GIS-BASED APPROACH FOR CHANGE AND PREDICTION OF SOIL EROSION

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ABSTRACT:

The paper has the goal to evaluate if the Universal Soil Loss Equation（USLE）applied using thematic paper maps and a DEM is sufficient to generate a model to map and predict the influences on the environment caused by soil erosion on Loess Plateau. Factors of USLE - R, K, S, L, P as well as C were adapted to the test area, the Nihe Gou catchment in Chunhua County in Shaanxi. Afterwards the parameters of the USLE were evaluated individually and merged in order to calculate the amount of soil loss. In order to derive all necessary factors, a TIN was generated out of a paper contour map. Furthermore, thematic paper maps and climate data completed the source of information for the implementation. The result of the study was a calculation of the amount of soil erosion over the corresponding years, the years 1977 and 2003. This result was visualized by thematic maps and the work flow was generalized and automatized by integrating it into a toolbox that can be applied on further areas of the Chinese Loess Plateau. Finally, the verification of the result was performed comparing the real world situation at the test area with the resulting thematic maps.

1. INTRODUCTION

The change and prediction of soil erosion has become an important discipline in the world of Geospatial Information Systems (GIS). On the one hand, the modelling of soil movements and their consequences plays a significant role for environmental planning. This includes the optimization of agricultural plantation, arrangement of urban and suburban dispersion, establishment of emergency plans for natural hazards and risk assessment for all kinds of building projects near steep slopes. On the other hand, the representation of environmental processes is extremely difficult, owing to the fact that it comprises plenty of different disciplines like Geography, Geology, Biology, Chemises, Hydrology and Meteorology. Therefore, the interest as well as the challenge in mapping change and prediction of soil erosion is very high.
At Loess Plateau soil erosion is more severe and the industrial development in this part is poor, so that the majority of the population is engaged in the agricultural sector and the farmers' principal income is based on their farm activities (Chen et al, 2003). However, many researches have shown that this intensive agricultural land use in combination with often occurring irrational land use, the low vegetation cover and the vulnerable soil is mainly responsible for the severeness of soil shipment at Loess Plateau (Fu and Gulinck, 1994; He et al, 2006). Consequently, the environmental planning concerning agricultural optimization and correlating reduction of soil erosion is the key to raise the life standard in this region. Additionally, monitoring of land use and land cover changes integrated in a GIS is essential to have an effective land management and to improve the output of agricultural activities (Malla, 1999). The problem of soil erosion has to be faced using as few financial resources as possible. Usually, the highest amount of the budget of a GIS – project has to be spent for the geographical source data (Longley et al, 1988a). For that reason one main goal of this study is to enhance the available higher quality paper maps in order to achieve as much additional value as possible. Consequently, this study abandons expensive high resolution data and financial resources are saved.

2. PREPARATION

According to the objective of this study, the analysis is implemented for two different time periods, the year 1977 and year 2003. USLE is chosen because the applicability of the USLE has been proven over the last decades and the reliability of the results is indisputable (Wishmeier and Smith, 1978; Laflen et al, 1991; Renard et al, 1997; Hammad, 2005). It needs fewer parameters to reach acceptable results. The tools utilized for the study, are the software packages ERDAS Imagine 8.4 and ESRI ArcGIS 9.0/ArcInfo. The former was utilized to preprocess the data sources. The later performed the processing of the data source and the calculation of the basic raster data sets for the parameters of the USLE.

2.1 Study Area

The Nihe Gou catchment, which is situated in the south of the Loess Plateau in Chun Hua County of Shaanxi Province, offers the typical characteristics of the southern zone of the plateau like high agricultural land use, extreme topographical disparities and the equal geological underground. That is why this catchment was chosen as large scale test area for the study.

The general landscape of the catchment is flat and characterized by a steep ditch, which embeds the dammed Nihe River, which serves as a water reservoir for the surrounding fields during the

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drought. The altitude ranges from 630 up to 1,809 meters. On the upper border as well as on the ground terrace agriculture dominates the landscape, whereas the steep slopes of the ditch are mainly fallow or sparsely planted. These slopes in combination with the loess present a severely endangered corroding surface for soil erosion.

The land is intensively agriculturally used throughout the whole year. The soil structure of the loess is characterized by a higher percentage of clay. Soil types of cinnamon are present. The annual precipitation rate ranges from 346.1 up to 822.9 mm during the last 30 years. The average rainfall during the growing season amounts to 454 millimetres.

2.2 Data Sources

In general this data sources are paper maps that provide information about the topography, the land use, the soil types and the extension of erosion at the Nihe Gou catchment. The source data was gained for two different years, the year 1977 and the year 2003.

Three topographic paper maps at a scale of 1:10,000 for one time period, altogether 6 topographic paper maps were utilized for the study. Each map describes an area of 0°3′45″ degree in length and 0°2′30″ degree in width.

Two land use maps were produced at a scale of 1:10,000 in the year 1977 and year 2003 which cover the test area. Generally, the maps are classified according to the same land use classes that distinguish between agriculture land, grassland, forestry, orchard, water and engineered land etc... They are hand made based on the information collected on the spot.

Two thematic paper maps at a scale of 1:10,000 representing the soil type at the Nihe Gou have got the same attributes as the land use maps. The soil type classes are the same for the two volumes, which are slope land, different soil in gully and table land.

The thematic map classified according to the extension of erosion has got a scale of 1:10,000 representing the Nihe Gou catchment. The information represented on the map is based on research studies at the catchment and reflect the impact of soil erosion. The map is divided into 5 classes that indicate the strength of the occurring soil erosion for each parcel.

The precipitation data over the last 30 years is collected by the Chunhua Research and Experiment Station situated at the Nihe Gou catchment.

3. IMPLEMENTATION OF THE STUD

3.1 Data Preparation

The source data had to be preprocessed in order to get the necessary data for the realization of the USLE implementation. The preprocessing included steps of scanning the maps in TIFF format raster image, georeferencing their location, merging 6 topographic maps to get 2 topographic maps of year 1977 and year 2003, digitizing the content and rasterizing the information to raster data sets.

3.2 Triangular Irregular Network

The digitalization of the dataset was indispensable for the classification of the raster data, and it had to be performed in order to keep the grade of accuracy of the datasets.

For computing the TIN the software package ESRI ArcGIS was used. This software calculates a TIN based on a Delaunay Triangulation and a vector dataset containing the input parameters. These parameters are the elevation information stored in the digitized shape files either represented as height points or as contour lines. For each year about 70,000 elevation points were digitized and converted to a TIN. The final result was examined using the ArcGIS add-on ArcScene. Finally, a detailed analysis and validation of the two resulting TINs succeeded at the test area itself.

3.3 Thematic Maps

Five thematic paper maps classified according to land use, soil type and extension of erosion, are the basic datasets for the evaluation of the K, P and C Factors of the USLE.

The land use vector files and the soil type Shape files that corresponds to the classes of the paper maps were classified. The Shape files derived from the thematic paper maps were transformed to 3D Shape files by adding the elevation data from the corresponding TIN. Afterwards they were visualized using the ArcGIS add-on ArcScene to represent and compare to the real world situation.

3.4 Implementation of the USLE

The implementation of the USLE was conducted according to the theoretical framework. At first every single factor was evaluated and stored in a raster dataset having the resolution of 2.5 meters. The R - factor was calculated based on the precipitation data. The K factor was calculated with the thematic soil type map and adopted factors for the local soil conditions that were provided by Lu and Stocking (1998). The topographic factors, the L and S factor were derived from the TIN and combined to a single LS – Factor. The P - factor and the C - factor were both derived from the land use map, which was reclassified according to the experimental values of this USLE factors. Finally the parameters of the USLE were combined to the result according to equation (1).

$$A = R * K * S * L * C * P \qquad (1)$$

In this equation, A represents the amount of soil eroded over a certain period in tons per hectare, R is the rainfall erosivity factor, K is the soil erodibility factor, S describes the slope steepness factor, L represents the slope length factor, C is the cover and management factor and P represents the conservation practice factor.

4. RESULTS

The thematic map containing information about the amount of soil erosion happened in the year 1977 and 2003 at the Nihe Gou catchment was presented in Figure 1.

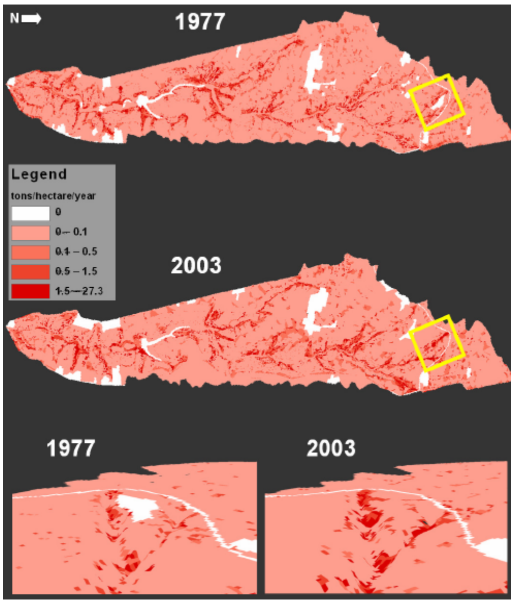

Figure 1.Thematic map showing the amount of soil erosion in the year 1977 and 2003.

As it is clearly visible the two years do not vary significantly. On the one hand on steep slopes the year 1977 had more strong erosion in the southern part of the ditch, whereas the distribution of strong eroding surfaces on steep slopes was higher in the north in the year 2003. On the other hand on flat areas generally the distribution of occurred erosion seems to be very similar for both years, although the map of the year 2003 exhibits more clusters of high concentrated erosion. In comparison to that the map of 1977 has a higher number of small isolated high erosive pixels.

The mean values of all parameters of the USLE as well as the mean amount of soil erosion for each pixel in the year 1977 and 2003 are presented as Table 1. This information makes it possible to compare the results according to the single parameters.

parameters	Δ1977	Δ2003	Δ
R	173.05	409.35	291.2
K	0.33	0.39	0.36
LS	10.52	10.26	10.39
C	0.33	0.32	0.325
P	0.90	0.87	0.895
Result(/t/ha/year)	0.2620	0.4079	0.33495

Table 1. Mean values for each pixel of all USLE parameters and of the resulting amount of soil erosion for the year 1977, 2003.

Looking at the total amount of soil shipment in the whole Nihe Gou catchment about 24.70 tons of soil was moved in the year 1977 and about 37.64 tons in the year 2003. However, the numbers alone may distort the result concerning the more detailed analysis of the environmental impacts. Therefore, the only external factor of the USLE was eliminated. This factor is the rainfall erosivity factor that differed extremely between these two years. The resulting datasets do not provide the information about the amount of soil loss. Nevertheless, the regions where the environmental conditions push the soil shipment are filtered out and a comparison between the situation in the year 1977 and 2003 is possible. In addition to that an overlay between these maps containing the internal factors of the USLE resulted in a direct comparison of the years. This map (Figure 2) shows the areas that have reduced their vulnerability as well as the areas that have become more vulnerable to soil erosion. In addition to that Table 2 contains the values for the areas that have changed according to this analysis.

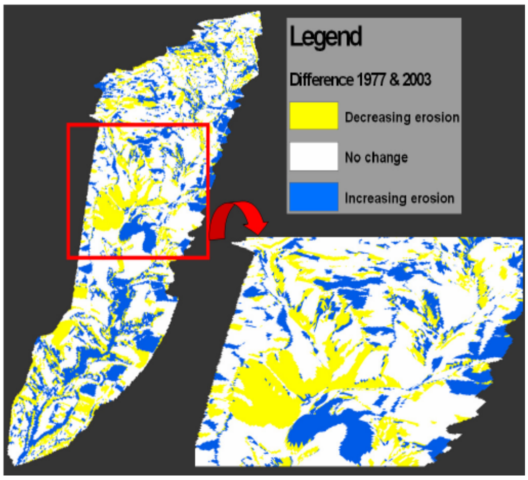

Figure 2. Thematic map showing a comparison between the internal factors of the USLE of the year 1977 and 2003.

Obviously, the visual impact of Figure 2 is supported by the values of Table 2, which show that generally the slopes at the Nihe Gou Catchment have reduced their overall internal factor, although more soil shipment took place in the year 2003. Nevertheless, there is neither a positive nor negative trend to read out.

	Area in km^2	Area in %
Decreased erosion	2.87 km^2	23.4%
No change	6.78 km^2	55.2%
Increased erosion	2.56 km^2	20.9%

Table 2 Area changed their vulnerability to soil erosion according to their internal factors

This study examined the correlation between heaviness of erosion and slope steepness. According to these results the soil erosion is generally much heavier on steep slopes than on fallow one. The graph presented in Figure 3 indicates that this relationship is also valid for this study. For that reason it is outlined that also at the Nihe Gou catchment the slopes length and steepness are the crucial factors concerning the impact of soil erosion.

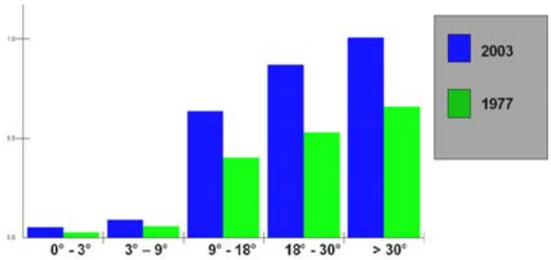

Figure 3: Yearly distribution of mean soil erosion of the areas according to their gradient classification.

Concerning the prediction of further soil erosion a risk analysis was performed. This analysis took the internal factors of the USLE into consideration, due to the fact that the external R – Factor is not influenceable by humans and so will not change because of any underlying analysis. Therefore, the already created layer with the internal factors of the year 2003 was taken as basis for the risk analysis. This dataset was reclassified into three classes in order to outline high risk areas (Figure 4). Obviously also this risk analysis shows that mainly steep slopes are very vulnerable and therefore likely to erode more severely than flat areas are.

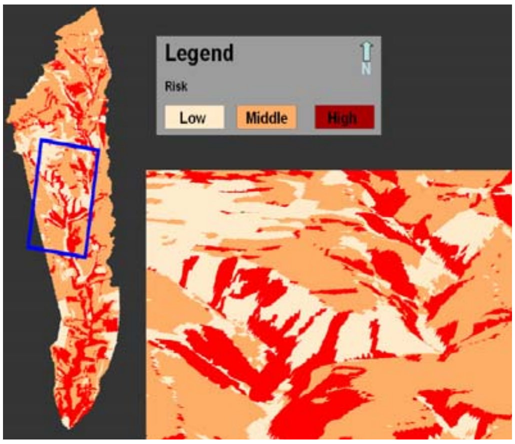

Figure 4: Risk analysis of the Nihe Gou Catchment.

5. CONCLUSION & DISCUSSION

The results show that soil erosion is an evident problem at the Nihe Gou catchment, because such high soil loss leads to desertification and so the percentage of cultivatable land reduces. Although positive measures about increasing plantation of shrubberies on slopes against the desertification have been taken, the situation has not significantly improved since 1977. In addition to that the number of terraces has increased, but mostly on flat areas where soil erosion is not as severe as on the steep slopes. Farmers grope their plants over the whole year without leaving the field fallow, such an intensive usage of the soil reduces in perpetuity organic matter and makes the soil more vulnerable to erosion. Based on the results of this study it is important to attend to the high risky areas, which are steep slopes as well as the edges, where slope increases significantly. Especially, on these edges the flow accumulation is very high and so the farmers have to decide whether they want to use these strips for plantation or whether it is better to plant a deep rooting plant that might provide no gain. However, the results of the study have indicated where positive changes have dammed the soil shipment and on which spots measurements are essential.

Critical steps during this study are the preprocessing of the data sources and the correct implementation of the USLE factors. Nevertheless, the study has shown that also paper maps have sufficient quality to quarantine an appropriate digital modulation of the real world's impacts on the environment. Furthermore, this study gives a good example for the fact that data do not necessarily have to burden a project's budget. Concerning the implementation of the USLE factors, the derivation of the slopes must be examined critically. In this study the slopes and their length were derived directly from the TIN without taking into consideration where deposition begins or where the flow reaches a concentrated channel as it is proposed by Wishmeier and Smith (1978). Additionally, the length of the slopes in this study depends on the range of the flow length that passes through the slope. However, the results have shown that this way of determining the slopes and their parameters slope steepness and slope length is an acceptable way around the problem, if hydrologic analysis tool is missing. For that reason it is outlined that the accuracy of the results did not suffer under data constraints or small detours in parameter calculation.

Generally, this comparison shows that the result of the study and the monitored scenarios in the past are conform to each other. Marginal discrepancies are explained with the different rainfall intensity and the change in agricultural cultivation and plantation. Therefore, it is outlined that the study's results mirror the real world situation and so the approach and realization of the study.

To sum up the study resulted in a verified approach to map the change of soil erosion using low quality data of the generic environment of the Loess Plateau in Shaanxi Province. This approach is based on the USLE and includes the generation of a complex DEM out of topographic paper maps as well as the utilization of several thematic paper maps to evaluate the USLE parameters. The resulting datasets contain information about the amount of soil losses over the test periods, as well as information about changes on the environmental conditions during the test period. Finally, an ArcGIS Toolbox was implemented and applied on the test area. Its results have been verified and so it is applicable on other areas of the Loess Plateau.

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