulating and slope is ranging 5-30%. The Dry Zone townships are characterized by clay, sandy loam and sandy soils (including gravel). Although annual rainfall ranges between 500 mm and 1000 mm, heavy individual storms and destructive showers occurring within a very short period causing flood and severe erosion.

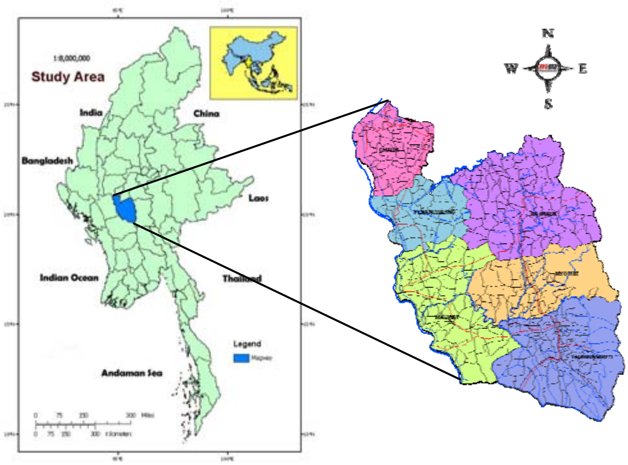

Figure 1: Location of the study area.

Data analysis

To achieve the objectives of the study, Multinomial Logit Model and ICONA erosion model with GIS technique were used. The study is carried out according to the following conceptual framework (Figure 2).

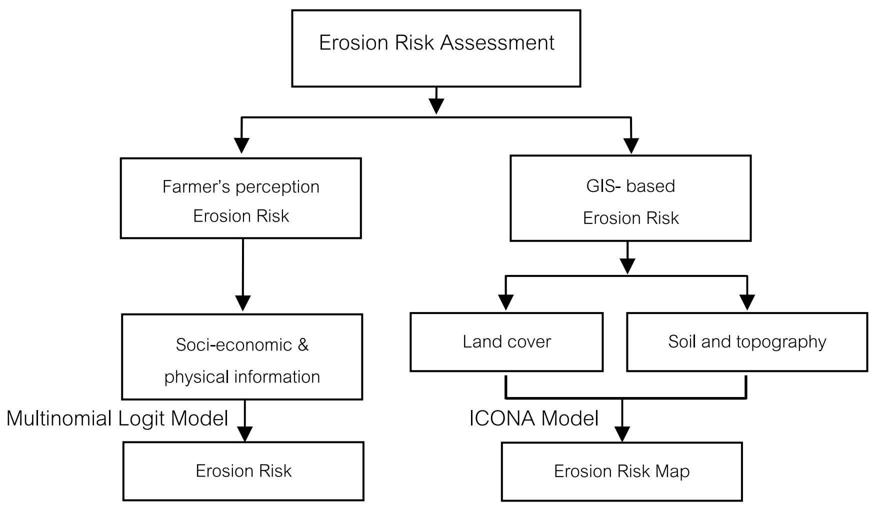

Figure 2: Conceptual framework of erosion risk study.

Farmers' Perception Erosion Risk

The methodological approach chosen for the empirical analysis of socio-economic and physical factors that influence on soil erosion is an explorative, econometric one, based on time series data. The multinomial logit model has chosen for this study. This model makes it possible to study the identification of major socio-economic and physical factors influencing on soil erosion in the context of individually farmer's specific data on multiple choice.

In this study, the dependent variables are assumed to be ranged from low occurrence (1) to high (3) reflecting increasing levels of erosion risk occurrence *(J)* (low= 1, medium= 2 and high= 3). Selected representative independents variables were included: farm household characteristics, land use management characteristics and soil conservation management characteristics. The following model was applied to compute the probability of occurrence of soil erosion *(J)* from selected socio-economic and physical driver variables.

$$P(Y = J) = \frac{\exp(\beta_J X_i)}{1 + \sum_{k=1}^{J} \exp(\beta_k X_i)} \qquad (1)$$

Where:

Y is the observed outcome of erosion occurrence J

X_i are the independent variables and

β_j are the estimated coefficients of unknown parameters

The relationship between the dependent variable and independent variables follows a logistic curve. The logistic transformation of Eq. (1) linearizes the model, so that the dependent variable of the regression is continuous in the range of 1–3, as indicated by Eq. (2):

$$ln\,(P/\,1+P) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_k X_i + \epsilon \qquad (2)$$

The model assumes that the data are generated from a random sample. There is no restriction on the independent variables, except that they cannot be linearly related.

To compute the model, statistical package of the SPSS version 12.0 has used with a Maximum Likelihood Estimation procedure to find the best fitting set of coefficients.

- The explanatory factors $x_1, x_2 \ldots x_i$ are assumed to be selected independent variables.
- ϵ is the error due to the postulated independent variables do not completely account for the variation in *P*.
- The parameter $\beta_0, \beta_1 \ldots \beta_k$ are the regression coefficients for the selected independent variables.

GIS Based Erosion Risk

Landsat TM images and GIS analysis techniques were used for land degradation and erosion mapping (Szabo *et al*., 1998). One of the most important factors to determine soil erodibility is the vegetation cover. As a general rule, the erosion risk decreases as plant intensity rises. Morgan *et al*. (1978), Berney *et al*. (1997) and Ahlcrona (1988) successfully applied RS data to determine vegetation cover and land use related to soil erosion.

To fulfill the second objective, Digital Elevation Model (DEM), digital geological map and Landsat TM image were used with the ICONA model. This method mainly consists of seven steps as shown in Figure 3.

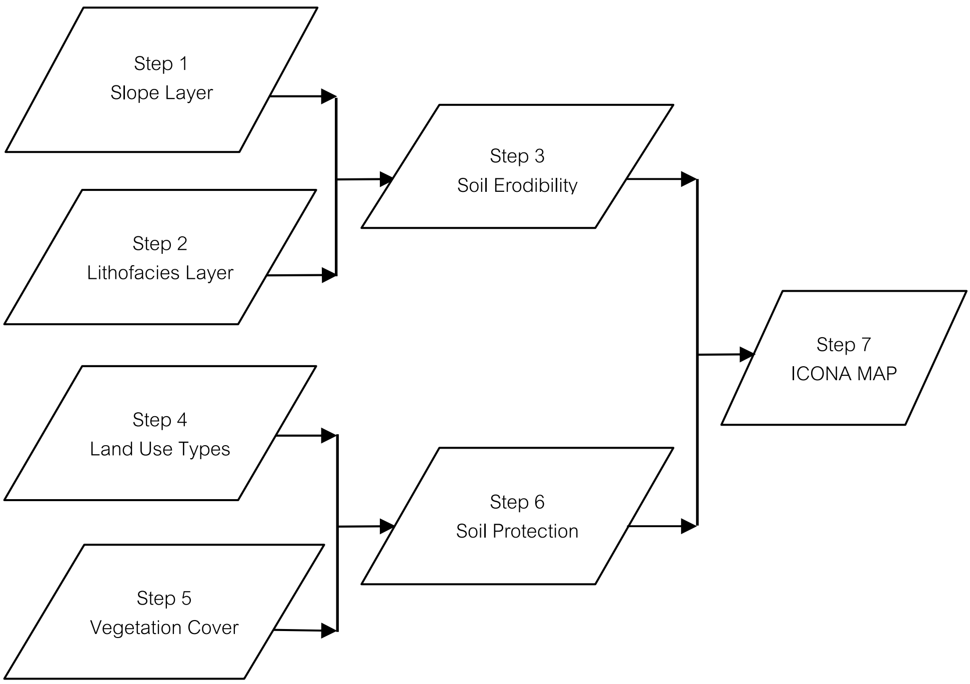

Figure 3: Steps of ICONA Model.
(Source: İlhami BAYRAMİN *et al*., 2003.)

Result and Discussion

Multinomial Logit Model for Erosion Risk

Data and information about farmers' perception on soil erosion risks were collected during household survey and field observation. The study was conducted with 100 farmers at different land use and slope levels. The most frequently mentioned soil erosion indicators were soil becoming coarse and stony, followed by rill formation, dissection of fields and gullies and topsoil removal.

Selected representative independents variables were included: farm household characteristics, land use management characteristics and soil conservation management characteristics.

- **Farm household characteristics** From the sampled farmers, 66% of farmers have primary education, 23% of those have secondary education, 8% have high school education and only 3% of those have university education. However, 80% of sampled farmers have no access to agricultural training and extension services.

- **Land use management characteristics** In Myanmar, the land is solely own by the State and farmers have only right to cultivate on it. Therefore, farmers are not willing to invest in erosion control measures other than doing small farmers' diverse ditches.

However, the trend in land use has been an expansion of agricultural land and a reduction in forest area in the study site. Currently, 76% of sampled farmers are doing in agricultural land, 23% in forest land and 1 % in grazing and barren land. The consequence of these trends is thought to be an increase in the likelihood of severe soil erosion in the past. According to the farmers' response, trend of changing number of tillage operation is increasing being top soil depth is getting shallow due to erosion.

- **Soil conservation management characteristics** From the sampled farmers, 86% of their soils are sandy loam and sandy soils, 10% of those are clay and only 3% is silt soil. Therefore, most are sandy and sandy loam soils and very sensitive to wind as well as water erosion during dry season. And trend of using fertilizer amount is increasing year by year probably causes of nutrient depletion by erosion and practicing mono-cropping. According to type of crop management, 72% of farmers are practicing weeding and crop rotation together, 13% are practicing weeding only. Application of farm yard manure (FYM) and compost is only 1% respectively.

Based on the erosion occurrence, major socio-economic and physical drivers that influence on soil erosion risk from farmers' perceptions and estimated regression equation are as follows;

$$ln\,(P/\,1+P) = 52.826 + 85.245EDU + 70.392TOL + \ldots + 64.898OSP + \epsilon \qquad (3)$$

Significant value of Household Head Education (EDU) is 0.000 and <0.05, it means that Education Level of household head is significantly influence on Erosion Risk Occurrence in his field. Significant value of Type of Land (TOL) is 0.001 and <0.05, it means that Type of Land such as forest land, barren land and agricultural land are significantly influence on Erosion Risk. Significant value of Cropping Systems (CS) is 0.013 and <0.05, it means that Cropping Systems such as mono-cropping and multiple-cropping are significantly influence on Erosion Risk Occurrence. Significant value of Type of Erosion (TOE) is 0.038 and <0.05, it means that Type of Erosion is significantly influence on Erosion Risk Occurrence. Significant value of General Topography of Land (GTL) is 0.000 and <0.05, it means that relationship between topography such as flat, rolling and hill and Erosion Risk Occurrence is statistically significant in the study area. Significant value of Occurrence of Soil Color Changes (OSC) is 0.000 and <0.05, it means that farmers perceive soil erosion by changing in soil colour and appearance. Significant value of Occurrence of Stone and Pebbles (OSP) is 0.002 and <0.05, it means that farmers perceive soil erosion mainly by occurrence of stony and pebbles followed by rill, sheet and gullies formation.

ICONA Model for Erosion Risk

To estimate a spatially-explicit of soil erosion risk in the study area, Digital Elevation Model (DEM), digital geological map and Landsat TM image were used with the ICONA model. First, the slope layer was generated from DEM data and classified into three groups, which are flat, medium and steep slope as shown in Figure 4.

By analyzing the digital geological map, geological formations were classified into three groups as non-weathered compact rock, medium weathered cohesive rocks and loose and non-cohesive sediments or soils according to their resistance to weathering in order to prepare the lithofacies layer (Figure 5).

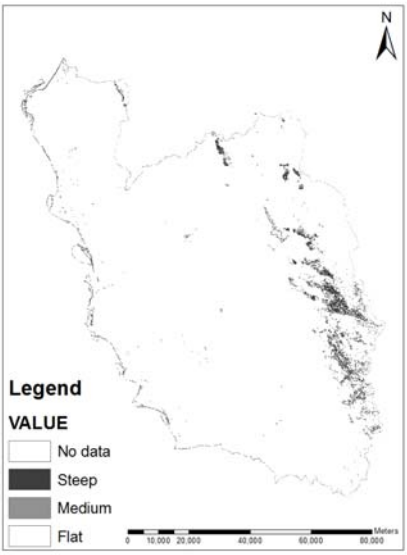

Figure 4 Slope Map of the study area.

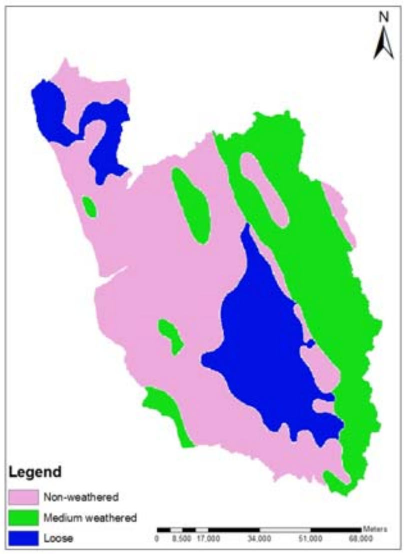

Figure 5 Lithofacies Map of the study area.

The slope layer and the lithofacies layer were then overlapped to produce a potential erosion risk (PER) map. The resulting soil erodibility map is presented in Figure 6. The map shows that 78.9% of total area has low erodibility, 21% has medium erodibility and only 0.1% has high erodibility.

Landsat TM imagery was classified using maximum likelihood algorithm to determine different land use categories within the study area. The resulting land use map is presented in Figure 7.

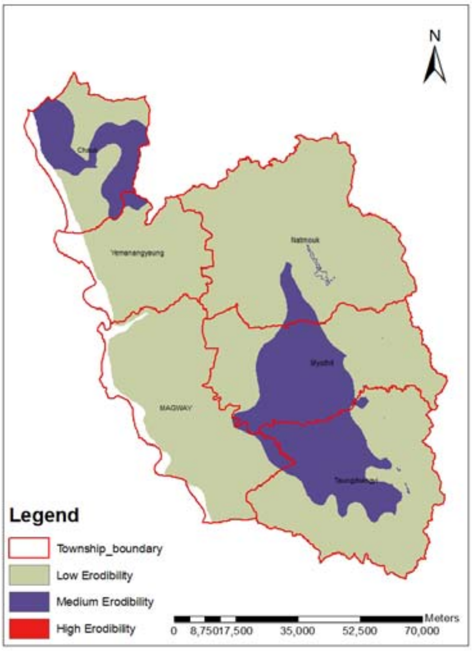

Figure 6 Soil Erodibility Map of the study area.

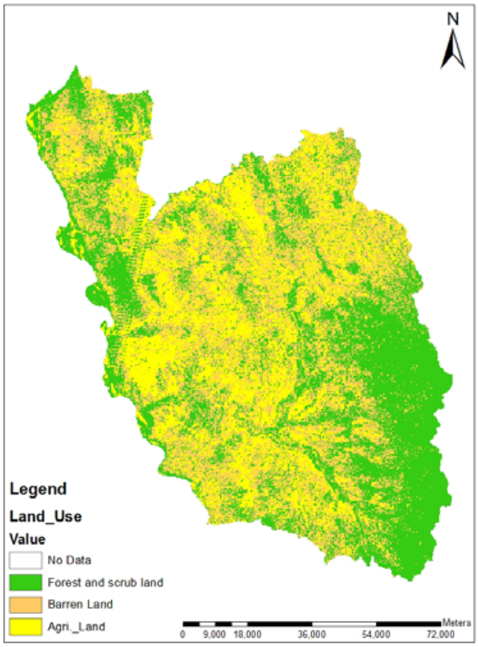

Figure 7 Land Use Map of the study area.

A Normalized Difference Vegetation Index (NDVI = NI band-R band / NI band + R band) defined by Tucker *et al*. (1985) was performed and applied to the Landsat TM image. The NDVI layer was classified into three groups and a vegetation cover layer was produced (Figure 8), which was then merged with land use for generating a soil protection layer.

In order to determine the soil protection layer map, vegetation cover index layer and the land use layer were overlapped. The resulting soil protection map is presented in Figure 9. The map shows that 37.7% of total area has low protection, 49.7% has medium protection and 12.6% has high protection.

During the final predictive phase, ICONA erosion risk map was generated by combining soil erodibility map (step-3) and soil protection map (step-6). The final erosion risk map shows that 76.5 % of the area has low erosive status. These areas are including agricultural land and already eroded area in the past.21.8% of area has medium erosion risk and 1.7% of the area is in high erosion risk status (Figure 10).

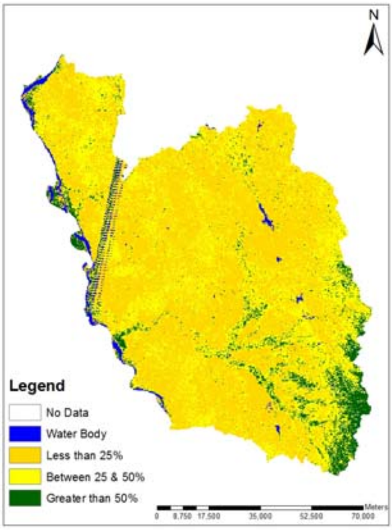

Figure 8 Vegetation Cover Map of the study area.

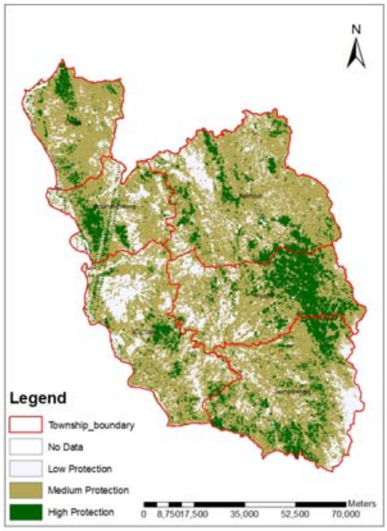

Figure 9 Soil Protection Map of the study area.

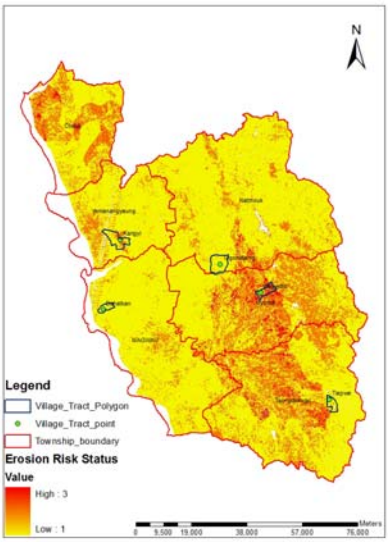

Figure 10 ICONA Erosion Risk Map of the study area.

Table 1 Erosion Risk Status of the study area

Erosion Risk	Area (ha)	Area (%)
Low Erosion Risk	77824.08	76.5
Medium Erosion Risk	22183.47	21.8
High Erosion Risk	1786.95	1.7
Total	101794.50	

Finally, to compare and explain the goodness of farmer's perception (identified factors) on soil erosion risk with the estimated soil erosion (spatial data) for the sampled villages; the Root Mean Square Error (RMSE) was used as a comparison measure. This error would be quantified the relationship between observed and predicted values.

$$\mathrm{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(Pi - Oi)^2}{n}} \qquad (4)$$

Where:

RMSE - Root Mean Square Error

P_i - the estimated value at sample i

O_i - the observed value at sample i

n - Number of the observation

From the above table, the total value of Root Mean Square Error is 0.031 and it shows that using ICONA model together with farmers' perception erosion risk may improve the estimation and accuracy of the ICONA model.

Table 2 Comparing Farmers' Perception erosion risk and ICONA erosion risk

Villages	Comparing Two Models		
	Farmers' perception	ICONA	RMSE
Dahatkan	1.55	1.02	0.014
Kangyi	1.80	1.32	0.011
Tagonetaing	1.30	1.05	0.003
Magyicho	1.90	1.99	0.000
Tiepwe	1.30	1.10	0.002
Total Root Mean Square Error			**0.031**

Conclusion and Recommendation

From the farmers' perception, the multinomial logit model identified the socio-economic factors that influencing soil erosion. Low education levels of household head are related to high erosion risk in their fields. Land use type such as forest land, barren land and agricultural land, which are significantly varied in erosion risk. Depend on cropping systems such as mono-cropping and multiple-cropping; erosion risk occurrence is significantly varied in severity. General topography of land such as flat, rolling and hill and erosion risk occurrence is statistically significant in the study area. The result of the ICONA erosion risk model shows that especially range land, barren land and dry agricultural lands, generally found on steep slopes and hilly and mountainous areas have high erosion risks. The dry agricultural land needs good management practices, since they are mostly sandy and sandy loam soils and very sensitive to wind as well as water erosion. From the erosion risk map, it can be seen that approximately more than 75% of the area have a relatively low risk from erosion point of view. During the field studies, it was seen that some of the areas are found to be under high erosion risk have already been eroded in the past. Therefore, due to the lack of top soil even base rock is visible in these areas; significant amount of erosion is not expected.

The ICONA erosion risk model is useful for forming erosion risk assessment framework of large areas. Although the model does not consider climatic data, by integrating climatic data such as rainfall intensity and distribution parameters together with farmers' perception may improve estimations and accuracy of the model.

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