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# INVESTIGATING THE EFFECT OF CONSERVATION TECHNIQUES ON THE LAND DEGRADATION OF TROPICAL CATCHMENT PRONE TO LANDSLIDE

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**Info Artikel**

***Keywords:*** *Conservation Technique, land degradation, Modelliing, Tropical Catchment, Dieng*

**Abstract**

Land degradation in Serayu watershed is a major concern in central Java and in Indonesia. As part of a broader effort to develop a land degradation assessment tool in tropical area, this study implemented a process-based watershed hydrology to assess the effect of conservation technique upon land degradation by using PCRaster. STARWARS was used to assess the watershed hydrology in the area based on their land use/ land cover, soil, and slope profiles. The results from STARWARS were used as inputs for the PROBSTAB model to simulate the slope stability in the area. DEM scenario were used, they are with terraces and without terraces.

The models show that the landuse practice in the study area work like two edges of sword. The promoting of bench terrace can be reducing the risk of soil erosion but in the other hands it increases in the risk of landslide. From the slope-stability modeling, we can see that the terrace increases the pore-water pressure significantly which lead to the ideal conditions for the failures. The extremely high intensity rainfall, in the other hands, may build a sharp increase of pore-water pressure. The increasing probability of failure might cause the soil erosion even worse. Therefore, in order to make the terrace practice is effective to control the land degradation process; the terrace has to be well maintained.

**Kata kunci:** teknik konservasi lahan, degradasi lahan, pemodelan, DAS Tropis, Dieng

**Abstrak**

Degradasi lahan di DAS Serayu sangat penting untuk dikaji. Sebagai bagian dari upaya pemahaman proses degradasi lahan di wilayah tropis, studi ini bertujuan untuk mengetahui pengaruh teknik konservasi terhadap degradasi lahan dengan menggunakan software PCRaster. Model STARWARS digunakan untuk memodelkan kondisi hidrologi di wilayah penelitian. Hasil dari model ini akan digunakan untuk input model PROBSTAB yang akan memodelkan stabilitas lereng di wilayah penelitian. Skenario penggunaan DEM dalam model ini juga akan di gunakan, yakni DEM dengan pemanfaatan lahan teras dan tanpa teras.

Hasil pemodelan menunjukkan bahwa pengguaan lahan dengan teras seperti pedang bermata dua. Pemanfaatan teras dapat menurunkan risiko erosi, namun di sisi yang lain dapat meningkatkan risiko terjadinya tanah longsor. Dengan intensitas hujan yang sangat tinggi, risiko terjadinya longsor menjadi semakin tinggi. Apabila lereng mengalami longsor, maka erosi yang terjadi akan lebih parah daripada erosi pada lereng normal. Sehingga pengelolaan teras sangat penting dalam mengurangi tingkat degradasi lahan di wilayah Dieng.

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## 1. INTRODUCTION

Java, the fifth largest island in Indonesia experiences severe land degradation. Over 62% of the Indonesia population lives in this island (~ 900 people/km2). The history of land degradation in the island is closely linked to the rapid land use/land cover changes that the region experienced since 1700's when the colonizers began to exploit the rich timber wealth (Lavigne and Gunnell, 2006). A major land degradation process in the region is shallow landslides. Landslides in Indonesia are triggered by rainfall and consequent increase in pore-water pressure (Marfai et al., 2008) or earthquakes. According to the database of the International Landslide Centre, Indonesia is the second most landslide affected country in the world after China (ILC, 2006). Between 2000 and 2007, Java experienced 57 landslides causing 249 human fatalities (DGHM, 2007). The fatalities and damages due to landslides are only to increase given the current trend of migration to the uplands, consequent rapid land use/land cover changes and continuing deforestation (Hadmoko et al., 2009).

Java's one of the most landslide prone areas is the Dieng Mountains which is frequently reported in the press due to the almost annual occurrence of the monsoon related hazards. A recent example of the disastrous effect of landslides in the region is the 9 November 2010 landslide in Sitieng which caused human fatalities and damaged houses. Several researchers have attempted to assess the landslide susceptibility of the region (eg., (DGHM, 2007; Hadmoko and Lavigne, 2007; Marhaento, 2006) using statistical and heuristic methods, according to which the highest landslide susceptibility in the region is to areas with steep slopes (>25°) along the escarpments. However, susceptibility only implies the spatial probability of landslide occurrence (van Westen et al., 2005).

Recently, Hadmoko et al., (2009) illustrated a method to derive both spatial and temporal probabilities (rainfall thresholds) for Indonesia with detailed rainfall and corresponding landslide inventory data. Applicability of this method is limited in most landslide prone regions of the country owing to the lack of such historical data. Given these limitations of landslide hazard assessment using statistical and heuristic methods a pragmatic alternative for landslide hazard quantification (spatio-temporal probabilities) in the region is the application of physically-based shallow landslide initiation models. Initiation of shallow landslides like debris flows is a consequence of perched groundwater tables or successive wetting fronts. Thus a model that attempts to capture the process must seamlessly integrate the generation of perched groundwater tables as a result of rainfall and the consequent failure. Takara et al., (2008) conducted sediment-runoff modeling using a physically-based dynamic model in the region and illustrated the use of such models for the early warning of debris flows. However, their model does not explicitly include pore-water pressure fluxes (the main trigger of shallow landslides in the region) thereby limiting its applicability for both landslide hazard quantification and landslide early warning.

Thus there is an apparent lacuna of a model that can quantify the spatial and temporal probability of landslides in the region. Such a model necessarily has to function in situations lacking historical landslide and rainfall data and should be capable of simulating the main trigger, pore-water pressure fluxes, as a consequence of rainfall input. Studies elsewhere have shown that physically-based dynamic models that couple slope hydrology and slope stability are suitable to evaluate shallow landslide initiation conditions in regions lacking historical data (eg., (Simoni et al., 2008; van

Beek and van Asch, 2004)). A set of models that has been applied and proven to be useful in regions lacking historical data (Kuriakose et al., 2009b) are the STARWARS (Storage and Redistribution of Water on Agricultural and Revegetated Slopes) coupled with PROBSTAB (Probability of Stability) (van Beek, 2002). In this research these models were applied to Serayu sub-catchment in the Dieng Mountains and validated against an available landslide inventory.

In the other hands, Dieng is one of the most productive areas in Indonesia, in term of agriculture.In order to support the agricultural activity, terracing was promoted as the most common land management practice in this area. In the sense of farming, there are several advantages of this land management. By building terraces, the farmer will be able to grow crops in such a steep land, generate more lands and reduce the erosion.

Due to its rough terrain and high intensity of rainfall, constructing terrace in Dieng might lead to other land degradation problem. The probability of infiltration will be increased as the slope reduces locally by the bench terrace. The objective of this study is to model the effect of terraces on the land degradation processes and assess how effective is the terrace practice in the study area.

**1.1 Study Area**

The study area is the Kali Putih catchment of Sitieng Sub-District, Wonosobo, Indonesia covering an area of 1 km2 (Figure 1). The sub-catchment is located in the upper part of Serayu watershed. The highest and lowest points in the study area are 2375 and 1675 m a.m.s.l, respectively.

There is significant evidence from the region that shallow landslides initiate in the wet season immediately after the clearing of natural forests (Lavigne and Gunnell, 2006). The current climate change scenario for Java proposes an increased influence of El Nino effects. Though the total rainfall will reduce owing to increased periods of meteorological drought, the intensity of rainfall is expected to increase (Hulme and Sheard, 1999). This increase will invariably reflect in the number of landslides occurring in the region. Through this research we attempt to understand the effect of land management practice and its relation to the hydrological and mechanical response of slopes to the current rainfall pattern of the region.

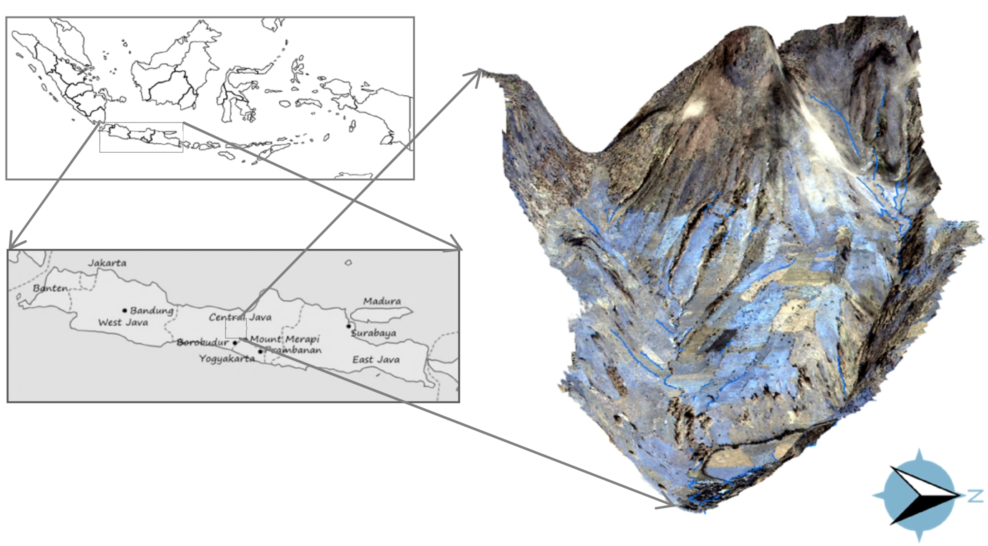



**Figure 1.** Study Area, Tieng, Wonosobo

## 2. METHODS

### 2.1 The Models

The models used for the study comprise a distributed dynamic hydrological model (STARWARS) that is coupled to a stability model (PROBSTAB); both were developed by van Beek (2002). The dynamic spatial outputs of the hydrological model are the inputs for the slope stability model. It will run on daily basis. An added advantage of the models is its open architecture allowing parameterizations appropriate for the study area. Both the models are embedded in PCRaster®, a GIS with an advanced Environmental Modelling Language (www.pcraster.nl). The model schema is illustrated in Figure 2.

**STARWARS**

STARWARS is an acronym for STorage And Redistribution of Water on Agricultural and Re-vegetated Slopes. The model simulates the spatial and temporal dynamics of moisture content and perched water levels in response to gross rainfall (P) and evapotranspiration.

**PROBSTAB**

PROBSTAB is an acronym for PROBability of STABility. The slope stability model is based on the infinite slope form of the Mohr-Coulomb failure law as expressed by the ratio of stabilizing forces (shear strength) to destabilizing forces (shear stress) on a failure plane parallel to the ground surface. The model is modified to account for root-induced cohesion and surcharge that were not originally considered by van Beek . The equation used is:

$$FS = \frac{(C_s + C_r) + \left[\{(\gamma_s.Z_s - \gamma_w.Z_w) + \gamma_s\}cos^2\beta\right].tan\emptyset}{[(\gamma_s.Z_s + \gamma_v)sin\beta].cos\beta}$$

where, Cs and Cr are the soil and root induced cohesion respectively (kPa), γs unit weight of soil, γw unit of weight of water, γv surcharge due to weight of vegetation (kPa), Zs soil thickness (m), Zw water height (m), β slope angle and ϕ angle of internal friction. The unit weight of soil is the sum of the unit weight of saturated soil and unsaturated soil respectively.

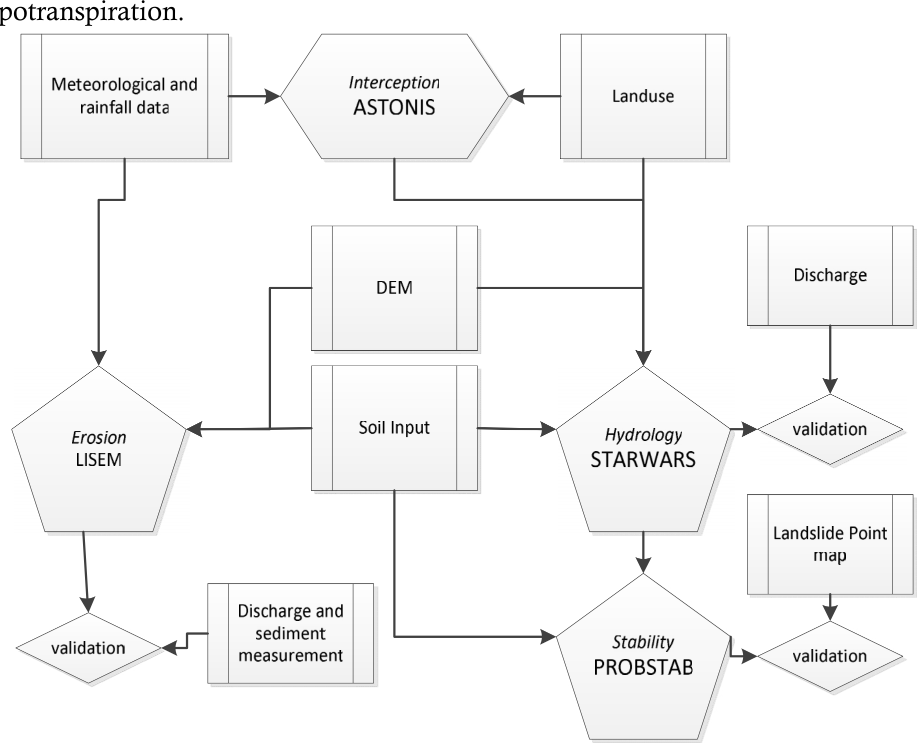



**Figure 2.** Methodology Flow-chart

**2.2 The parameters**

A detailed list of inputs necessary for the models is provided in van Beek (2002) and Kuriakose et al., (2009b). Individual parameters were prepared as detailed below.

***Climatic parameters***

Daily rainfall data was available for the area from 1989 to 2009 (daily basis) and 2010 (detailed data). From the analysis of the average monthly rainfall it is evident the dry season in the region starts in May and ends in September and the wet season starts in October and extends up to April. Potential evapotranspiration (RPET) was derived from Penman's equation (Penman, 1948) and interception and bulk throughfall ratio was computed from Quickbird image outside the model environment as suggested by Kuriakose et al., (2006; 2009b). All non-intercepted rainfall was assumed to be reaching the land surface while any canopy storage was made available for evapotranspiration. RPET was adjusted to crop-specific PET using crop factors of the respective land use types. All RPET exceeding the available canopy storage in a given day was assumed to be the fraction of PET that is to occur from the soil (FPET). Within STARWARS, evapotranspiration occurs at the actual rates (which is FPET adjusted to crop-specific FPET) when the soil is close to saturation; else FPET was scaled down linearly depending on the soil moisture content in a given time step.

***The DEM***

An available semidetail-dem was combined with Trimble DGPS and semi-automatic elevation measurements to generate a digital elevation model (DEM) with a terrace impresion (Figure 3). In order to update the DEM by inputting the terrace on the DEM (figure 4), digital terrain modeling was applied. One of the inputs is terrace map. The terrace map was derived from high-res satellite image of Quickbird recorded on 2009. Digital terrain modeling was produce using semi-automatic method using ILWIS 3.8. The result then was validated with several data: 1. Elevation point from DGPS, 2. Transect line from field work, including number of terraces on each transect and different height of the terraces.

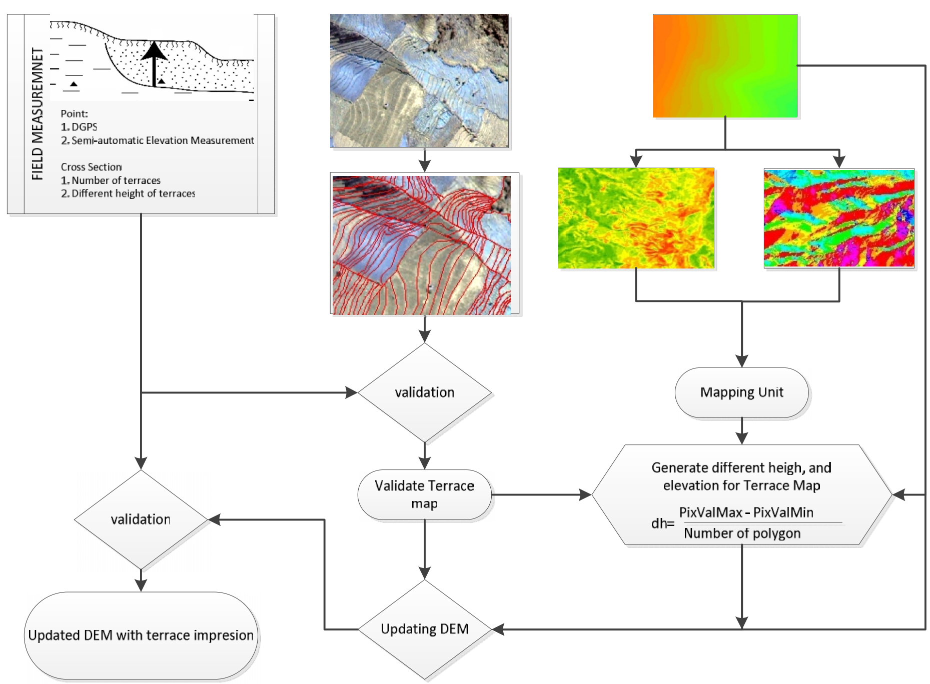



**Figure 3.** Dem generation

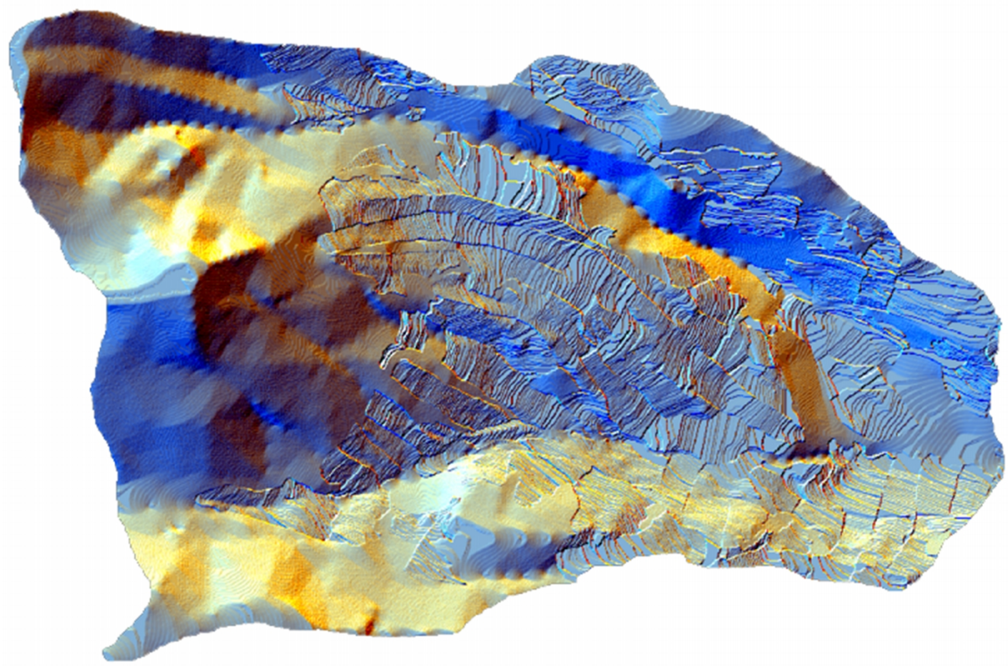
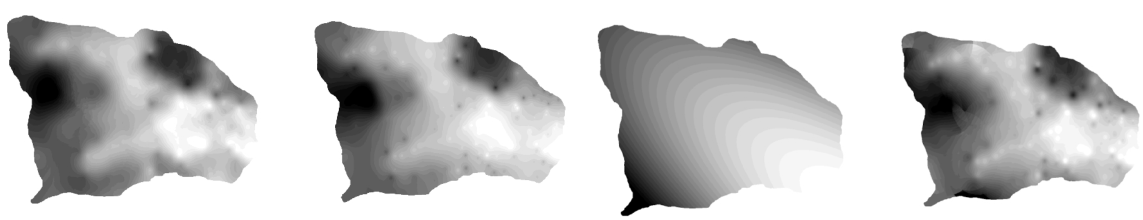


**Figure 4.** DEM with terrace impression

***Soil depth***

Soil depth was one of the important parameters to run the slope stability model. This information was obtained by field investigation as suggested by Kuriakose et al., (2009a). About 108 locations were measured. Soil depth was measured from top soil to the bedrock at the escarmnet, terrace cutting, river valley or using bor hole. These measurements were interpolated using ILWIS software to produce a spatially distributed soil depth map. Four methods were compared namely, Krigging ,Moving Average, Trend Surface, Moving Surface (figure 5). The accuracy of the results was tested based on the coefficient of determination ($R^2$) (Nash and Sutcliffe, 1970) between observed and predicted soil depths at a selected set of validation locations. 20% from the total sample were randomly selected for this validation processes. Total 22 points were selected. From the result, Figure 5, we understand that kriging result was significantly better than the moving average results and thus this map was used for the modeling.



a. b. c. d.

**Figure 5.** Soil depth modeling. a. Krigging b.Moving Average c. Trend Surface d. Moving Surface

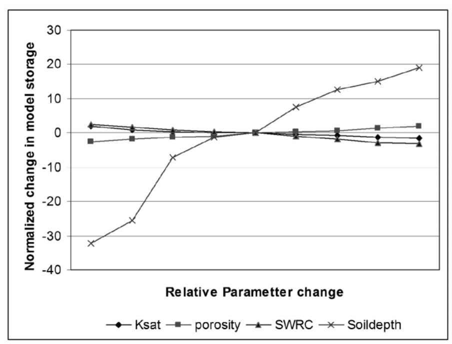
***Soil properties***

Several soil properties were necessary for running the model. Undisturbed and disturbed soil samples were collected from the field in order to derive the soil mechanical and hydrological properties. A stratified random sampling was conducted. Measured variables include saturated hydraulic conductivity, infiltration rate and bulk density. Cohesion and angle of internal friction were derived from undisturbed samples tested in the laboratory using triaxial (UU) tests.

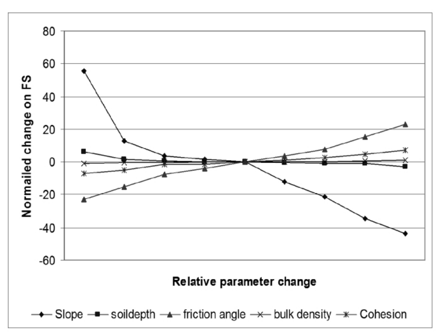
## 3. RESULTS AND DISCUSSION

The STARWARS was run on a daily basis from 1st January – 8th November 2010 to get the initial conditions for modeling the 9th November 2010 slope hydrology. The results of the 8th November 2010 was reported and used as the initial condition for the simulation of 9th November 2010. The slopes were most saturated on the 13.10 pm with the overall highest mean water level reported being 1.8 m. There was no data available for assessing whether this date was in reality the most saturated. However, from the average monthly rainfall it is known that December is the wettest month in the region and hence this model prediction is plausible. So also, it is known that it was on 13.00 pm that the Sitieng landslides occurred in the region and thus the assumption that landslides occur as a consequence of high pore water pressure seems valid.

A sensitivity analysis was performed to understand the contribution of individual parameters to the overall performance of the model. This in part compensates for the lack of appropriate calibration and validation of STARWARS. The sensitivity analysis was performed keeping the same initial conditions as that used for the actual simulation of November 2010 and the meteorological data of the month. Several simulations were carried out, each time varying only one of the parameters by a certain percentage. The model output based on which sensitivity was assessed was total soil water storage. The parameters towards which sensitivity was tested were ksat, n, α and soil depth. The parameter change that was imposed was 25%, 50% and 100% of the standard deviation to the mean parameter value and the corresponding results were also quantified in terms of normalized change in soil storage. Figure 6-a shows the sensitivity of STARWARS towards individual parameters. It is evident that soil water storage predictions by STARWARS are highly sensitive to soil depth followed by porosity. This clearly reflects reality and thus has a physical meaning; with increase in porosity and soil depth there is more pore space available for water to be stored.




(a)




(b)

**Figure 6.** Sensitivity of STARWARS model (a) and Sensitivity analysis of PROBSTAB model (b)

A sensitivity analysis was performed to assess the normalized change in overall factor of safety towards slope, angle of internal friction, bulk density and cohesion. Figure 6-b shows the result of this sensitivity analysis. It is evident that there is a linear relationship between slope angle and factor of safety. With decreasing slope angle the factor of safety increases rapidly and vice versa. In descending order, the other parameters to which factor of safety are sensitive is angle of internal friction, cohesion and soil depth. In contrast with slope angle, the slope stability increases as the friction angle increases. This was also the case with cohesion. The safety factor increases as cohesion increases implying that cohesive soils are less prone to slope stability problems.

### 3.1 Model validity

Figure 7 shows overall stability in the November 2010 overlaid by the landslide locations. The result shows that all the landslides occurred in unstable area. The probability of occurrence of landslides can be calculated using the prior probability concept (Equation 3) developed by Bonham-Carter et al., (1994).

$$P_p = \frac{N_{pix}(slide)}{N_{pix(total)}} \qquad \text{Equation 3}$$

where $P_p$ is the spatial probability of landslides, $N_{pix}$(slide) is the number of pixels occupied by landslides and $N_{pix}$(total) is the total number of pixels occupying the map.

Based on the area occupied by the actual landslides (pixels) of the November 2010 and the total number of pixels in the study area (pixels), the actual probability of landslides at that time was 0.09. The predicted overall probability of landslides in the area was 0.127 given 8851 pixels having FS<1. With reference to the location of landslides the model was >70% accurate, while in terms of the area predicted as failed the model was only 10% accurate.

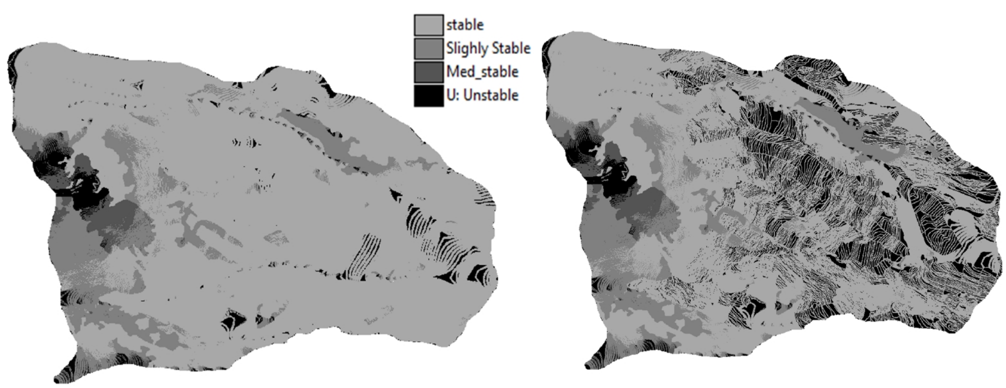



**Figure 7.** Overall factor of safety a). No terrace b).With terraces

## 4. CONCLUSIONS

The models shows that the landuse practice in the study area work like two edges of sword. We understand from several paper that promoting of bench terrace can be reducing the risk of soil erosion but in the other hands it increases the risk of landslide. From the slope-stability modeling, we can see that the terrace increase the pore-water pressure significantly which lead to the ideal conditions for the failures. The extremely high intensity rainfall, in the other hands, may build a sharp increase of pore-water pressure. The increasing probability of failure might cause the soil erosion even worse. Therefore, in order to make the terrace practice is effective to control the land degradation process; the terrace has to be well maintained. The farmers in the study area always maintain the terrace. They immediately re-construct the terrace after the landslide event take place. In this way, terrace practice will effectively control the land degradation processes.

Even when geomorphic processes are well understood, their descriptions must often be simplified in order to operate within landscape models. Model predictions are likely sensitive to both the processes included and how they are simplified (Lancaster and Grant, 1999). It will not be long since now that with such well-defined models, it will be possible to answer questions that might seem very simple such as "**Where** will the land degradation occur; **why** do they occur and **when** will they occur"?

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