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Soil erosion types in the loess hill and gully area of China*

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Abstract—The loess hill and gully area of China is the region with the most serious soil erosion in the world, and there is an urgent need for erosion control and soil conservation. This project uses a geographic information system(GIS) for studying soil erosion types. Elevation contours from a topographic map of the study area were digitized to generate a digital elevation model(DEM). Slope and aspect were then computed from the DEM. The current land uses were obtained by air-photo interpretation. DEM, slope, aspect and landuse were integrated by GIS and their interrelationships were analysed. Combining GIS analysis and erosion survey, a rule of vertical distribution of soil erosion types from hill top to gully bed was derived. The basic erosional systems in this area were described at the catchment level. This systematic analysis will help to organize erosion surveys and mapping and also to guide conservation strategies.

Keywords: soil erosion type; geographical information system; loess hill and gully area.

1 Introduction

Soil erosion is a well known problem in the loess hill and gully area of China. Land degradation and erosional processes seem to be increasing in severity in this area. Average and maximum erosion rates are 150 t/(ha. a), and 390 t/(ha. a), respectively(Chen, 1989), which are equivalent to a surface lowering of 1.2 and 3.1 cm/a. Dai(Dai, 1988) estimated that the region's soils have been cultivated for up to 5000 years, and that accelerated erosion has taking place for about 3000 years. Because of increasing population, there is a tendency to increase agricultural production by cultivating steep slopes with very erodible soils. The cultivation is often on slopes as steep as 40 degrees, and has resulted in ecological and environmental deterioration (Fu, 1989). Although there have been some soil erosion studies in the loess plateau, there are still no studies of

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erosion types at the catchment level.

A main objective of erosion research should be to analyze the type, process, rate and causes of erosion, and to show the distribution of the risk of erosion in specified areas (Albaladejo Montoro, 1988). This project focuses on erosion types in one catchment based on an erosion survey and a GIS integrative analysis. The Quanjiagou catchment, a typical loess hill and gully basin, was the study area. This study will help understand soil erosion processes and control soil erosion at the catchment level.

2 The study area

Quanjiagou catchment lies in the northern part of loess plateau in northern Shaanxi Province in China (37°46′N, 110°16′E; Fig. 1). It is the second tributary of the Wuding River. The area of the catchment is 5.19 km^2 and gully density is 4.66 km/km^2. The area above the gully-edges forms 47% of the whole catchment and that below the gully-edges 53%. Within the study area, there are significant topographic variations and the maximum elevation difference is 160m. It is typical loess hill and gully landforms.

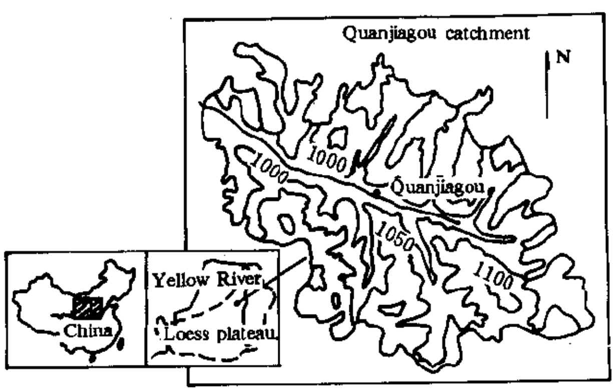

Fig. 1 Location map of the Quanjiagou catchment

The area has a semi-arid climate with an average annual temperature of 8.4℃, 23.5℃ in July, and −9.9℃ in January. The average minimum temperature is −24.8℃ in January, and the average maximum temperature is 38.2℃ in July. Winters are bitterly cold and summers are hot. The area has high total sunshine, with an average of 2732 hours per year. Frost-free days number is 162. The average annual precipitation is 422mm and 69.5% of this concentrated in July to September. The rainfall varies greatly from year to year. Between 1951 and 1990, the minimum rainfall was 280mm in 1978, and the maximum was 692mm in 1960. The average annual potential evapotranspiration is 1556mm.

The soil in the study area is mainly loessic soil, which makes up above 90% of the whole area. It contains 7%−14% clay (<0.001mm), 10%−13% fine silt (0.001−0.01mm), 48%−56% coarse silt (0.01−0.05mm) and 23%−30% sand (>0.05mm). It is only weakly resistant to erosion. Soil erosion is very serious with a loss of about 16300 tons $km^{-2}.a^{-1}$ (Zhang, 1990). The natural vegetation has been destroyed in this area because of long term cultivation. The current land use is farmland, fruit land, forest and grassland, making up 53.4%, 4.8%, 21.3% and 14.8% of the whole area, respectively. Crop grown on the cultivated parts of the catchment include millet (*Panicum miliaceum*), sorghum (*Sorghum* spp.), beans(*Phaseolus vulgaris*), maize(*Zea mays* L.), wheat (*Triticum* spp.) and potatoes. On the gully slopes, bush and forest, including *Abrotanum lavandulaefolia*, *Caragana korshinskii*, *Zizyphus jujuba*, *Hippophae rhamnoides* and *Robinia pseudoacacia* L. are presented.

The complex landform types, steep slope, great gully density, loose soil structure, concentrated rainfall and irrational land use are the main causal factors of the soil erosion in this area.

3 Materials and methods

A GIS is a computer system designed to allow users to collect, manage and analyze large volumes of spatial data and associated attributes. The GIS used here was IDRISI developed by the graduate school of geography at Clark University. The topographic map(Shaanxi Province Survey Bureau, 1980) and land use map(Northwest Institute of Soil and Water Conservation, 1990) of the study area at a scale 1:10000 were digitized manually using the TOSCA program of IDRISI and were divided into 6.7×6.7 meter cells for analysis.

Elevation contours from a topographic map of the area was digitized to generate a digital elevation model(DEM). This displayed the diversity of landform types from hill top to gully bed (Fig. 2). Slope and aspect were calculated from the DEM. The slope was determined by calculating the maximum slope around each pixel from the local slopes in X and Y. Only the neighbors above, below and to either side of the pixel are used in this procedure. The slopes were output in decimal degrees and 5 classes(0—3°, 3—8°, 8—15°, 15—25° and >25°; Fig. 3). The aspect is the direction of maximum slope, expressed as standard azimuth designations, 0° to 360°, clockwise from north. Eight aspect classes were recognized in the area(Fig. 4). Slope, aspect, land use combining with erosion survey were intergrately analysed for soil erosion types in the catchment.

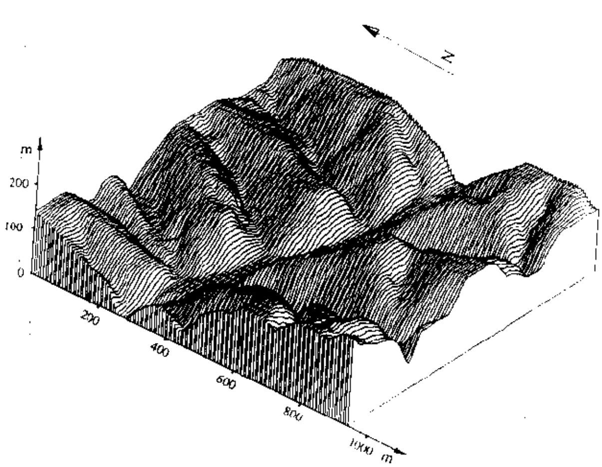

Fig. 2 Digital elevation model(DEM) of the study area

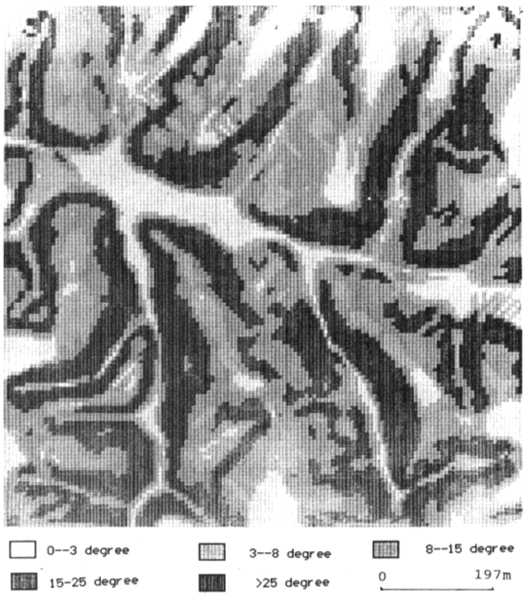

Fig. 3 Slope map of the study area

Fig. 4 Slope aspect map of the study area

4 Results

4.1 DEM, slope, aspect and land use integrative analysis

The land use map was integrated and analysed together with the DEM, slope and aspect to study the distribution pattern of land use classes in relation to the terrain parameters. Land use classes of the study area were terrace farmland, check - dam farmland, slope farmland, fruit land, forest, bush, natural grassland, and man - made grassland. Overlaying land use map and DEM, it was found that check - dam farmland is distributed in gully beds, terrace farmland is on upper hill slopes, slope farmland and man - made grassland are on the lower hill slopes, and forest, bush, and natural grassland are on gully slopes. When land use map and aspect data were combined, it was found that in general north - facing slopes are mostly vegetated, whereas south - facing slopes are eroded and almost unvegetated. This may result from differences in soil moisture and temperature.

From the DEM of the study area, the tops of the hill and the edges of the gullies can be found clearly. They are important lines for dividing micro - landform types, such as, hill top, hill slope and gully slope. These landform types are the basis of the soil erosion types.

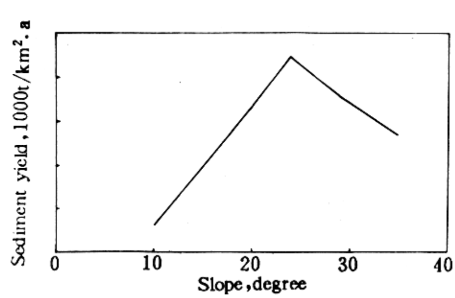

Fig. 5 The relationship between slope and soil erosion

4.2 Terrain parameters, land use and soil erosion

Terrain parameters are important factors affecting soil erosion. Aspect affects soil erosion through soil features and land use. Soil erosion is also influenced by slope. Soil erosion development can be explained by land use, slope materials and slope hydrology; all these factors are partially controlled by slope gradient. The relationship between slope and sediment yield is shown in Table 1. Statistical analysis of the data derived from field observation shows that 14° and 24° are crucial thresholds, sediment yields increase with slope. Where the slope exceeds 14° the sediment yields rapidly increase and surface wash is greatly intensified. From 24° to 35°, the sediment yields decreased (Fig. 5) and the process of erosion changes from surface wash to gravitational erosion (Yang, 1990).

Table 1 The relationship between the slope and sediment yields (after Yang, 1990)

Observation data	July 1, 1988	July 7, 1988	July 17, 1988	July 31, 1988	July 17, 1988
Slopes, degree			Sediment load, t/km^2		
10	375.9	321.3	976.6	269.6	1137.0
14	1514.7	420.9	1756.1	1525.8	3213.0
20	8059.7	563.0	1908.6	2410.6	3487.5
24	5341.7	304.3	5058.9	4516.4	7027.5
29	6751.9	485.2	3169.4	1579.7	5881.5
35	7456.5	937.4	2489.3	1360.3	1198.5

Land use is an important factor in determining soil erosion types and processes. In general, as the protective canopy increases, the sediment yield decreases. The relationship between land use and soil erosion in the loess hill and gully area is shown in Table 2 (Yang, 1992). The rate of erosion is greatest on farmland.

Table 2 Soil erosion on different land use in loess hill and gully area (after Yang, 1992)

Land use types	Slopes, degree	Vegetation cover, %	Sediment yield, t/(km^2. a)
Farmland	25	—	1147.5
Natural grassland	29.5	40	318.0
Forest	25	90	20.7
Bush	22	75	4.5

In the study area, the top and upper slope of hills are characterized by gentle slope of <10 degrees that have been terraced and cultivated. Immediately below are the lower slopes which are usually cultivated. At the gully slope and with a sharp break from the lower slope of hill is located an even steeper zone that is not cultivated but is grazed by sheep and goats. Finally, there is the gently inclined valley floor, where ephemeral stream flow is concentrated. In the gully beds, check - dams have been constructed to catch the sediments. From hill top to gully bed, micro - landform types, can be divided into hill top, upper hill slope, lower hill slope, gully slope and gully bed. The differences of micro - landform types, slope and soil characteristics are reflected in the types of land use. From hill top to gully bed, land use sequence is terrace farmland - slope farmland - grassland - bush - check dam farmland. Because of the difference of micro - landform type and slope and their effects on soil characteristics and land use, soil erosion types also differ from hill top to gully bed.

5 Discussion

Through integrative analyzing the relationships among DEM, slope aspect, land use and soil erosion, and erosion survey in the field, a vertical sequence of soil erosion types from hill top to gully bed was found (Fig. 6). From hill top to gully bed, the erosion types are splash erosion, sheet erosion, rill erosion, shallow furrow erosion, gully erosion, cave erosion, and gravitational erosion.

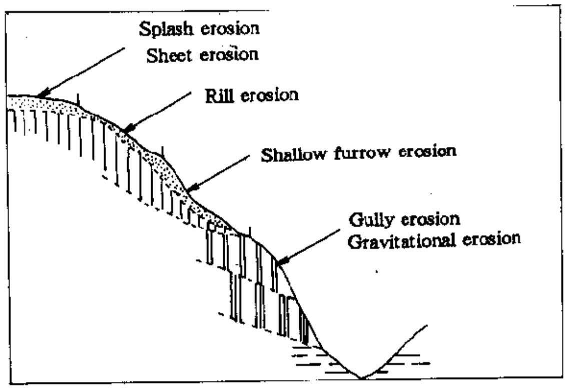

Fig. 6 The vertical distribution of soil erosion types and processes

Splash erosion and sheet erosion occur on the tops of hills and ridges. The slope is 0—8 degrees and the soil is thick. Runoff production and soil loss are small. Splash erosion is dominant on fields with a high aggregate stability and rapid infiltration. Sheet erosion is dominant on fields where topsoils are prone to liquefaction. Surface flow may produce saturated overland flow on the slope, but even there erosion is limited.

Rill erosion is dominant on the upper hill slopes. The land use here is farmland. Slopes are 8—20 degrees, and as slope gradient and slope length increase so, runoff changes from sheetwash to stream flow. Shallow channels, meters in width, may be generated especially when plough pans are presented. The position of the rills is often related to the microtopography of hills and ridges. Rill erosion makes up 50%—75% of the sediment yield from hillslopes.

Shallow furrow erosion occurs in the lower hill slopes. The land use here is farmland and uncultivated slopes. Slope angle is 20—25 degrees. Shallow furrow erosion is developed from rills with slope gradient increases. Near the gully edge, small gully erosion and cave erosion often occur. According to the field survey, shallow furrow erosion occurs mainly on hill slopes of 22—31 degrees; there slopes account for 74.4% of all the shallow furrows.

Gully erosion and gravitational erosion are the main erosion types on the gully valley. The land use here are natural grassland and farmland. The slope is >25 degrees. Gullies on the slopes are channels for silt transportation from hillslope to gully bed. There are active gully headcuts on the slope. Suspended gully erosion occurs in the steep slopes of gully valleys and gully heads. Landfall and landslide are main types of gravitational mass movement in the study area. They occur on the steep slopes of ravines and big gullies.

6 Conclusions

This study demonstrates that a digital elevation model can provide a rapid and objective evaluation of terrain parameters for use in the study of soil erosion types. GIS is a very useful tool for integrative analysing of spatial data. The results show a vertical distribution of soil erosion types in the loess hill and gully area of China. From hill top to gully bed, the erosion types are splash erosion, sheet erosion, rill erosion, shallow erosion, cave erosion, gully erosion, and gravitational mass movement. At present, the key issue in this area is that the current land use is not the most suitable(Fu, 1994). A vertical erosion control system should be set up in the catchment (Fig. 7). Different erosion control measures for soil conservation are required for different erosion types and processes. It is important to focus on the hillslopes and gully valleys. Level terraced fields and strips may be built on the upper hillslopes, but the steep cultivated slopes must be abandoned in favour of sown grass and planted trees. Forests and bushes should be planted on the gully slopes and grass on the lower hillslopes. Check dams should built on the gully beds.

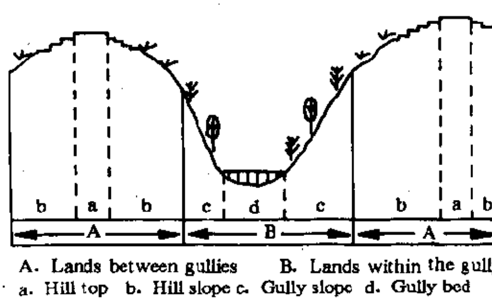

Fig. 7 Cross - section of erosion control measures in the catchment

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