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A Systematic Analysis of Human Activity on Landform Evolution of Loess Plateau

——Taking loess plateau area in Gansu Province as an example

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ABSTRACT

It is common knowledge that landform evolutionary process is controlled by two processes, endogenic forces processes and exogenic forces process. Endogenic forces and exogenic forces processes history is as long as the earth's history. Comparing with landform evolutionary history, human history is a very short instance. But people have to undertake cultivation, animal husbandry and other productive activities for their living since they came to the world. This affects landform evolutionary process. Especially, the effect of human activity on landform evolution of loess plateau is becoming more and more violent for several thousand years. Watersoil erosion is one of very important landform evolution phenomenon of loess plateau. The authors have studied water-soil erosion of loess plateau area in Gansu province as example, analyzed the effect of human activity on water-soil erosion. Thus the position and the effect of human activity on landform evolution of loess plateau have been shown from one point.

KEYWORDS human activity, landform, evolution, plateau

1 Endogenic and exogenic forces processes

Modern geomorphological theory regards that landform evolution is controlled by two processes, endogenic forces process and exogenic forces process. Endogenic forces are from the interier of the solid earth. Generally, celestial form, tremendous form, great form and some middle and small forms are formed by endogenic forces, and their forming is decided by tectonic qualities. Exogenic forces are from atmosphere and pydrosphere. Landform evolution is affected by exogenic forces, such as wind, flowing water and glacier, while endogenic forces work simultaneously. The action of exogenic forces makes the landform formed by endogenic forces

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complicated or simplified. Exogenic forces reform middle and small landforms on first situation, raze the undulate of primary landform on second situation, and hide the landform formed by endogenic forces or make them complex through kinds of accumulation on third situation. The effect of exogenic forces on the landform formed by endogenic forces is mainly decided by the tendency of landform developing, i.e. the earth's crust is raising or falling. All kinds of complicated landform are the instaneous results of the antagonic action of endogenic and exogenic forces[7], and this is called the antagonic theory of land surface evolution[8].

When the endogenic forces are relatively stable, the forces of landform evolution are exogenic forces mainly, thus the landform system can be regarded as an exclusive system[2]. The process of transportation of substance on the earth's surface can be described by the following differential equation,

$$\frac{\partial H}{\partial t}=a\frac{\partial^2 H}{\partial x^2}+b\frac{\partial^2 H}{\partial y^2} \tag{1}$$

where $H=H(x,y,t)$ is the height of the earth's surface, is the function of x, y and t, while x and y are horizonal co-ordinates, t is time. However, considered long geological period and the whole globe, landform evolution is controlled by both endogenic and exogenic forces, so the landform system is a open system, and its evolution can be described as

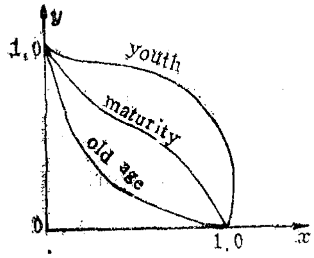
$$\frac{\partial H}{\partial t}=a\frac{\partial^2 H}{\partial x^2}+b\frac{\partial^2 H}{\partial y^2}+f(x,y,t) \tag{2}$$

Where $f(x,y,t)$ is the action of endogenic forces. Generally, we do not know the exact form of endogenic forces, but it can be regarded as that it is independent of space and time[5] i.e.

$$f(x,y,t)=\phi(x,y)T(t) \tag{3}$$

W.M. Davis' theory of erosional cycle[4] think that landform evolution can be divided into three stages, youth, maturity and old age. The three stages can be described by area S, which is the area contained by Strahler's curve[9] and the two co-ordinates. This can be obtained as the following steps, measure the area (let be a) above each isogram, measure the height between each isogram and the lowest point of the drainage (let it be h). Let the total area of the drainage be A, the height between the highest and lowest point be H, and let the co-ordinates $x=a/A$, $y=h/H$. It is evident that x and y are in [0,1]. From a series of points (a,h), we can obtain the Strahler's curve (Fig.)

$$y=f(x) \tag{4}$$



and integral

$$S=\int_0^1 f(x)\mathrm{d}x \tag{5}$$

is called the Strahler's integral. The Davis' evolution stages of the drainage may be divided as $S>0.6$ … youth, $0.35\leq S\leq 0.6$ … maturity, and $S<0.35$ … old age. The antagonic theory of land surface evolution thinks that the three stages do not describe the order

Fig. The Strahler's curve

of landform evolutionary process, and it shows that the intensity of the antagonic action of endogenic and exogenic forces. This can be described by comentropy in erosional drainage-system[11].

W.M. Davis' theory of erosional cycle thinks that the endogenic forces raise the earth's smooth surface, and later, the three evolutionary stages are regarded as the further modifying stages. This process may be mathematically described as

$$\lim_{\Delta t\to 0}\int_0^{\Delta t} T(t)\mathrm{d}t=1 \tag{6}$$

Thus the effect of endogenic forces on landform evolution is only to provide equation (1) with an initial condition. Davis' theory is the evolutionary theory of the exclusive landform system. Evidently, this has its limitation. Comparing with Davis' theory of erosional cycle, W. Penck's geomorphological theory[6] condsidering the action of both endogenic and exogenic forces is the evolutionary theory of the open landform system. The endogenic forces action of penck's model can be described mathematically as

$$T(t)=1/d \qquad (0<t<d)$$

and it satisfies

$$\int_0^d T(t)\mathrm{d}t=1 \tag{7}$$

The authors[10] have given the stage hypothesis of endogenic forces action. We thinks that the intensity of endogenic forces action has its stage quality, i.e. it is stronger during some geological periods and weaker during the other geological periods. This can be described as following,

$$T(t)=\begin{cases} f_k(t)\neq 0 & T_{2k-1}\leq t<T_{2k} \\ g_k(t)\approx 0 & T_{2k}\leq t<T_{2k+1} \end{cases}$$

and it satisfies

$$\sum_{k=1}^{\infty}\int_{T_{2k-1}}^{T_{2k}} f(t)\mathrm{d}t=1 \tag{8}$$

2 Human activity of landform evolutionary process

Geo-history science tells us that the earth has its history at least 4.6 billion years. There had been primary living things before one billion years ago, and there had been fish species in ocean before 0.4 years ago. There had been reptile species before 0.2 years ago. Human history has only several million yaers. Comparing with the earth's history, human history is only very short instance. Landform evolutionary history is as long as the earth's history. But people have to do long and arduous struggles with natural world, have to plant, graze and undertake other productive activities for their living since the came to the world. Natural landform evolution process has been changed because of human activity. primary prairie and forest, some of them became cultivated lands and some of them became desert. Culture landscape changes natural landscape. Especially, the effect of human activity cf loess plateau is becoming more and more intensive for several thousand years. By way of example, the important phenomenon of landform evolution, soil erosion, natural erosional process was acceerated greatly. Studies[3] show that soil erosional rate of loess plateau has become 25% since Tang dynasty, but it was only 7.9% before Tang dynasty. So it is evident that the landform evolutionary process of part landform is affectd by three procesess. endogenic forces process, exogenic forces process and human activities process, i. e.

$$G_s(t)=\begin{bmatrix}E_n(t)\\E_x(t)\\H_m(t)\end{bmatrix} \tag{9}$$

Where $G_s(t)$ is landform evolutionary process, $E_n(t)$, $E_x(t)$ and $H_m(t)$ represent endogenic forces process, exogenic forces process and human activities process respectively.

But human activity is not as endogenic and exogenic forces, it does not change the laws of endogenic and exogenic forces action. It only changes the intensity or trend of exogenic forces. For example, erosional process can become accumulative process through productive activities and water and soil conservation methods etc., and vice versa. The landform formed by endogenic and exogenic forces can be reformed by human activities. Human activity can affect landform evolutionary process indirectly by modifying the earth's surface in small area, coverage of plants, trees and grasses etc. For example, engineering projects can change erosion-accumulation process through raising up the local temporary base level, and biological projects can retard soil erosional process through changing the properties of the earth's surface.

Human activity on landform evolutionary process can be controlled by human itself. If the landform evolution is helpful for people, man should accelerate this evolution. If the landform evolution is hurtful for human, people should retard this evolution. For example, water-soil erosion is regarded as one of serious challenge people face up to, so many water and soil conservation methods are used by people. Certainly, people can not change endogenic and exogenic forces processes completely, especially, man can not change endogenic forces process.

3 Quantitative analysis of human activity on water-soil erosion of losess plateau

Qantitative study of human activity on landform evolution is a very hard task. The authors want to show the effect of human activity on landform evolution of loess plateau from one point through analysis of human activity on water-soil erosion.

According to the stage hypothesis of endogenic forces action, we can only consider exogenic forces and human activity when we analyze the effect of human activity on soil erosion of part area during one short period. That is to say, the soil erosion is mainly caused by exogenic forces and human activity. Thus the soil erosional process can be regarded as a series of input factors of exogenic forces, such as wind, flowing water and glacier etc. is changed into silt output, while human activity works simultaneously. If only flowing water is considered, the erosional process is water-soil erosion. Our study[11] shows that silt output is greatly relative with runoff, and runoff is greatly relative with precipitation on loess planteau area in Gansu province. Thus we can give the productive functions of runoff and silt as following[12]

$$G = M_1 f_1(H) \tag{10}$$

$$Y = M_2 f_2(G) \tag{11}$$

where Y is silt output, G is runoff and H is precipitation, M_1 and M_2 represent the intensities of human activity in runoff productive process and silt productive process respectively. H, G, M_1 and M_2 are functions of time t.

Total differential of G is as following,

$$\frac{dG}{dt} = \frac{dM_1}{dt} f_1(H) + \frac{\partial G}{\partial H} \cdot \frac{dH}{dt}$$

When it is divided by G, let $\alpha = \frac{\partial G}{\partial H} \cdot \frac{H}{G}$, and α be the elastic coefficient of runoff production from precipitation. The we have

$$\frac{dG}{dt} \Big/ G = \frac{dM_1}{dt} \Big/ M_1 + \alpha \frac{dH}{dt} \Big/ H \tag{12}$$

The left side of formula (12) is the increase rate of runoff, the first part of the right side is the increase rate of intensity of human activity in runoff productive process, and the second part is the product of the coefficient and increase rate of precipitation.

By the same method above, we obtain,

$$\frac{dY}{dt} \Big/ Y = \frac{dM_2}{dt} \Big/ M_2 + \beta \frac{dG}{dt} \Big/ G \tag{13}$$

where $\beta=\frac{\partial Y}{\partial G}\cdot\frac{G}{Y}$ is the elastic coefficient of silt production from runoff.

The left side of formula (13) is the increase rate of silt output, the first part of the right side is the increase rate of intensity of human activity in silt produtive process, and the second part is the prodution of the coefficient and the increase rate of runoff.

We often substitute formulas (12) and (13) with the equation of differential quotients respectively as following,

$$\frac{\Delta G}{\Delta t}\Big/G=\frac{\Delta M_1}{\Delta t}\Big/M_1+\alpha\frac{\Delta H}{\Delta t}\Big/H$$

$$\frac{\Delta Y}{\Delta t}\Big/Y=\frac{\Delta M_2}{\Delta t}\Big/M_2+\beta\frac{\Delta G}{\Delta t}\Big/G$$

If Δt in each part of upper formulas is the same and $\Delta t\neq 0$, we have

$$\frac{\Delta G}{G}=\frac{\Delta M_1}{M_1}+\alpha\frac{\Delta H}{H} \tag{14}$$

$$\frac{\Delta Y}{Y}=\frac{\Delta M_2}{M_2}+\beta\frac{\Delta G}{G} \tag{15}$$

Where $\frac{\Delta H}{H}$, $\frac{\Delta G}{G}$ and $\frac{\Delta Y}{Y}$ can be obtained from observation data. If the coefficients α and β are determined, the increase rates of intensity of human activity in runoff productive process and silt productive process, $\frac{\Delta M_1}{M_1}$ and $\frac{\Delta M_2}{M_2}$ can be obtained from formulas (14) and (15) respectively. The contribution of human activity on increases of runoff and silt output can be described respectively as following,

$$m_G=\frac{\Delta M_1}{M_1}\Big/\frac{\Delta G}{G} \tag{16}$$

$$m_Y=\frac{\Delta M_2}{M_2}\Big/\frac{\Delta Y}{Y} \tag{17}$$

It is evident that the relative rate of runoff changing should be the same as precipitation, and the relative rate of silt output changing should be the same as runoff for the situation of natural erosional process. So we can determine the coefficients as $\alpha=\beta=1$.

The loess plateau area in Gansu province has had s systematic decrease process of runoff and silt output. The average data per year of some drainages are shown in Table 1.

Table 1. The average data per year of precipitation, runoff and silt output in some drainages

Drainage	Period	Silt output (10^4T)	Runoff (m^3/s)	precipitation (mm)
D_1	1955～1969	7220	4.93	382.5
	1970～1985	4530	3.47	364.5
D_2	1955～1969	15700	54.3	500.9
	1970～1985	11900	42.7	481.2
D_3	1955～1969	9800	30.2	571.1
	1970～1985	7779	23.6	537.1
D_4	1955～1969	14190	14.8	505.1
	1970～1985	11120	13.9	492.3

In Table 1, D_1, D_2, D_3 and D_4 represent Zuli river drainage, Wei river drainage, Jing river drainage controlled by Yan Jiaping station and Jing river drainage controlled by Yu Luoping station respectively.

From Table 1, we can calculate $\frac{\Delta H}{H}$, $\frac{\Delta G}{G}$ and $\frac{\Delta Y}{Y}$. thus $\frac{\Delta M_1}{M_1}$ and $\frac{\Delta M_2}{M_2}$ of each drainage can be obtained with formulas (14) and (15), and the contributions of human activity on decreases of runoff and silt output, m_G and m_Y can be obtained with formulas (16) (17). The calculated conclusions are shown in Table 2.

Table 2. The decrease rate of intensity of human activity and its contributions on decrease of runoff and silt.

Drainage	$\frac{\Delta M_1}{M_1}$	m_G	$\frac{\Delta M_2}{M_2}$	m_Y
D_1	−24.9%	84.12%	−7.6%	20.43%
D_2	−17.6%	82.24%	−2.8%	11.57%
D_3	−15.9%	72.60%	0.6%	−2.80%
D_4	−3.6%	59.02%	−15.5%	71.76%

4 Discussion

From Table 2, we know that the effect of human activity on the decrease of runoff in each drainage is very outstanding, as an example, the contribution of human activity on decrease of runoff in Zuli river drainage is as high as 84.12%. But the effect of human activity on decrease of silt output is not outstanding, for example, the contribution of human activity on decrease of silt output in Jing river drainage controlled by Yan Jiaping station is −2.80%. Our study shows that the reason for decrease of runoff of loess plateau area in Gansu province is mainly caused by human activity, because there are lots of engineering projects for water and soil conservation, such as terraced fields, dam and middle or small reservoirs have been made since 1950′. According to incomplete statistics, there are more than one hundred middle or small reservoirs have been built since 1950′. The engineering projects play a very important part for water conservation. Silt output decreased while runoff becreased. But the decrease of silt content is not able comparing with decrease of silt output (see Table 3).

Table 3. The comparing of decrease of runoff, silt output and silt content.

Drainage	$\frac{\Delta G}{G}$	$\frac{\Delta Y}{Y}$	$\frac{\Delta P}{P}$
D_1	−29.6%	−37.2%	−13.47%
D_2	−21.4%	−24.2%	−14.90%
D_3	−21.9%	−21.3%	13.48%
D_4	−6.1%	−21.6%	−16.14%

(In Table 3, p (kg/m³) is silt content)

For example, the silt content of Jing river drainage controlled by Yan Jiaping station is not only no decrease, but also increased 13.48%. This shows that the effect of human activity on silt output decrease is not outstanding. We think that this conclusions correspond with the fact situation of loess plateau area in Gansu province.

The upper analysis shows that human activity on water-soil erosion should be noticed by people, and this shows the position and the effect of human activity on landform evolution from one point. We have advanced human activity on landform evolution as a problem, and hope that there will be a lot of scholar to take part in this study.

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