5 Water Erosion in the Drylands of China

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China is one of the most serious water erosion countries in the world. In this chapter, we overview regional distribution characteristics of water erosion, analyze the damage from water erosion and introduce some successful water control measure in drylands of China.

5.1 Distribution of water erosion and its regional characteristics

China is located on the eastern inclined plane of Eurasia where it grades towards the Pacific Ocean. Its mountainous area accounts for approximately two thirds of the total territory. The landform is divided into three large terraces from west to east that extend throughout the entire country. The regional distribution of soil erosion is controlled by the geomorphological features of the terraces.

The first terrace is the Tibetan Plateau with an elevation of more than 4,000 m. It is surrounded by mountains, of which the Kunlun and Qilian mountains border the north, the Himalayan mountain system borders the southwest and the Hengduan mountain region borders the southeast. In the central part of the plateau, mountains, platforms, hills, basins and lakes are interspersed throughout the region.

The second terrace is located in the western part of China along the route of the Da Xing'anling and Taihang mountains and the Wushan and Xuefeng mountain region, and is bordered by the eastern and the northern sections of the Tibetan Plateau. Mountains, plateaus and basins are widely interspersed throughout the terrace with the Altai, Tianshan and Qinling mountains, Yunnan-Guizhou Plateau, the Loess Plateau and the Inner Mongolian Plateau with an elevation of more than 1,000 m, and the Junggar Basin and Tarim Basin with an elevation of less than 1,000 m.

The third terrace is located at the eastern boundary of the second terrace.

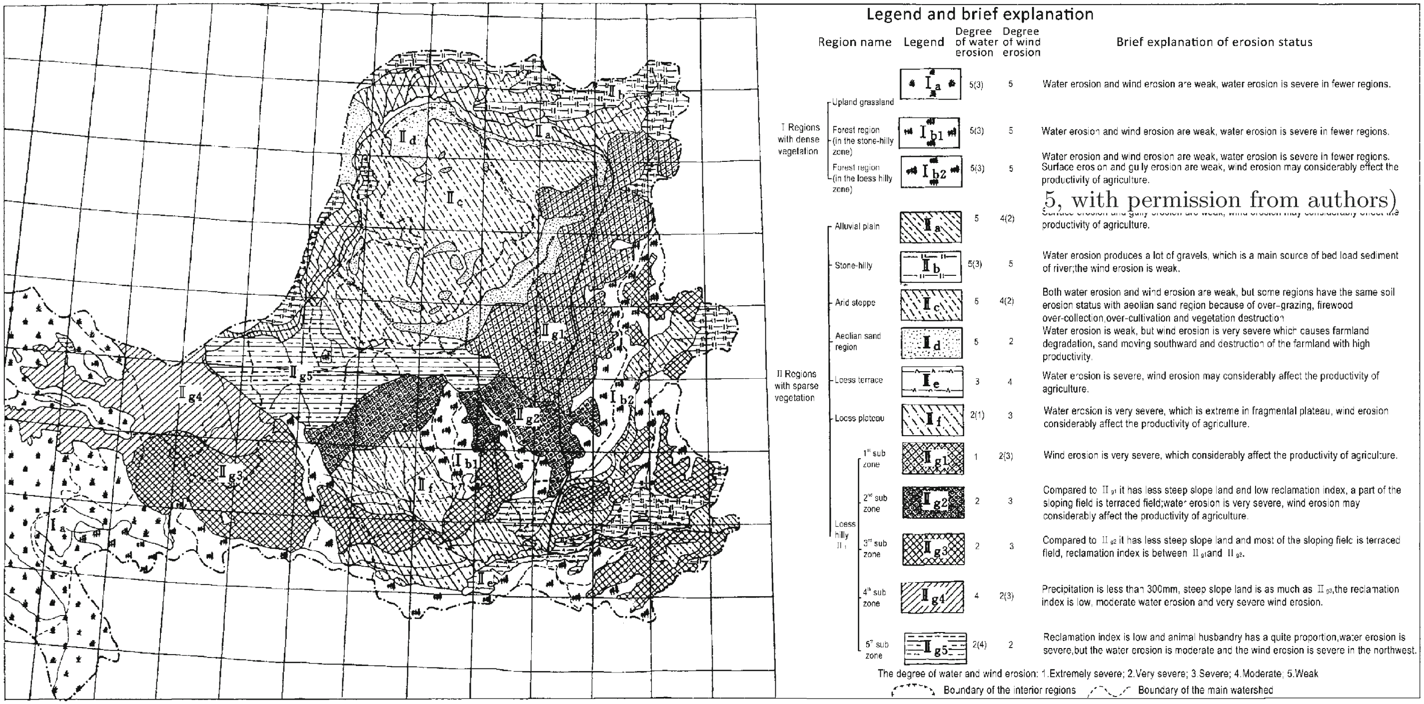
Typical topographic features of this terrace are rivers, plains, valleys, basins, low mountains and hills. The elevation of the majority of the hills is less than 500 m while the less mountains exceed 1,000 m. The elevations of plains and valleys are less than 200 m, and the majority of area within the Huang-Huai-Hai Plain and the middle and lower reaches of the Yangtze River Plain have elevations of less than 50 m. Hills cover a wide range of the area of the terrace, interspersed with valleys and basins.

Topographic characteristics give rise to complex inclined planes which allow all types of erosion mechanisms. Due to the different natural conditions that occur in the different regions and to human activities, the soil erosion zone is widely spread throughout the three terraces. Soil erosion regions are divided on the basis of regional similarities and discrepancies in terms of soil erosion forces, types, and intensity as well as natural and socioeconomic factors. The study of soil erosion regionalization began at the end of the 1950s as part of the Yellow River disaster control planning where soil and water conservation was introduced as a part of the strategic plan.

5.1.1 Distribution scope

In 1955, Huang (1955) compiled a soil erosion map of the middle reaches of the Yellow River in which soil erosion regions were divided into three different categories: class, region, and subregion. The class was further divided into two types: the vegetated class and the non-vegetated class. The vegetated class was then divided into three regions, i.e., alpine grassland, rocky mountainous forest and loess hill forest, while the non-vegetated class was divided into seven regions according to geological and topographic factors. These were finally divided into subregions by land use and landform where, for example, the loess hill forest region was divided into five subregions. The map has been widely applied due to its clarity and simplicity and its ability to illustrate key points (Fig. 5.1). In 1956, Zhu (1956) developed the principles of soil erosion regionalization and summarized five classification categories: zone, region, subregion, section, and subsection. These five classification categories have become the fundamental basis for national and regional soil erosion regionalization.

The soil erosion zone is divided by the driving forces of erosion and the bioclimatic zones, according to the principle that topographic features and natural forces (e.g., water, and wind) are the main elements that cause large-scale soil erosion in many regions of China. The three soil erosion regions (the water erosion region, the wind erosion region, and the freezing-melting erosion region) were divided by Xin and Jiang (1982). Xinjiang, the Hexi Corridor of Gansu, the Qaidam Basin of Qinghai and the sandy areas of Ningxia, the northern area of Shaanxi, Inner Mongolia, and the western area of northeast China are all part of the wind erosion region. The Tibetan Plateau, glacier ar-



Legend and brief explanation

Region name		Legend	Degree of water erosion	Degree of wind erosion	Brief explanation of erosion status
I Regions with dense vegetation	Upland grassland	I_{a}	5(3)	5	Water erosion and wind erosion are weak, water erosion is severe in fewer regions.
	Forest region (in the stone-hilly zone)	I_{b1}	5(3)	5	Water erosion and wind erosion are weak, water erosion is severe in fewer regions.
	Forest region (in the loess hilly zone)	I_{b2}	5(3)	5	Water erosion and wind erosion are weak, water erosion is severe in fewer regions.
II Regions with sparse vegetation	Alluvial plain	II_{a}	5	4(2)	Surface erosion and gully erosion are weak, wind erosion may considerably effect the productivity of agriculture.
	Stone-hilly	II_{b}	5(3)	5	Water erosion produces a lot of gravels, which is a main source of bed load sediment of river;the wind erosion is weak.
	Arid steppe	II_{c}	5	4(2)	Both water erosion and wind erosion are weak, but some regions have the same soil erosion status with aeolian sand region because of over-grazing, firewood over-collection,over-cultivation and vegetation destruction
	Aeolian sand region	II_{d}	5	2	Water erosion is weak, but wind erosion is very severe which causes farmland degradation, sand moving southward and destruction of the farmland with high productivity.
	Loess terrace	II_{e}	3	4	Water erosion is severe, wind erosion may considerably affect the productivity of agriculture.
	Loess plateau	II_{f}	2(1)	3	Water erosion is very severe, which is extreme in fragmental plateau, wind erosion considerably affect the productivity of agriculture.
	Loess hilly II_{1} 1st sub zone	II_{g1}	1	2(3)	Wind erosion is very severe, which considerably affect the productivity of agriculture.
	Loess hilly II_{1} 2nd sub zone	II_{g2}	2	3	Compared to II_{g1} it has less steep slope land and low reclamation index, a part of the sloping field is terraced field;water erosion is very severe, wind erosion may considerably affect the productivity of agriculture.
	Loess hilly II_{1} 3rd sub zone	II_{g3}	2	3	Compared to II_{g2} it has less steep slope land and most of the sloping field is terraced field, reclamation index is between $\mathrm{II}_{g1}$and II_{g2}.
	Loess hilly II_{1} 4th sub zone	II_{g4}	4	2(3)	Precipitation is less than 300mm, steep slope land is as much as II_{g3},the reclamation index is low, moderate water erosion and very severe wind erosion.
	Loess hilly II_{1} 5th sub zone	II_{g5}	2(4)	2	Reclamation index is low and animal husbandry has a quite proportion,water erosion is severe,but the water erosion is moderate and the wind erosion is severe in the northwest.

The degree of water and wind erosion: 1.Extremely severe; 2.Very severe; 3.Severe; 4.Moderate; 5.Weak

Boundary of the interior regions

Boundary of the main watershed

Fig. 5.1 Soil erosion regions in the middle reaches basin of Yellow River (Huang, 1955, with permission from author) eas, uplands and the high mountainous areas of Xinjiang, Gansu, and Yunnan are all part of the freezing-melting erosion region. The other parts of mountainous and hilly areas of China are part of the water erosion region. Water erosion regions are distributed on the eastern part along the Da Xing'anling, Yinshan and Helan mountains as well as the Qinghai-Tibetan Plateau. The water erosion region includes six subregions, i.e., the Loess Plateau, the low hilly and mountainous areas in northeast China, the mountains and hills of north China, the mountains and hills of the south China, the Sichuan Basin and its surrounding hills and lowland area, and the Yunnan-Guizhou Plateau. The national soil erosion zones described in the "Standards for classification and gradation of soil erosion" enacted by the Ministry of Water Resources in 1997 (MWR, 1997), and the National Ecological Environment Improvement Plan issued by the State Council of China in 1998 applied the erosion regionalization described in Table 5.1.

Table 5.1 National water erosion regions (MWR, 1997)

Region	Scope and features
Loess Plateau in Northwest China	The eastern side of the Da Xing'anling, Yinshan and Helan mountains, the eastern edge of the Qinghai-Tibetan Plateau, and the Riyue Mountains of Qinghai are the western border, the Helan Mountains are the northwestern border, the Yinshan Mountains are northern border, the Guanqin Mountains and the Taihang Mountains are the eastern border, and the Qinling Mountains are the southern border. The Great Wall forms the center line, the northern part is the Ordos Plateau, and the southern part is the Loess Plateau. In the early and middle periods of the late Pleistocene, aeolian loess approximately 100–200 m thick accumulated on the Shaanxi-Gansu-Ningxia Basin. Since the Quaternary Period, new tectonic movement has largely occurred by means of intermittent uplift. The basin became the Loess Plateau. Zonal soil types from west to east are grey drab soil, black loam soils and drab soil in the sub-humid climatic zone, and grey calcium soil, brown calcium soil and chestnut soil in the arid and semi-arid climatic zones. Soil erosion on the Loess Plateau is extremely severe. Among the nine sub-regions, the loess hilly and gully sub-region and the plateau gully sub-region have the most severe soil erosion. An 110,000 km^2 area in the Hekou-Longmen catchment section of the Yellow River is the most severely eroded region and the main source of coarse and silt sedimentation in the Yellow River. The main watershed covered is the middle reaches of the Yellow River.
	The southern part of Jilin Province is the southern border and the Changbai, Da Xing'anling, and Xiao Xing'anling mountains are the borders in the other three directions.

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Region	Scope and features
Black soil region (low mountains and hills and the rolling hill region) in northeast China	Songnen Plain is a rolling hill region. The topography of the diluvial and alluvial piedmont tablelands of the extension of the Da Xing'anling and Xiao Xing'anling mountains inclines roughly from northeast to southwest, interspersed with hilly ridges. The main geographic feature of this area is gullies alternating with hillocks. The typical well-developed black soil on the sandy shale on the second tableland of the Songhua River is eroded (moderately to severely). Northeast rolling hills and adjacent areas include (i) The Da Xing'anling and Xiao Xing'anling mountainous area which is part of the forest zone. The third uplift zone of the geologic Neocathaysian structure is where granite and shale predominates and dark brown soil is developed. Soil erosion is slight to moderate. (ii) The hilly areas of the Changbai-Qianshan Mountains are composed of forest and grassland. Granite, shale, and gneiss predominate, and dark brown soil and brown soil are well developed. Soil erosion is slight to moderate. (iii) The Sanjiang Plain area (alluvial plain of the Heilongjiang, Wusuli and Songhua rivers). Ancient riverbeds and low hillocks form a natural mound. Swamp meadows prevail in the bottomlands between rivers with plains distributed between them. Soil erosion is slight. The main watershed is Songhua River basin.
The earth-rock mountainous regions in north China	The rolling hills of northeast China are the northern border, the Loess Plateau is the western border, the Huaihe River is the southern border, and the region includes the southern part of northeast China and parts of Hebei, Inner Mongolia, Henan, and Shandong. The Taihang Mountain area is part of the warm temperate and subhumid zone and includes the Wutai, Xiao Wutai, Taihang, and Zhongtiao mountains, and the headwaters of five branches of the Haihe River. The area is mainly composed of gneiss and carbonate rocks. Brown soil is the main soil type. It has moderate to severe erosion and is the most seriously eroded region in northern China. The western Liaoning and northern Hebei mountainous area. Brown soil and chestnut soil are well developed on granite, gneiss, and sandy shale. Debris flows occur frequently. Soil erosion in the Chaoyang region is the most serious. The entire region suffers from moderate erosion. The hilly area of Shandong (located on the Shandong Peninsula). Thin brown loam soil and brown soil are well developed on gneiss, granite and other rock types, particularly in the Yimeng Mountains. Soil erosion is moderate. The Altai Mountain area is located on the southern slopes of the Altai Mountains in Xinjiang and is a part of the Irtysh River watershed where alpine forest-steppe is the main vegetation. Soil erosion is slight.

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Region	Scope and features
	Songliao Plain is the alluvial plain of the Songhua River and Liaohe River, excluding the Horqin Sandland. Thick black calcium soil and meadow soil are well developed. Soil erosion is slight in the lower hillocks. The Huang-Huai-Hai Plain. The alluvial plain of the Yellow River, Huaihe River and Haihe River. The Taihang and Yanshan mountains are the northern border and the Huaihe River and Hongze Lake are the southern border. Only slight erosion occurs in the hillock areas of ancient riverbeds. The main areas include the middle and lower reaches of the Yellow River, and the Huaihe and Haihe River watersheds.
The red soil hilly regions in south China	Dabie Mountain is the northern border, the Bashan and Wushan mountains are the western border (including the whole of western Hubei), the Yunnan-Guizhou Plateau is the southwestern border (including western Hunan and western Guangxi) and this region extends to the sea in the southeast, including Taiwan, Hainan Island and islands in the South China Sea. Zonal red and yellow soils are widely distributed in tropical and subtropical regions throughout the country, as well as purple soil and limestone soils. Soil minerals weather strongly under high temperature and humidity conditions. The hilly mountain area of the southern Yangtze River region is situated in the southern part of the Yangtze River with the Nanling Mountains as the southern border and the Yunnan-Guizhou Plateau as the western border, including the Mufu, Luoxiao, Huangshan and Wuyi mountains. Granite and clastic rocks constitute the mountains and hills, and small red basins are distributed between mountains and hills. Red soil, yellow soil, and paddy soils are well developed. The plain and hill region in Lingnan includes Guangdong, Hainan Island and eastern Guangxi. Latosolic red soil is well developed on granite and sandy shale, and a thick weathered granite layer exists in some parts. Serious collapsed erosion occurs. The plains area in the middle and lower reaches of the Yangtze River is located in the eastern area from Yichang, including the Hubei and Hunan plains, the Poyang Lake plain, Taihu Lake plain, and the Yangtze River delta plain. Soil erosion is slight. The main scope is the middle reaches of the Yangtze River and the Hanshui River basin, Dongting Lake and the Poyang Lake watershed as well as the middle and lower reaches of the Pearl River.

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Region	Scope and features
The earth-rock mountainous regions in south-west China	The Loess Plateau is the northern border, the red soil hilly region is the eastern border, and the Qinghai-Tibetan Plateau freezing-melting region is the western border. The region includes the Yunnan-Guizhou Plateau, the Sichuan Basin, and western Hunan and western Guangxi. It is located in the sub-tropical zone. In addition to carbonate rock, there are also granite, purple sandy shale, mudstone, limestone, etc.
	The region is characterized by tall mountains and steep slopes, more stones and less earth, high temperatures and abundant rainfall, karst landforms, and collapsed rocks. Landslides and debris flows occur widely and frequently.
	The Sichuan hilly mountainous area is also known as the Sichuan Basin. In addition to the Chengdu Plain, most of the area is covered by mountains and hills where purple-red sandy shale and clay shale predominate. Paddy soils such as purple soil and purple clay soil are typically well developed. The region is seriously eroded and debris flows occur frequently. It is one of the main silt production sources in the upper reach of the Yangtze River.
	The mountainous areas of the Yunnan-Guizhou Plateau include the Xuefeng, Dalou, Wumeng and other mountains. Loess, red, and yellow-brown soils are typically well developed on carbonate rocks and sandy shale. A thin soil cover and exposed bedrock are the main surface features. Calcium soil is distributed in the plain regions. Karst landforms are the primary erosion mechanism. Soil erosion is slight to moderate.
	The Hengduan Mountain area includes the mountains and valleys of southern Tibet, the Hengduan and Wuliang mountains and the Xishuangbanna region. Loess, red, and dry red soils are typically well developed on metamorphic, granite, and clastic rocks. Soil erosion is slight to moderate and serious debris flows occur locally.
	The Qinling and Dabie mountains and the western Hubei mountainous regions are located between the Loess Plateau and the Huang-Huai-Hai Plain in the north and Sichuan Basin and the middle and lower reaches of the Yangtze River Plain in the south. Thick yellow brown soil is typically well developed on the light metamorphic and granite rocks. Soil erosion is slight.
	The western Sichuan alpine meadow region includes the Daliang, Honglai, Daxueshan and other mountains composed primarily of clastic rocks. Brown loam soil and brown soil are well developed. Soil erosion is slight to moderate.
	The main scope is the upper and middle reaches of the Yangtze River and the upper reach of the Zhujiang River.

5.1.2 Regional characteristics (Tang et al., 2004)

Considering that desertification caused by water erosion primarily occurs in arid and semi-arid areas in northern China, this chapter only describes the Loess Plateau, the northeast black loam plain region and the northeast rock mountainous region.

5.1.2.1 Loess Plateau in Northwest China

The Loess Plateau, located on the upper and middle reaches of the Yellow River, includes the western Taihang Mountains, the eastern Helan Mountains, the northern Qinling Mountains and the southern section of the Great Wall of China. The total area is 480,000 km^2. During the national "Seventh Five-Year Plan" (1986 to 1990), the integrated management and development of the Loess Plateau was incorporated into the National Key Science & Technology Research strategy. Taking into account the need for land reclamation and disaster control for the Yellow River, its northern boundary was extended to the southern slope of the Yinshan Mountains, including adjacent areas of northern part of the Loess Plateau, covering a total area of approximately 624,000 km^2, which is known as the Loess Plateau region. Approximately 560,000 km^2 of the total area is located on the upper and middle reaches of the Yellow River between Longyangxia in Qinghai Province and Taohuayu in Henan Province; the remaining 60,000 km^2 is located in the adjacent Haihe River valley. The geographic location of the Loess Plateau is $33°43'$–$41°16'$ N and $100°54'$–$114°33'$ E and stretches across seven provinces and autonomous regions which are Shaanxi, Gansu, Qinghai, Shanxi, Ningxia, Henan, and Inner Mongolia, and 286 counties with a total population of 81 million people (1985).

Based on regional differences in erosion factors and erosion types and intensity, the zoning of soil erosion for the Loess Plateau can be divided into three classes: region, district, and subdistrict. Following comprehensive debate on relevant research, the regional soil erosion characteristics and approaches to erosion control in the Loess Plateau region have been summarized below.

(i) Loess Plateau soil erosion classification and characteristics

From the early 1950s to the period of the Seventh Five-Year Plan (1986 to 1990), the experience and progress of soil and water conservation, especially the massive data accumulated in hydrological stations constructed along the Yellow River valley region, provided significant scientific and practical data for the classification of soil erosion.

A large amount of survey and research data including the background environmental status described above were used to develop the erosion types and intensity levels, also considering the demand for sustainable development of resources in the Loess Plateau region. The principles of soil erosion classification must not only reflect regional differences of soil erosion, but also serve soil and water conservation regionalization and planning requirements.

The principles must also take into account the interdependence between soil erosion control and resource exploitation, and environmental protection and industrial development as well as transitional relationships between water erosion and wind erosion at regional levels.

Tang and Chen (1990), based on their long term field observations and studies on general zonation differences of water erosion and wind erosion, identified that the overlying water and wind erosion belt had particular erosion characteristics which have great significance for the sustainable resource management and development of the Loess Plateau region. Moreover, they classified this belt as a complex water and wind erosion region. Yiduan Huang and Pincang Zhang developed a specific three-class system for soil erosion classification of the Loess Plateau region, i.e., region, district, and subdistrict. Based on intra-regional similarities and inter-regional differences of geomorphology, erosion force, type and intensity, and the development trends and management approach, the former two classes are generally used, while the third class is only used in combination with erosion types for large area erosion regions (Table 5.2) (Tang and Chen, 1990).

Table 5.2 Soil erosion classification of the Loess Plateau region (Tang and Chen, 1990)

Region	District	Subdistrict
I Wind erosion on Ordos Plateau	I_1 Slight wind erosion district in the Helan Mountain area	
	I_2 Slight wind erosion district in the Yinchuan Hetao Plain	
	I_3 Moderate wind erosion district in the foothills of the southern Yinshan Mountains	
	I_4 Severe wind erosion district at the southern edge of the Tengger Desert	
	I_5 Extremely severe wind erosion district in the Hedong Sandland	
	I_6 Severe wind erosion district in the Mu Us Sandland and the Qubqi Desert	
II Complex wind and water erosion districts in the northern part of the Loess Plateau	II_1 Slight wind and water erosion district in the northern Shanxi Basin	
	II_2 Slight wind and water erosion district in the eastern Qinghai Mountains	II_{2a} Daban and Laji mountains subdistrict II_{2b} Yellow River-Huangshui River valley subdistrict
	II_3 Moderate wind erosion and slight water erosion district in the low Mountains and hills of southern Ningxia and central Gansu	

Continued

Region	District	Subdistrict
	II_4 Slight wind erosion and severe water erosion district in the low mountains and hills of southern Ningxia and eastern Gansu	II_{4a} Huang County subdistrict II_{4b} Liangxi subdistrict
	II_5 Moderate wind and severe water erosion district in the gentle hills of northwestern Shanxi Province	
	II_6 Moderate wind erosion and extremely severe water erosion district in the loess hills of northern Shaanxi Province	II_{6a} Baiyu Mountain subdistrict II_{6b} Suide-Mizhi subdistrict
	II_7 Severe wind and water erosion district in the sandy loess hills of Shanxi, Shaanxi, and Inner Mongolia	
III Water erosion areas in the southern part of the Loess Plateau	III_1 Slight water erosion district in the mountains of Shaanxi and Gansu provinces	III_{1a} Guan-Long Mountain subdistrict III_{1b} Northern slope of Qinling Mountains subdistrict
	III_2 Slight water erosion district in the Huanglong and Ziwuling mountains	
	III_3 Slight water erosion district in the valleys along the Fenhe River and the weihe River	
	III_4 Slight water erosion district in the Taihang Mountains	
	III_5 Slight water erosion district in the Luliang Mountains	
	III_6 Slight water erosion district in the valleys and hills of southeastern Shanxi Province	
	III_7 Slight water erosion district in the loess tablelands and low mountains of western Henan Province	
	III_8 Moderate water erosion district in the basins and valleys of central Shanxi Province	
	III_9 Moderate water erosion district in earth-rock hills and low mountains of western Gansu Province	

Continued

Region	District	Subdistrict
	III_{10} Severe water erosion district in the loess hills of western Gansu Province	
	III_{11} Severe water erosion district in the loess tablelands of Shaanxi and Gansu provinces	
	III_{12} Severe water erosion district in the loess hills and relic tablelands of northern Shaanxi and western Shanxi provinces	$\text{III}_{12\text{a}}$ Liulin-Yanchuan subdistrict $\text{III}_{12\text{b}}$ Jixian-Yichuan subdistrict

(ii) Outline of soil erosion classification for the Loess Plateau region (Tang et al., 2004)

i) Wind erosion on the Ordos Plateau (I)

The Ordos Plateau is surrounded by Helingeer County and Dongsheng City in Inner Mongolia to the east, Yulin City in Shaanxi Province, and the Helan Mountains to the west, the Yinshan Mountains to the north and the Great Wall to the south. The plateau includes the Mu Us Sandland and the Qubqi Desert, the Hedong Sandland, Yinchuan Hetao Plain and parts of the neighboring mountainous areas. This region is characterized by a desert landscape, arid climate, high transpiration rate, and limited annual precipitation (below 300 mm). Annual days with greater than or equal to force 8 winds (on the Beaufort Scale) can exceed 20 days (even 40 days or more in some districts). Annual dust or sandstorm days are 10 days or more (a maximum of 27 days in some districts). The vegetation is composed of desert steppe. Land management is focused on animal husbandry. Overgrazing can have serious consequences such as steppe degradation, wind erosion and a high rate of desertification spread.

According to the intensity of wind erosion and its particular characteristics, this region can be divided into six erosion districts.

The I_4 and I_6 districts are characterized as having severe or extremely severe wind erosion, and cover the edge of the Tengger Desert, the Mu Us Sandland, the Qubqi Desert and their marginal areas. Large areas of shifting sand and mobile dunes and the reactivation of fixed dunes have resulted in the expansion of desertification to the southeast. Establishment of artificial plantations of sand-fixing plants in Shapotou of Ningxia, for example, has successfully controlled desertification in that region. Taking full advantage of the fields on the plain along the Yellow River valley and the exploitation and utilization of groundwater resources, managed irrigated farming and fruit orchards have become the main agricultural activities in the region. The establishment of windbreaks, sand-fixation vegetation belts and the improvement of natural rangeland should also be promoted.

Districts classified as I_1, I_2, and I_3 are slightly or moderately eroded by wind. Wind erosion in the piedmont hills and the basins near the Helan and Yinshan mountains as well as the Yinchuan Hetao Plain is not severe. The management focus should be on the protection of existing vegetation. Moreover, the advantages of the Yinchuan Hetao Plain irrigation areas should be fully developed for sustainable agriculture.

The Hedong Sandland district (I_5) is extremely eroded by wind. Animal husbandry is the main economic activity, and population growth has resulted in serious over-cultivation and overgrazing, leading to a significant expansion of land desertification and the occurrence of severe wind erosion. The main tasks are to protect and improve rangeland and to control land degradation.

ii) Complex wind and water erosion districts in the northern Loess Plateau (II)

This region is broadly located with the southern boundary of the Great Wall and the northern area along Shenmu and Suide counties of Shaanxi Province; Yanchi, Lingwu, Xingxian and Guyuan counties of Ningxia Autonomous Region; and Qingyang, Dingxi and Dongxiang counties of Gansu Province. The geomorphology is mainly sand-covered loess ridges, hills and gullies. The underlying strata is mainly composed of aeolian sand, sandy loess, and severely weathered and denuded sandy shale.

The region is part of the semi-arid steppe zone and is covered with sparse vegetation where natural rangeland is mostly desertified and degraded. The annual precipitation is 250–450 mm. Water erosion is more prevalent during the summer and autumn seasons while wind erosion occurs in the winter and spring seasons. The total annual number of windy days greater than or equal to force 8 on the Beaufort scale (a fresh gale) are 5–20 days (up to 27 days in some districts). The mean annual days of sandstorms are more than 4 days (15 days in some districts). Water and wind erosions occur alternately throughout the year in the region. The ecological environment is vulnerable, and the erosion that affects the districts of the Loess Plateau is also the main source of coarse sand and silt sedimentation in the downstream riverbed region of the Yellow River.

This region is divided into seven districts and six subdistricts. Regional differences in characteristics are basically divided into three categories. The first category includes wind and water erosion, but the intensity is slight to moderate; the second category borders the water erosion area where intensive water erosion prevails with slight wind erosion; and the third category exhibits intensive wind and slight water erosion processes.

The districts in the first category include the northern Shanxi Basin (II_1) and the east section of the Qinghai Mountain basin valley (II_2) where slight wind and water erosions occur, and the low mountain hilly and gully district in southern Ningxia and the central part of Gansu (II_3) where moderate wind erosion and slight water erosion occur.

The two districts (II_1 and II_2) mentioned above have many basins, valley plains, or earth and rock mountain configurations. The annual precipitation is

300 mm to 400 mm, and the climate is dry and windy. Arable land is mostly located on flat depressions and basin and valley areas where gentle terrains have been affected by slight water erosion. Irrigation conditions also exist in some areas. Natural grazing lands are protected at certain scales, and forests are distributed on the shady hill slopes.

Due to topographic conditions and erosion types, the mountain basin valley districts in eastern Qinghai can be divided into two subdistricts. First is the Yellow River-Huangshui River valley subdistrict where the primary landscape type is farmland with gully and gravity erosion formations in the key cropland areas. The other is the Daban and Laji mountains subdistrict where farmland practices and freezing-melting processes have caused slight erosion to the landscape.

Another district (II_3) is the low mountain hilly and gully areas of southern Ningxia and the central part of Gansu, including all or parts of Lanzhou, Baiyin, Gaolan, Yongdeng, Yongjing, Jingyuan, and Jingtai counties in Gansu Province as well as Tongxin and Haiyuan and other counties (cities) of the Ningxia Hui Autonomous Region. Annual precipitation in the subdistrict is less than 300 mm where stronger winds and serious drought occur. Vegetation coverage is very low and the majority of vegetation is grasses and shrubs. The protection and reintroduction of grasses and shrubs are the key control measures to mitigate drought and control erosion.

The second category in this region includes slight wind erosion and intensive water erosion in the low mountain hilly district in eastern Gansu Province and the southern Ningxia Hui Autonomous Region (II_4); moderate wind and severe water erosion in the gentle hilly plains district in northwestern Shanxi Province (II_5); and moderate wind erosion and extremely severe water erosion of the loess hill district in northern Shaanxi Province (II_6).

In these districts, severe water erosion is the result of sloping farmland erosion caused by deforestation, grassland degradation, and the inappropriate cultivation of hill slopes, as well as gully erosion in the gully tablelands and gravity erosion on the valley slopes. The erosion modulus is typically between 5,000 and 10,000 $\text{t}\cdot\text{km}^{-2}\cdot\text{a}^{-1}$. An important reason for the accelerating water and wind erosion is the lack of the “three materials” (fuel, feed and fertilizer) which leads to the destruction of vegetation. The Baiyu Mountain subdistrict ($\text{II}_{6\text{a}}$) in the II_6 district is the river source for the Wuding, Luohe and Yanhe Rivers. In addition to slope farmland erosion, gully and gravity erosion are also active while wind erosion is relatively strong. Consequently, the terrain is often covered with aeolian sand and the erosion modulus has increased to 10,000 to 15,000 $\text{t}\cdot\text{km}^{-2}\cdot\text{a}^{-1}$. Slope farmland management should therefore be prioritized, and, at the same time, catchment dams and ponds for watershed management should be constructed.

The third category in this region is the severe wind and severe water erosion located in the sandy loess hills in Shanxi, Shaanxi, and Inner Mongolia (II_7).

This district borders both sides of the Shanxi-Shaanxi Gorge of the Yellow River and along the northern periphery of the Great Wall, including all or parts of Shenmu, Fugu, Jiaxian, Hequ, Baode, Pianguan, Xingxian, Junggar, Dongsheng, Qingshuihe and other counties (banners).

The two landform types in the district are sandy loess hills or loess hills covered with sand. This district is located within the transitional zone between the Ordos Plateau and the Loess Plateau as well as between the arid and semi-arid bioclimatic transitional zones and between the water and wind erosion eco-zones. Agriculture and animal husbandry are the common land uses in the area. Climate change is severe in the district due to the transitional zones, and consequently, it is a typically vulnerable ecological zone.

The mean annual precipitation is 400 mm and the rainfall distribution is typically uneven within the year and between years. Strong wind conditions, dust storms, droughts, floods, and hail storms frequently occur. Soil erosion is active throughout the year while wind erosion occurs mainly in the winter and spring seasons. Denudation is severe and severe water erosion frequently occurs in summer and fall seasons. Wind and water erosions are due to both superposition and interactive acceleration leading to an increase in erosion where the erosion modulus reaches 15,000 to 20,000 $\mathrm{t{\cdot}km^{-2} \cdot a^{-1}}$. The district experiences the majority of severe erosion conditions in the Loess Plateau.

The district was a key pastoral area in the past and was once densely vegetated with grasses and shrubs. However, population growth and inappropriate agricultural practices and overgrazing are leading to transition zone vulnerability, and subsequently, the rapid deterioration of the ecological environment. This district contains abundant coal resources, and three large coalfields are presently under exploitation in Hedong, Shenfu, and Dongsheng counties where the largest coal deposits are found. They will be developed in China as energy and chemical industry bases in the 21st century.

Severe water and wind erosion in the border areas of Shanxi, Shaanxi, and Inner Mongolia are not only key sand sedimentation sources for the Yellow River, but also an important constraint for coal mining and the development of agriculture, forestry, and animal husbandry. This district has been listed as a priority area that should be given primary importance for the sustainable development of the Loess Plateau.

The coalfield development project was officially launched in 1987. This state scale project has not only promoted the development of the coal mine industry, migration from rural to urban areas, and the rapid development of railways and highways, but has also targeted the demand for local environmental and agricultural improvement as well as a need for sideline product development. These new situations and perspectives are helpful in developing soil and water conservation to reach to new level of sustainability, accelerating water and wind erosion control and ecological improvement. However, these developments have also caused further soil erosion and environmental deterioration by means of coalfield development.

iii) Southern Loess Plateau water erosion region (III)

The northern section of this region is connected to the wind and water erosion eco-zone while the southern section extends to the northern slopes of the Qinling Mountains. Landform types are complex, such as loess hills, loess tableland, river valley plains, earth and rock hills, and mountains. Annual precipitation varies from 500 mm to 700 mm. The climate is warm and humid. Forest and forest steppe are the main landscape types.

Slight water erosion areas are distributed throughout the mountainous and tableland areas while flat plain areas are typically covered with vegetation. Moderate water erosion areas mainly occur alongside valleys, on earth and rock hills, and lowlying hills. The most severe water erosion areas are distributed on the loess hills. Twelve erosion districts and four subdistricts have been identified according to topography, vegetation, land use, and erosion intensity. They can be divided into four categories.

The first category comprises of the mountainous areas which are well covered with vegetation and shrubland and experience slight water erosion. This includes the water erosion mountain district in Shaanxi, Gansu Provinces (III_1), the slight water erosion district of the Huanglong and Ziwuling mountains (III_2), the slight water erosion district of the Taihang Mountains (III_4), and the slight water erosion district of the Luliang Mountains (III_5).

This category is primarily composed of rocky mountains with some loess hills. Annual precipitation is abundant, varying from 600 mm to 700 mm, while the climate is warm and humid. The region is primarily covered by natural secondary forest or dense forest and shrub vegetation. Water erosion is slight and the erosion modulus is typically less than 1,000 $t{\cdot}km^{-2} \cdot a^{-1}$.

With population growth and migration into the forested regions, forest vegetation has become severely damaged and the cultivation of crops on steep slopes has led to accelerated erosion where frequently occurring mountain torrents and debris flows have been the result. In the forest region of the loess hills on Ziwuling Mountain where deforestation and grassland degradation are severe, the edge of the forest region has receded 20 km in approximately 30 years, leading to the rapid acceleration of soil erosion processes. The protection of the remaining vegetation should be strengthened while deforestation should be strictly controlled. Moreover, forest conservation in these mountain forest regions and the secondary forest regions of loess hills should be continuously supported while existing forests and woodlands must be enclosed to prevent further deforestation.

The second category has slight water erosion, and primarily consists of gentle tablelands, plains, and flat fields. These include: the slight water erosion valley district alongside the Fenhe River in Shanxi Province and the Weihe River in Shaanxi Province (III_3); the slight water erosion districts in the basin valley hilly areas in southeast Shanxi Province (III_6); and the loess tablelands and low mountain district in western Henan Province (III_7).

The main land use in this category is farming. The farmlands that suffer from slight erosion are distributed throughout the gentle flat lands or tablelands which in some areas can be irrigated. Erosion occurring on the side slopes of the tableland and the broken tableland gullies is severe. Erosion developed after brushland and vegetation on local hills were destroyed. Terraced lands on hills should be protected while irrigation projects should be installed to make full use of potential productive land. At the same time, biological and engineering measures to protect tablelands and control gullies should be adopted.

The third category is the moderate water erosion districts of the basin valley hilly region, including the moderate water erosion district of the basin valley hills in central Shanxi Province (III_8) and the moderate water erosion district of the earth rock hills and low mountains in western Gansu Province (III_9).

Most farmland in this category is distributed throughout the tablelands, river valleys, and gentle slopes of hills. Erosion in this region is relatively minor. Gully and gravity erosions usually occur on broken tablelands. The erosion modulus is greater than 2,500 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ and can reach 5,000 $\mathrm{t{\cdot}km^{-2}{\cdot}a^{-1}}$ in the earth-rock hilly region of western Gansu Province. Land management practices should be used to improve the construction of basic farmlands so that vegetation is reintroduced to degraded grasslands and degraded shrublands and the further protection of existing forests in the gully and gravity erosion affected areas is enhanced.

The fourth category is the severe water erosion districts of the hilly and gully region of the Loess Plateau, including the severe water erosion district of the loess hills in western Gansu Province (III_{10}), the severe water erosion district of the loess tableland in Shaanxi and Gansu provinces (III_{11}), and the severe water erosion district of the loess hills and the broken tablelands in northern Shaanxi and western Shanxi provinces (III_{12}).

Inappropriate cultivation practices and grassland destruction have led to deforestation and sparse vegetation in the region. Erosion primarily occurs on farmland slopes. The gully density is 3–5 $\mathrm{km{\cdot}km^{-2}}$ where gully erosion has obviously occurred. Landslides, collapses, and other gravity erosion events often take place, particularly on the broken tablelands in the gully region. The erosion modulus is 5,000 to 10,000 $\mathrm{t{\cdot}km^{-2} \cdot a^{-1}}$.

Reintroducing vegetation to steeply sloping land is the key control measure. This includes leveling land on tablelands and basic farmland operation as well as the protection of tablelands and the control of gully erosion. Gully erosion control should be combined with the installation of dams or reservoirs as well as the reintroduction of vegetation. Moreover, cash crop plantations and reforestation to target ecological efficiency and economic benefits should be prioritized. For example, gully slope management in the Luochuan and Changwu uplands has occurred by means of reforestation on a large scale through the plantation of apples, pears, and other fruit trees as well as cash crops.

5.1.2.2 Northeastern low hilly mountains and undulating hilly region

The southern boundary of this region extends to the southern section of Jilin Province while the eastern, western, and northern sections are surrounded by Da Xing'anling, Xiao Xing'anling, and Changbai mountains. Soil erosion occurs to some extent in the region beyond the Heilongjiang, Songhuajiang, and Nenjiang river plains and the forested area of the Da Xing'anling Mountains and the Xiao Xing'anling Mountains. Based on landforms and erosion types, the region can also be divided into four districts: the Da Xing'anling Mountain district, the Xiao Xing'anling Mountain district, the low hilly mountain district, and the undulating hilly district.

(i) Da Xing'anling Mountain district

The geological formation of the district is the third uplift belt of the Neocathaysian system that primarily consists of volcanic rock. The topography is high in the western and northwestern areas and low in the eastern and southern areas where the elevation ranges from 300 m to 1,400 m. Undulating mountain formations are mostly surrounded by low mountain hills and broad valleys. The district is part of the frigid temperate climate zone where the summer season is short and the winter season is long and cold.

The Da Xing'anling Mountains in Heilongjiang Province cover a total area of 84,700 km^2, of which 72,800 km^2 is affected by potential soil erosion. The soil erosion area is 25,300 km^2 (or 29.9% of the total land area), of which 379 km^2 is severe, 583 km^2 is moderate, and 24,370 km^2 is slight, accounting for 1.5%, 2.3%, and 96.2% of the total erosion area, respectively. The primary erosion types include gravel surface erosion, rill and gully erosion, river course erosion, collapse, slump, and freezing-melting process erosion.

Unsustainable forest cutting and bushfire practices have led to further erosion and flood damage in the district. According to local records, during the 32-year period between 1955 and 1986, only eight floods took place causing moderate damage, but during the five-year period from 1987 to 1991 (including the infamous "May 6th" bushfire), three severe floods took place causing massive damage. The extreme flooding seen in 1991 was especially severe in comparison to historical records where Tahe City in Heilongjiang Province was washed away leading to 130,000 people homeless with an associated economic loss estimated at 510 million RMB.

In this region, outcrops of sandstone caused by soil erosion from burning and cutting activities have led to an area of 379 km^2 of open deforested land and sloping farmland where debris and mudflows frequently occur in steeply sloping areas. In addition, collapsed riverbanks and soil roughness on sloping farmland are under serious threat of soil erosion as the erosion modulus of sloping farmland is between 5,000 and 8,000 $\text{t}\cdot\text{km}^{-2}\cdot\text{a}^{-1}$, and exceeding 9,000 $\text{t}\cdot\text{km}^{-2}\cdot\text{a}^{-1}$ in some seriously affected areas.

(ii) Xiao Xing'anling Mountain district

The Xiao Xing'anling Mountain district is located in the northern part of Heilongjiang Province with a total area of 115,000 km^2. The mountain range extends from southeast to northwest, and the elevation ranges from 250 m to 1,000 m. Broad mountain topography, gentle slopes, and low mountain hilly regions account for 85.3% of the total land mass while pediment tablelands cover 12% and alluvial plains cover 2.7%. The mean annual precipitation is 523 mm. Although forest coverage is greater in this district, the risk of soil erosion prevails in many hilly regions where flood events are frequent natural disasters. For example, in the forest region in Yichun County six floods took place in the 1980s that have caused a direct economic loss of approximately 400 million RMB.

According to a survey done in 1985, the area of soil erosion in the Xiao Xing'anling mountain region was 2,480,900 ha, accounting for 21.55% of the total land area, of which 1,250,900 ha was farmland, 21,100 ha was wasteland, and 1,208,900 ha was woodland and forestland. Rill erosion has occurred on sloping farmland, and fish-scale erosion has occurred in the wasteland areas covered by sparse vegetation. Gully erosion prevails alongside unsealed roads of the logging area, and landslides occur along riverbanks.

The Da Xing'anling and Xiao Xing'anling mountains are important timber bases in northeastern China, an area where forest resources should be continuously supported and illegal cutting should be strictly prohibited. The prevention of bushfires and gully erosion caused by unsealed roads must be undertaken, and a monitoring network should be established.

(iii) Low hilly mountain district

This district contains the central and eastern sections of Jilin Province, the Tangwang River valley located in the southern Xiao Xing'anling mountain region, the upstream region of the Woken River valley on the western periphery of the Wanda mountains, the Mudan River valley, the Mayi River valley, the Ashi River valley, and the Lalin River valley all located in the western Zhangguangcai Mountains. The elevation in the district varies from 200 m to 1,500 m.

The low mountain area is primarily composed of granite, local volcanic rock, and sandy shale. The landform of mountain summits is broad and flat. Soils with weathering crusts and humus layers are well developed. The hilly area is composed of metamorphic rock and red sandy conglomerates from the Tertiary Period with thick tectum structures. Due to a long period of development and a large amount of sloping farmland, sloping land with a gradient of more than 10° has been cultivated with a reclamation rate reaching up to 20%.

The district, however, comprises many natural secondary forests and therefore has a high coverage of vegetation. Most areas are slightly to moderately eroded by soil erosion mechanisms that prevail on land surfaces. Local gully erosion is the most serious erosion mechanism. In the Mudan River valley, the original thickness of the dark brown forest soil was 50 cm or more, and humus content reached up to 50 $\mathrm{g \cdot kg^{-1}}$. With erosion, 5 mm of topsoil has washed away annually leading to an annual topsoil loss of approximately 3,000 $\mathrm{t \cdot km^{-2}}$

to 5,000 $t\cdot km^{-2}$. In the low mountainous hills of western Liaoning Province, rainfall is scarce and the rapid development of sericulture has resulted in land degradation and desertification. Large scale sericulture has also caused serious soil erosion in the Liaohe River valley.

(iv) Undulating hilly district

The undulating hilly district is located on the alluvial and diluvial fans of the Xiao Xing'anling Mountains piedmont plains and consists of a gentle and undulating topography. The elevation is between 180 m to 300 m above sea level, the relative difference in height varies from 10 m to 40 m and the boundary between hills and mountains is visible. This district is typical of the luxuriant meadow grasslands seen in the past. The land reclamation coefficient is as high as 0.7 in the district due to reclamation during the last five or six decades, and as result, the affected area and the intensity of soil erosion are increasing and becoming widely distributed in almost 20 counties. Erosion in this district is representative of the black soil region in northeastern China.

Soil erosion is severe along the Wuyu'er and Yanlu river valleys, the Nenjiang River tributary, the Hulan River valley, the Songhua River tributary, and is widely distributed in Keshan, Baiquan, Kedong, Wangkui, Bei'an, Yi'an, Hailun, and Longjiang counties. The area of soil erosion accounts for 40% of cultivated land in Keshan and Kedong counties, 47% in Wangkui County, 56% in Baiquan County, and 80% in Longjiang County. The thickness of soil has been reduced from the original 1–2 m to 0.2–0.3 m in Keshan County.

The slope gradient is less than 7° in the undulating hilly black soil area, and most of the area slopes between 2° and 4°. The length of slope in the area for typically ranges from 1,000 m to 2,000 m with a maximum of 4,000 m. The volume of water flow is significant and the flow rate is rapid, which increases the scouring force of flooding or runoff. The cultivated black soil layer has a total porosity of 60%, and the infiltration rate of topsoil over the 0 cm to 20 cm depth is 96 $mm\cdot h^{-1}$. For many decades, under the impact of unsustainable indigenous farming practices, approximately 5 cm to 6 cm of plow pan below the fixed plough horizon was formed with a density of 1.5 $g\cdot cm^{-3}$ to 1.6 $g\cdot cm^{-3}$ and an infiltration rate of 2.5 $mm\cdot h^{-1}$ to 8.6 $mm\cdot h^{-1}$. The subsoil layer and parent material horizon of the black soil terrain are primarily composed of loessial clay which has an inherently slow infiltration rate. When the moisture content of the topsoil reaches saturation, both soil erosion on the land surface and gully erosion will result. Permafrost can linger for almost 6 months during the long and cold winters with a thickness of approximately 2 m, and consequently, a waterproof aquiclude layer within the plough layer will form. Therefore, meltwater in the spring and subsequent rainfall or runoff in summer cannot be absorbed within the short timeframe, and consequently, excessive runoff can occur on slopes and floods in the valleys may also occur, leading to soil erosion and mudslides. The rainy season in this area is in the summer when more extreme weather events occur. Rainfall events occur where 120 mm to 160 mm of precipitation may fall in one session, and on occasion, as much as 200 mm can fall in one event. The maximum rainfall intensity recorded is 1.6 mm·min^{-1}. Such concentrated rainfall and water volume has accelerated soil erosion in the black soil region in northeastern China.

The main forms of soil erosion in the district are land surface erosion, gully erosion, and wind erosion. Approximately 0.5 cm to 1.0 cm of topsoil is lost to land surface erosion each year where the erosion modulus ranges from 6,000 to 10,000 t·km^{-2} · a^{-1}. Gully erosion is closely related to the intensity and time scale of land reclamation. The average frequency of gully erosion in the southern region is higher than that in the northern region. The gully density typically ranges from 0.5 km·km^{-2} to 1.2 km·km^{-2} and the highest density is 1.61 km·km^{-2}. The annual development speed of the gully outlet averages approximately 1 m with peaks at 4 m to 5 m annually.

Long term soil erosion effects have caused the black soil layer to gradually thin and the subsoil to be exposed in some areas. On some soil types with low fertility, such as black loess soil, yellow black soil, and yellowish biological soil, a crust has formed. The deterioration of physical and chemical properties in soil causes further development of soil erosion to the point where the land is abandoned and wasted. For example, the area of abandoned barren land caused by soil erosion around Dongfeng Village in Gubei Township, Keshan County, and Jilin Province is 60 ha, and on average 6 ha to 7 ha is abandoned each year.

The black soil region of northeastern China, where landforms are primarily composed of undulating hills, plains, and platforms, is a key area for the control of soil erosion. This area mainly encompasses the eastern and northern sections of the Songnen Plain distributed between Nenjiang and Bei'an counties in Heilongjiang Province in the north, Siping County in Jilin Province in the south, the edge of Da Xing'anling Mountain in the west and Tieli City and Bingxian County in Heilongjiang Province in the east. It includes 32 counties (cities and districts) and forms an integral black soil zone. In this region, the cultivation rate is as high as 60% to 70%, and soil erosion occurs primarily on sloping terraced farmland which represents 86% of the total erosion area. Due to soil erosion and deterioration of the ecological environment, droughts and floods occur frequently and have become more serious than they were in the past. Management of sloping farmland is a key approach to controlling soil erosion in the black soil zone. Terraces should only be built on sloping farmland with a gradient of less than 15°. Infertile sloping farmland with a gradient greater than 15° must be reintroduced back into forest or grassland. Shelterbelt networks should also be established alongside these soil erosion control measures.

5.1.2.3 Mountainous hilly region in northern China

This region covers the southern undulating hilly section of northeastern China as well as the eastern section of the Loess Plateau and the northern section of the Huaihe River, including the mountainous and hilly areas where erosion prevails in the southern section of northeastern China, Hebei, Shanxi, Henan, Shandong, Inner Mongolia and other provinces and autonomous regions. The topography in this region is characterized by two specific features described below.

First, plains are typically surrounded by mountains and hills. For example, the North China Plain is surrounded by the Yanshan Mountains in the north, the Taihang Mountains in the west and a series of residual ridges formed in conjunction with the curving shape of the Qinling Mountains in the south. Similarly, the Liaohe River Plain is surrounded by the mountains in eastern and western Liaoning Province.

Second, alpine areas, low mountains, hills, valleys and plains are interspersed in terrace formations. For example, the elevation of the mountains in Weichang and Fengning counties in northern Hebei Province is approximately 1,500 m, the elevation of the mountains in Chengde and Qinglong counties is 1,000 m, and the elevation of hills and valleys in Zunhua and Qian'an is less than 500 m. The primary geomorphologic features of the Taihang Mountains in northwestern Henan Province are high and low mountains, hills and intermountain basins where the average elevation of mountains is 1,000 m to 1,500 m, the elevation of the low mountains and hills is typically 400 m to 800 m and the elevation of the Linxian depression is approximately 300 m.

These geomorphologic features suggest that water erosion, and debris flows that prevail in the mountainous and hilly areas have resulted in sedimentation of river courses and show that soil erosion and floods are related to each other. Therefore, floods that occur in the Haihe River Plains region are related to soil erosion that occurs in the Taihang Mountain region; floods that occur in the Liaohe River Plain area are related to soil erosion that occurs in the mountainous areas of eastern and western Liaoning Province; and floods that occur in the Huaihe River Plain area are related to soil erosion that occurs in the mountainous areas of eastern Henan Province.

Taking into account the various landforms in the erosion regions, including erosion formations and the differences in sediment material seen in rock mountains, earth rock mountains and loess hills, this region is characterized by soil erosion in both the earth rock mountains and the Loess Plateau in northern China. Accordingly, the region can be divided into three districts.

(i) Loess covered low mountains and hilly district

The foothills of the low mountains and the uplands of the hills are extensively covered by loess soil. For instance, the hills and piedmont plains on both sides of the Liaohe River Plain, the Taihang and Yanshan Mountains in Hebei Province, and the low mountains and hills in western Henan Province are all covered by loess soil. Further distribution of residual loess soil occurs in some valleys in eastern Liaoning Province and the Shandong Peninsula. The types of erosion in this district are similar to the Loess Plateau region. The thickness of the loess soil varies from a minimum of several meters to a maximum of twenty meters. The mean annual precipitation is 400 mm to 500 mm. Sloping farmland erosion that developed from land surface erosion and gully erosion is the primary erosion mechanism. The erosion modulus is approximately 4,000 $\mathrm{t{\cdot}km^{-2}\cdot a^{-1}}$. Soil erosion and sedimentation occur primarily during the rainy season from June to September and the most severe erosion events take place in July and August. Gravity erosion types like landslides and collapses that are the principle types of erosion on the Loess Plateau can also be seen within this district.

(ii) Rocky and earth rock mountainous and hilly district

The medium and small rock mountains or earth rock mountains and hills are covered in a thin layer of coarse soil, and are composed primarily of sandy shale, limestone, outcrops, and gravel formed under strong weathering and denudation. The bedrock is mostly exposed due to steep slopes and shallow soil layers. Following vegetation loss and heavy rains, all types of severe water erosion can occur and even debris flows can be a result. Disastrous debris flows have occurred in the Xishan Mountain range in Beijing and its adjacent districts, such as Nankou, Zhaitang, Xiangshan, Miaofengshan, and Yanqing. Evidence of ancient debris flows has been found in areas along the Luanhe River valley. For example, four large scale events took place in Luanping, Xinglong and Qinglong between 1958 and 1971. Massive debris flows have been known to wash through and clog up river courses. The riverbed of the Wulie River in Chengde City was clogged with silt between 1–3 m deep when the flood discharge capacity was reduced by one third. The riverbed of the Luanhe River has risen between 0.1 and 0.3 $\mathrm{m{\cdot}a^{-1}}$ on average, greatly reducing the flood control capacity of the river course.

Precipitation and soil erosion intensity in this district are as follows:

In the mountainous areas of Weichang and Fengning counties in Hebei Province, the annual precipitation is 400–500 mm, the mountain slope gradient is up to 30° in most areas, vegetation coverage is as high as 50% to 70% and the annual erosion modulus is 800 to 1,300 $\mathrm{t{\cdot}km^{-2}\cdot a^{-1}}$.

In areas with small mountains, the slope gradient is 20° to 30°, vegetation coverage is approximately 30% to 50%, and the erosion modulus is 1,500 to 1,800 $\mathrm{t{\cdot}km^{-2}\cdot a^{-1}}$.

In the Taihang Mountain district, medium sized mountains, low mountains, hills, basins, and valleys are interspersed and form the headwaters of the most tributaries of the Haihe River. The annual precipitation increases gradually from 500 mm to 600 mm in the southern section and from 700 mm to 1,000 mm in the northern section, where more than 80% of rainfall occurs during storms in the months from June to September. The earth rock mountainous area has an elevation of less than 800 m and has become a barren hilly area due to unsustainable human activities. It is susceptible to floods and debris flow disasters. This area is the most severe soil erosion area within the Taihang Mountain district. These remote mountains with an elevation of 800 m or more are densely vegetated and, without the burden of human economic development activity, soil erosion is slight. Reforestation and the reintroduction of vegetation and other engineering measures should be carried out in this district to increase vegetation coverage to guarantee its water storage capacity and to enhance water and soil conservation.

The headwaters of the Huaihe River are located in the Xiong'er and Funiu mountains in western Henan Province. Soil erosion occurs in some areas due to sparse vegetation. The annual erosion modulus is 1,300 $\text{t}\cdot\text{km}^{-2} \cdot \text{a}^{-1}$. This area includes the low mountains and hills of the Songshan Mountains in Henan Province, in addition to local valleys with limited secondary forest coverage. Most mountainous areas are covered in grassland and most hills have bare exposed rocks, resulting in severe soil erosion.

(iii) Severe wind erosion district on the Bashang upland,Hebei Province

The Weichang part of Bashang upland located upstream of the Luanhe River region was a luxuriant grassland in the early 1950s. Now, other than in reserved forests and orchards, severe wind erosion occurs in most sections of the district and serious desertification-prone land area covers approximately 350 km^2. There are as many as 950 sand mounds and sand pits with a volume greater than 100 m^3, and sandy areas cover approximately 67 km^2 in the severely affected areas of Yudaokou.

From the early 1950s to the end of the 20th century, the population of the Fengning part of Bashang upland has doubled. Grasslands or grazing lands have been reduced from 860,000 ha to 510,000 ha. Arable land has increased from 400,000 ha to 700,000 ha and pastures are over-grazed and over-loaded by more than 100%. Severely degraded grazing lands and sandy grasslands are the result of a sharp increase in sand-dust storm frequency and intensity, threatening the natural ecology and the living environment of Beijing, Tianjin, and the adjacent provinces and autonomous regions. The frequency and intensity of all types of natural disasters on the Fengning part of the Bashang upland, has increased from three to five events per year in the 1960s to eight events per year in the 1970s. The frost-free period has reduced from 94 to 80 days, and the number of days of strong winds has increased by up to 40%. During the last three decades, due to the ongoing destruction of vegetation, desertification processes have accelerated and started to expand in the Weichang part of the Bashang upland. The area of desertification-prone land has expanded and now occupies 36.4% of the total area of the affected lands of the county.

This district must be protected against overgrazing and over-cultivation and biological measures such as tree and grass planting should be strengthened. Windbreaks and sandbreaks to stabilize dunes and sand should also be established.

5.2 Damage from soil erosion

Long term soil erosion will result in the loss of land resources as well as the deterioration of soil quality, which may threaten local agricultural production. In addition, large amounts of sediment will be transported into valleys and will clog river courses, causing damage by contaminating rivers, catchments, reservoirs, and lakes, and eventually reducing the availability of the water resource. River courses and reservoirs become blocked with silt, which increases flooding risks and decreases the serviceability of the water system.

5.2.1 Impacts of soil erosion on land productivity

Data from the World Resources Institute (WRI) "Survey Report of the World Observation Research Institute" asserts that 26.4 billion tons of soil is lost globally every year as a result of cropland production. The soil erosion in China is particularly severe where the total area of land affected by soil erosion is approximately 3.56 million km^2, accounting for 37% of the total land territory. It is estimated that the annual volume of soil loss is 5 billion tons, which means that the equivalent of 3 mm of fertilized cropland topsoil is washed away each year over the entire country. The resulting nutrient loss of N, P, and K equals to 40 million tons of fertilizer, exceeding the total production of fertilizer in China. It is also estimated that more than 10 billion RMB has been lost due to the degradation of croplands and the reduction in productivity of arable lands caused by soil erosion since 1950s.

It is estimated that the total volume of organic matter loss, including nitrogen and phosphorus, caused by wind erosion in sandy desertification areas is 55.906 8 million tons, equal to 268.493 1 million tons of chemical fertilizers. Under the impact of wind erosion, crop yields have decreased by 20% to 25% and grassland productivity has been reduced by 30% to 40%. Pasture and grazing lands in the western section of Jilin Province have been reduced by up to 40% in recent years compared to the 1950s, which equates to a rate of decrease of 2% per year. The area of low yield grassland or grazing lands in western Jilin is approximately 689,000 ha and the yield of dried forage material is approximately 750 $kg{\cdot}ha^{-1}$. This is a 60% decrease in yield compared with the past. In the hilly gully areas of the Loess Plateau region in northern Shaanxi Province, the annual loss of soil nutrients by means of erosion equals to 2,250 $kg{\cdot}ha^{-1}$. The annual nutrient loss from sloping croplands is 17.9 times higher than the nutrient input from the total annual fertilizer application. The annual nutrient loss contained in sediments of red soil from sloping cropland areas in southern China is 89.8 $kg{\cdot}ha^{-1}$ of total nitrogen, 16.3 $kg{\cdot}ha^{-1}$ of hydrolysable nitrogen, 244.4 $kg{\cdot}ha^{-1}$ of total phosphorus, and 3,870.3 $kg{\cdot}ha^{-1}$ of total potassium.

Along the Yangtze River valley, there is approximately 11 million ha of sloping croplands and 36 million ha of barren hills as well as sloping land, sparse forest farms, and artificial plantations. The soil erosion modulus in steep croplands and barren lands is greater than 10,000 $\text{t}\cdot\text{km}^{-2}\cdot\text{a}^{-1}$. More than 400 million tons of sediments are annually transported into the Yellow River where some sections of the river course in the Shaanxi Province region of the Loess Plateau are clogged with silt.

It is estimated that 500 million tons of topsoil is lost annually in Yunnan Province. This volume is equivalent to the destruction of 160,000 ha of cropland, and also causes an annual loss of 9.75 million tons of organic matter, 720,000 tons of nitrogen, 1.2 million tons of phosphorus, and 5,000 tons of potassium.

In some parts of Zhushan County, Hubei Province (Zhang, 1999a), steeply sloping land has been cultivated and caused soil loss is equivalent to 1,067 ha of the ploughing layer. A heavy loss of soil nutrients has also occurred, equivalent to 14,000 tons of ammonium sulphate and 16,500 tons of superphosphate, 1.47 times and 9.8 times, respectively, of the total amount of the two chemical fertilizers consumed annually in the county.

Research data on the granite denudation area in southern China reveals that the topsoil in the denudation and erosion areas has been totally washed away, accounting for 20% to 40% of the total land area in the severely eroded region. The content of organic matter in the non-eroded red soil is four times higher than that of the severely eroded soil and eight times higher than that of the most severely eroded soil. Similarly, the content of total nitrogen in non-eroded red soil is 3.9 times higher than that of severely eroded soil and 40 times higher than that of the most severely eroded soil. In addition, the content of total phosphorus in non-eroded soil is 4.6 times higher than the severely eroded soil and 16.7 times higher than the most severely eroded soil. The content of organic matter in the severely and most severely eroded sites has decreased to 0.57% and 0.16–0.25%, respectively.

The main consequence of soil nutrient depletion due to soil is a decrease in land productivity, especially a reduction of crop yields. Experimental results in the Weibei Highlands, Shaanxi Province (Liu et al., 1992), showed that the yield of wheat will decrease by 22.5 $\text{kg}\cdot\text{ha}^{-1}$ to 43.5 $\text{kg}\cdot\text{ha}^{-1}$ for every 1 cm of topsoil that is lost under general conditions. Yang (1999) analyzed the spatial differences of N, P, and K content in soil and noted that these available soil nutrients will decrease in erosion conditions, especially on the topside of slopes where nutrients are rarely contained within soils. Erosion can reduce the amount of soil organic matter and change the soil texture (the ratio of sand, silt, and clay materials) causing soil roughness to occur on land surfaces. With the negative impacts of erosion on soil fertility, the reduction of land biomass productivity will result in the reduction of the economic productivity of land.

Water erosion will directly affect soil development and agricultural productivity (Xu, 1999). As the slope gradient increases, the intensity of water erosion will worsen and the humus layer will disappear completely. The thickness of the humus layer on gentle sloping lands with a gradient of less than 3°, for example, is approximately 65 cm to 75 cm, but when the gradient increases to 25° the thickness is only approximately 10 cm thick, which is also the case when intense water erosion occurs. The physical composition of soil is also correlated to the intensity of water erosion. For example, the content of clay particles (<0.01 mm) can be as high as 83.59% in the topsoil of sloping lands with a gradient of 3° to 5°, but can be reduced to 40% at 7° to 15°. Soil bulk density and porosity will also change, and, consequently, the physical and chemical properties of the soil and the nature of how the soil material moves will change. When the slope gradient is more pronounced, soil erosion is more severe, soil development worsens and land productivity decreases. In general, when the gradient increases by 1° in gently sloping areas, land productivity will decrease by 0.5% to 1%. When the slope gradient is greater than 15° and less than 25°, land productivity will decrease by 50% to 100% with an increase in slope of 1°, and when the slope gradient is greater than 25°, land productivity will decrease by 100% to 200% as the slope increases by 1°.

As the fertile topsoil is washed away, the soil layers become thinner. Soil thickness is an important factor for plant growth. When soil is saturated with water, the storage of soil nutrients and the spatial distribution of root systems of plants are primarily affected by soil thickness. Water and nutrients are the fundamental materials that generate plant growth, but growth is limited by soil thickness. The thicker the soil layer, the greater its water holding capacity, and with higher moisture and nutrient contents in the soil, the plants will grow better. Moreover, a thick soil layer is helpful for root development and thus increases the distribution of root systems, providing more space for nutritional uptake. Therefore, a thick soil layer is more helpful to plant growth and regeneration. An effective soil thickness ensures that the root system distribution of crops, timber trees, fruit trees, and grasses is sufficient to maximize growth. A thick soil layer, which allows a wide root system distribution, can hold more water and nutrients improving plant regeneration and growth while enhancing plant suitability, tolerance, and productivity. Effective soil thickness, therefore, is a key factor when trying to identify the suitability and restrictions of land resources. Soil thickness, especially in mountainous regions, is the dominant limiting factor of agriculture, forestry, and animal husbandry. Generally, if soil thickness is less than 30 cm, the capacity of root systems to grow healthy crops, forests, fruit trees, and grasses will be directly limited.

Soil erosion are the primary mechanisms that damage fertile land, wash away ploughing layers and organic materials and, as a result, turn healthy soil into infertile soil and land resources into dead zones. The impact of soil erosion on land quality results primarily in the progressive deterioration of fertile land into unproductive or barren land. According to a survey report of forest resources in Guizhou Province, the rocky hill area has increased from 5% to 9.6% of the total land area in the province between 1975 and 1998. In Nayong County, Guizhou Province, topsoil on 17,000 ha of upland terrain was washed away due to soil erosion. The upland is now completely covered by rocky mulch or rocky desertification, and the productive land used in the past has been completely desertified and turned into wasteland or barren land. From the point of view of flood prevention, Liang and Shi (1998) conducted research on soil erosion. His results show that a topsoil layer with a thickness of 5 cm in moderate erosion zones on the upstream area of the Yangtze River can hold or absorb 7.8 mm of rainfall or runoff. On average, a topsoil layer with a thickness of 4 cm can hold or absorb 6.2 mm of rainfall. Applying this to the moderate soil erosion zone on the upstream area of the Yangtze River with an area of 352,000 km^2 would mean that if 4 cm of topsoil was washed away over a period of ten years, this would equate to a reduction in the total holding and absorption capacity of 2.197 billion m^3 of water. This is equal to 10% of the total water storage volume (22.15 billion m^3) of the Three Gorges Reservoir.

It is evident that the soil's water holding capacity is dramatically reduced due to the thinning of soil layers. According to data from the second national soil survey, the total area of soil resources in the upstream region of the Yangtze River is approximately 963,500 km^2, of which 90% is comprised of the sum of the areas of the 11 main soil types. Based on the weighted average area occupied by soil layers of various soil types, it can be concluded that the average soil layer thickness on the upstream region of the Yangtze River is 78.5 cm in depth. The water holding capacities of these soil layers mean that up to 430 mm of rainfall can be completely absorbed and stored without any runoff occurring. The maximum water storage capacity of the soil is 416.03 billion m^3 or 18.78 times that of the planned flood control storage capacity of the Three Gorges Reservoir.

The thinner the soil layer, the lower its water storage capacity will be, and the lower the soil moisture content, the weaker its ability will be to cope with drought. Consequently, in areas affected by soil erosion, rainwater or runoff will easily flow away as the water storage capacity of the soil is poor, resulting in crop and plant stress caused by drought and the lack of soil moisture. The potential for soil and water conservation, therefore, will obviously be reduced and the severity and intensity of soil loss will, without doubt, increase. These factors will interact with each other forming a vicious cycle.

5.2.2 Water erosion and water quality

Agricultural development brings about an increase in the land utilization rate and increases the use of pesticides and chemical fertilizers so that pollutant contents in cropland runoff also increase sharply. Floodwater or runoff from croplands can contain a large amount of sediment, various sorts of organic matter, inorganic materials, and nutrients like nitrogen and phosphorus as well as pesticide residues, which are important sources of pollutants in water bodies. Unlimited use of large amounts of chemical fertilizers and pesticides will reduce the water quality. Fertilizer runoff also increases the nutrient concentrations in water bodies which can accelerate eutrophication. The leaching of pesticides and chemical fertilizers into groundwater is a primary pollutant source of drinking water bodies. Certain varieties of fish and birds are sensitive and vulnerable to aqueous materials and sediments from foreign sources. Migration or extinction can be the result.

At present, pollution is the primary factor in causing global water quality deterioration. Data from the United States Environmental Protection Agency (US EPA) indicates that 50% or more of the water quality problems that the United States currently faces is probably caused by pollution sources. This shows that pollution sources are harmful to water quality and water body environments. Concerning agricultural development, large areas of wasteland were developed and cultivated increasing the utilization rate of the land, but resulting in further severe water erosion along river valleys and increasing nutrient contamination in the rivers. To add to this problem, both pesticides and chemical fertilizers were extensively used to increase land productivity. During periods of rain, croplands experience a series of physical, chemical and hydrological processes including surface flow, infiltration, scouring, adsorption, and confluence. Following those processes, runoff transports pollutants into rivers and accelerates the severity of water pollution. As a result, even in cases where all point source pollutants were fully controlled, the water quality in rivers, lakes, and reservoirs decreases by 42% to 65% (Zhu et al., 2000).

The World Fertilizer Conference concluded that approximately 30% of grain yield in developing countries is grown from chemical fertilizers. Agricultural land resource utilization in China is at the point of over-development and the irresponsible and increasing use of chemical products for agricultural production are the primary means to raise agricultural output.

Leaching of pesticides and chemical fertilizers into groundwater is another major way in which the water body can become polluted. According to the statistics from concerned agencies in the United States, approximately 10% to 15% of nitrogen fertilizer is leached into groundwater every year. The amount of chemical fertilizer application in China has increased by 90.7% from 1984 to 1994, but grain yield has increased by only 9.1%. Taking nitrogen fertilizers as an example, the total amount of fertilizer applied per unit area in China was 191.6 $\mathrm{kg \cdot ha^{-1}}$, 3.55 times the world average, but grain yield per kg of added nitrogen was 20.95 kg, less than 50% of that the world average. The leaching of chemical fertilizers is, therefore, a primary factor in the low utilization ratio of nitrogen. According to a survey from the agricultural sector, the average utilization ratio of nitrogen in China is only 20% to 30% while the average leaching ratio of nitrogen is greater than 60%. The annual weight of nitrogen fertilizer applied in China is 20 million tons. It is assumed that if the annual leaching rate is 50%, nitrogen leaching will be as high as 10 million tons per year.

At present, there are more than 1,000 varieties of pesticides used in the world, with the annual weight of applied pesticide being greater than 1.80 million tons. In China, it has been found that more than 150 million ha of cropland uses pesticides to control plant diseases and insect pests, which results in a 7% increase in the total grain yield. However, field experiments show that only 20% to 30% of the pesticides used adhere to crops; 30% to 50% fall to the ground and the remaining pesticide is volatilized into the atmosphere. It is clear that large amounts of chemical fertilizers and pesticides are discharged into rivers, streams, lakes, reservoirs and other water bodies by means of rainfall runoff and leaching.

Nitrogen and phosphorous leaching not only impinges on river water quality, but also results in serious impacts to estuaries and offshore areas. The limiting nutrient of nitrogen and phosphorous for major rivers in China is typically phosphorus (Duan, 1999). The Yellow River contains relatively high amounts of phosphorous and low amounts of nitrogen, while the ratio between nitrogen and phosphorus in the Yangtze River approaches the background value of rivers throughout the world. However, the Pearl River contains relatively rich amounts of nitrogen but is deficient in phosphorous. The Loess Plateau is the most severely affected water erosion region and the silt in the Yellow River primarily originates from the middle reaches of the Loess Plateau. The Yellow River contains rich amounts of phosphorus that are primarily derived from its watershed where soil erosion occurs.

Agricultural land pollution is one of the primary reasons that water becomes eutrophic (Zhu, 2000). Inappropriate use of pesticides and chemical fertilizers, and livestock and poultry feces, can leach and runoff into waterways, accelerating agricultural land pollution. In 1997, 1.2 million tons of pesticides was applied to approximately 9.067 million ha of cropland to control plant diseases and insect pests, polluting the land and resulting in deterioration of the agricultural eco-environment, and also polluting agricultural and associated products. In developed regions with advanced economic growth, an average of 600 $\text{kg}\cdot\text{ha}^{-1}$ to 750 $\text{kg}\cdot\text{ha}^{-1}$ of nitrogen is used each year. The more nitrogen fertilizer used, the lower the effective utilization rate, which is only 20% to 25% on average. Leaching of large amounts of chemical fertilizers into rivers and lakes, in conjunction with water erosion, is one of the primary reasons for high concentrations of total nitrogen in water bodies. Inappropriate use of pesticides, including low utilization rates of application ranging from 40% to 50%, can pollute the atmosphere, soil, agricultural crops, and agricultural sideline products, and also significantly pollute water bodies.

Eutrophication is a phenomenon that is exacerbated by human activity where massive amounts of nitrogen and phosphorous and other nutrient materials are transported into water bodies. This excessive amount of nutrients feeds organisms that flourish in the slow currents of water bodies like lakes, estuaries, and gulfs. Eutrophication also results in the rapid breeding of algae and other plankton which reduces the dissolved oxygen content in water bodies, water quality deteriorates, and in some situations, killing great numbers of aquatic organisms like fish (Chen, 1999). The algal communities of natural water bodies are primarily composed of diatoms and green algae. The appearance of red algae is a sign of eutrophication, while blue algae become dominant in water bodies with the development of eutrophication. Algae breed and mature quickly, feasting on the available nutrient material and reproducing rapidly under appropriate environmental conditions forming algal blooms.

Dead aquatic organisms either decompose by means of microorganism activity exhausting oxygen reserves, or decompose under anaerobic conditions, generating hydrogen sulfide and its noxious odor. Both decomposition methods cause a relative deterioration in water quality. The eutrophication of water bodies often results in distortions to aquatic ecosystems. For example, patina microvesicle algae in eutrophic lakes and reservoirs are extremely poisonous and can result in liver tumors in animals and congestion causing rapid death. The impacts and damages caused by eutrophic water include: (i) noxious odors and water opaqueness; (ii) a change in the dissolved oxygen content as the dissolved oxygen becomes exhausted, causing an anaerobic state to form in deep water when serious, making it impossible for aquatic organisms to survive; (iii) toxic materials leaching into water bodies; (iv) a deterioration in the quality of water supplies, increasing the cost of water treatment; and (v) a decrease in the stability and diversity of aquatic organisms leading to the destruction of the ecological balance of water bodies.

Pollution caused by agricultural fertilizers induced the eutrophic state of Dianchi Lake in Yunnan Province and resulted in a dramatic increase of algal blooms. Guo (2000) studied the pollution load flowing into Dianchi Lake and his results show that of total nitrogen in the surface flow, 53% was sourced from chemical fertilizers, while 42% of the total phosphorus also came from fertilizers. Therefore, the pollution in a water body can be reduced by controlling soil erosion.

Controlling the diffuse source pollution from agricultural runoff is a key method for controlling water pollution and lake water eutrophication. To control the diffuse source pollution caused by chemical fertilizers, and reduce nitrogen and phosphorus leaching, the use of fertilizers must be adjusted so that different types of manure and fertilizers are applied on different soil types and at different rates so that the agricultural development is sustainable, and the water environments remain healthy. Note that chemical fertilizers contribute greatly to the increase of agricultural production, but over-use of agricultural fertilizers can result in huge negative impacts for society in general and the environment in particular. It is estimated that only approximately 15% to 30% of chemical fertilizers applied to croplands are effectively absorbed by crops, while 70% to 85% are leached into rivers, lakes, coastal areas, and underground water tables by means of infiltration, runoff, and water erosion. Fertilizer leaching is a major diffuse chemical pollution source for lakes, rivers, and coastal areas.

In Dali City, Yunnan Province (Du, 1999), the area affected by water erosion is 1.3×10^4 ha. In the Cangshan Mountains in western Yunnan, 11 of the 18 valleys and streams are affected by mudflows or erosion gullies and the annual mud and silt sediments can be as high as 90×10^4 t, of which 0.54×10^4 t is total nitrogen, 0.32×10^4 t is total phosphorus, 58 tons is soluble nitrogen, and 3.5 tons is soluble phosphorus. Annual mud and silt sedimentation in the mountainous regions in eastern Yunnan account for 17.4×10^4 t, of which 0.75 tons is total nitrogen, 0.113 tons is total phosphorus, 56.8 tons is soluble nitrogen, and 3.3 tons is soluble phosphorus. Annual mud and silt sedimentation in the mountainous areas in southern Yunnan are 17.1×10^4 t, of which 0.058×10^4 t is total nitrogen, 0.035×10^4 t is total phosphorus, 67.3 tons is soluble nitrogen, and 4.0 tons is soluble phosphorus.

The sediment and nutrient materials that flow into Erhai Lake in Yunnan Province through streams cause siltation and the increase eutrophication processes and can even destroy croplands while endangering the health and welfare of people and domestic animals alike. It must also be pointed out that pollutant materials (including poison-free materials that can introduce toxic materials from other pollutant sources) that flow into groundwater environments at a remote distance will also either result in an increase in the contamination index or produce associated pollutant effects. For example, detergents flowing into groundwater through sewage water irrigation can transfer pollutants to surface water, increasing the concentration of contaminants 2 to 7 times.

Direct drainage of sewage water and fertilizer and pesticide leaching are the key factors that have accelerated eutrophication in water bodies during the last decade. The nutrient content of major freshwater lakes and reservoirs have basic standardized eutrophication concentrations. Among the 26 lakes that have been surveyed so far, 39% had a medium level of nutrient concentrations and 61% possessed a high or heavy nutrient loads. Eutrophication is therefore a nationwide environmental issue affecting lakes and reservoirs throughout China.

5.2.3 Water erosion and mud and silt sedimentation

Water erosion not only causes a reduction in land productivity, flood overflow capacity, and mud and silt sedimentation in downstream sections of water bodies, it also causes siltation to occur in water channels and reservoirs. This can affect inland water movements, lessen the storage and regulation capacity of reservoirs, erode and damage water conservation devices and hydro-electric facilities, clog riverbeds with silt and block floodflows, increase flood control costs and flooding risks, and endanger the lives and property of people living along river channels.

Siltation and sedimentation in lakes, reservoirs, and catchments weaken flood control capacities. In regions affected by serious water erosion, soil erosion upstream, and sedimentation downstream in water bodies are the rule. Water erosion and the sedimentation of reservoirs and catchments are global issues. Water catchments, reservoirs, and irrigation canals for controlling flood events are often clogged with mud and silt, and as a result, the effectiveness in controlling flooding is reduced and the service life is shortened and these facilities may even be completely destroyed.

Lake and reservoir siltation and sedimentation due to water erosion have raised the beds of rivers and reservoirs, reduced the capacity of reservoirs to store water, and generally reduced the size of these water storage facilities. Consequently, hazards associated with small floods and high water tables have increased, and massive floods along river channels have occurred in recent decades in China. The Yellow River is known as a "suspension river" that stretches for hundreds of kilometers through Henan Province. A suspension river has also formed in Jingjiang along the Yangtze River while Dongting Lake is in the process of becoming a "suspension lake." Since 1949 (Zhu, 1999e), more than 500 lakes have disappeared and 20 billion m^3 of accumulated storage capacity in reservoirs and lakes was lost due to water erosion processes. There are over 80,000 reservoirs of different sizes built along 50,000 rivers nationwide, and the annual loss of storage capacity through siltation and sedimentation is as high as one billion m^3.

The area of water erosion along the Yangtze River has increased from 363,800 km^2 in 1957 to 560,000 km^2 in 1999 (Cheng, 2000). Meanwhile, the rate of siltation in some sections of the Yangtze River is as much as 10 $cm \cdot a^{-1}$. From 1960 to 1979, 20,860 km of shipment routes were reduced. The average annual loss of shipment routes is 1,043 $km \cdot a^{-1}$. The mean annual mass of sediment and silt flowing into existing reservoirs of various sizes in upstream sections of the Yangtze River is 150 million tons and with a further 77.67 million tons flowing into catchments and dams. In the downstream section of the Yangtze River, five major lakes and reservoirs are experiencing severe sediment and silt accumulation due to water erosion, where water storage capacities have declined, flood management capacities are reduced, and the necessity to discharge flood peaks has increased. Under the effects of siltation and sedimentation and the inappropriate act of reclaiming land from marshes or lake systems, flood regulation and water storage capacities of lakes have decreased on a large scale. In 1949, lakes covered a total area of 25,828 km^2 in the middle and lower reaches of the Yangtze River. In 1997, only 14,074 km^2 of lake area remained, representing a loss of approximately 50%.

The sedimentation and siltation of river systems limits shipping enterprises. The available shipping lane span on the Yangtze River was 70,000 km in 1957, but only 35,000 km by the middle of the 1980s, which is a 50%

reduction in access.

During recent decades, an enormous volume of silt and mud has been transported downstream and deposited, accumulating along the river banks of the Yangtze River from water erosion. According to data collected by the Yichang Hydrological Station, Hubei Province, 522 million tons of silt per year flowed down to the middle and lower reaches of the Yangtze River before the 1950s. The silt volume had increased to 720 million tons per year by the 1980s and into the 1990s (a 38% increase). Additionally, 825 million tons of silt flowed into the main course of the Yangtze River from the middle reaches and the downstream area, accounting for a total of 1,545 million tons of silt and sediment deposited into the Yangtze River course in a year. Of this amount of sediment, only 9.3% was carried into the sea while 90% was deposited and accumulated around the Yangtze River mouth. It is estimated that the mean annual silt sedimentation rate is 752,000 $\mathrm{t \cdot km^{-2}}$. For example, 45 cm deep silt filled the riverbed between Chenglingji to Hankou (a distance of 240 km) with sand dykes and beaches formed along the river course, resulting in direct threats to shipping and harbors. At the same time, the river course narrowed while the flood control and overflow capacity declined, increasing the risk of flood disasters. The siltation of river channels makes them prone to flooding disasters as well as the more narrow shipping channels. The flood discharge that occurred on the Yangtze River in 1998 was less than that of 1954, but the water table in 1998 was higher than it was in 1954. More than 3,000 lives were lost and, the direct economic loss from the 1998 flood disaster was approximately 160 billion RMB. More than 300,000 soldiers and 2 million farm workers were mobilized to meet the emergency. This particular flood disaster severely compromised both economic production and daily livelihoods.

The Gongzui Hydropower Station on the Dadu River was designed with a dam water storage capacity of 350 million m^3, but according to statistics (Zhao, 1999), it has almost turned into a run-of-river power station since it now relies almost solely on runoff due to the effects of siltation and sedimentation following a twenty-year operating period.

Data show that compared to conditions in the 1950s, the current water discharge that flows into Dongting Lake from the Jingjiang River has decreased over 50%. By 1988, the water storage capacity of Dongting Lake reduced by 36.1% to 47.9% compared with the storage in 1952. The relationship between the Jingjiang River and Dongting Lake has altered due to the increase in local sediment and silt flowing into Dongting Lake. According to historical records, a flood occurred once every 41 years on average during the period from 285 AD to 1968. However, floods occur at a rate of more than one every five years today. The surface area of Dongting Lake decreased from 4,350 km^2 in 1949 to 2,740 km^2 by 1977.

The Qili River was severely clogged with silt between 1952 and 1971 and the riverbed was raised by approximately 4.12 m, while its water storage capacity was reduced from 1 billion m^3 to 330 million m^3. The canal built to store water and regulate flood water became dysfunctional.

The annual amount of silt sedimentation that flows into Dongting Lake is approximately 98 to 120 million m^3. Of this sediment 83.5% originates from the Yangtze River and the remainder comes from local siltation from Dongting Lake. Dongting Lake has the most severe silt sedimentation problem in China. The lake is an important pathway for water storage and for flood regulation in the middle and lower reaches of the Yangtze River. Since 1949 the average amount of sedimentation on the lakebed has been as high as 1 m. The western section of Dongting Lake is now mostly clogged with silt and is used as reclaimed land. In particular, since the 1970s, the average annual rise in the lakebed resulting from sedimentation is 3.7 cm and, accordingly, the water storage capacity of the lake has been reduced from 29.3 billion m^3 in 1949 to 17.8 billion m^3 today. It has been predicted by authorized sectors that the eastern and southern areas of Dongting Lake will be completely depleted of water within a short time period.

The average rate of sedimentation and siltation in Poyang Lake has increased from 8 million m^3 in the 1970s to 9 million m^3 in the 1990s. Its function, to store water and regulate flood, has decreased year after year. During the last two decades, the surface area of the lake has been reduced to 1,210 km^2 and 5 billion m^3 of water storage capacity has been lost. From 1950 to 1998, the water table at the intake of Poyang Lake increased in height until it was 20 m higher than that of the Wusongkou outlet of the Yangtze River. Four floods occurred during the years between 1950 and 1973, an average of one flood every 5.8 years. From 1974 to 1998, one flood occurred every 2.4 years. Since the 1990s, an average of one flood has occurred every 1.2 years.

Today, the pressure to control flood events is becoming greater. It is estimated by the scientific community that the service life of the Three Gorges Dam will be less than 30 years if water erosion in the upstream area of the Yangtze River is not effectively controlled. The worsening water erosion in the upper and middle reaches of the Yangtze River is becoming a serious risk throughout the valley and will directly threaten the Three Gorges Dam. Silt and sand sedimentation is a particularly serious problem that the Three Gorges Dam faces. Until now, the area affected by water erosion in the upper reaches of the Yangtze River is 355,000 km^2, accounting for 60% of the total area of water erosion in the Yangtze River valley. Water erosion severely threatens the Three Gorges Dam as well as the entire Yangtze River valley.

An annual silt layer 4–12 cm thick accumulates on the riverbed of the Yellow River. The Yellow River is known as a “suspension river” in China where the riverbed is clogged with silt and narrows to a point where the flood carrying capacity is reduced. When a massive volume of sedimentation rushes down and clogs river courses, peoples’ lives and property are severely damaged and the vicious cycle of “the poorer life is, the faster reclamation is; the faster reclamation is, the poorer life is” is repeated year after year. Due to severe water erosion, the riverbed downstream of the Yellow River has been clogged with silt, and consequently, several massive overflows have taken place. During the last 2,500 years, from the Qin Dynasty to 1949, there were 1,500 floods and overflow events recorded and 26 recorded changed to the river course. On average, one breach on the Yellow River has taken place every three years and one alteration of the river course has taken place every one hundred years. Although no breaches have occurred since 1949, the riverbed is being clogged with silt by about 10 $\mathrm{cm{\cdot}a^{-1}}$. As a consequence, in some areas the riverbed is now 3 m to 5 m higher than the terrain outside of the river bank, and as much as 10 m in some parts of the middle reaches of the Yellow River. The riverbed of the Yellow River in Xinxiang City, Henan Province is 20 m higher than the terrain, and the riverbed is 13 m higher than the terrain that surrounds it in Kaifeng City, Henan Province. From 1949 to 1998, the sedimentation in the downstream section is estimated to have increased by nearly 10 billion tons. During recent years, the Yellow River has dried up in the lower reaches due to prolonged dry spells where silt and sand that flow into the river are deposited within the main river course.

Approximately 700 km of the downstream area of the Yellow River is protected by river banks and dykes alongside the river where the riverbed itself is higher than the surrounding land which is a common phenomenon of suspension rivers. The maximum recorded peak flood discharge of the Yellow River is 22,300 $\mathrm{m^3 \cdot s^{-1}}$ in 1958 and water flowed unencumbered to the sea through measures that took strict precautions against flood disasters. In 1984, the peak flood discharge was 15,300 $\mathrm{m^3 \cdot s^{-1}}$. During this period of time, Dongting Lake was used to divert flood water. By 1996, the peak flood capacity was only 7,600 $\mathrm{m^3 \cdot s^{-1}}$, the suspension river had become ineffective at channeling flood flows, and disastrous damage finally occurred. What will happen if two or three times of the amount of flood discharge that occurred in 1996 takes place during another wet cycle?

Silt and sand carried downstream by water erosion are the primary factors reducing the flood carrying capacity of rivers, and therefore increasing the risk of flood damage. The riverbed of the Yellow River was clogged with silt by 2 m to 4 m on average during the last five decades. Artificial dykes and protection measures have thus far guaranteed that the Yellow River has flowed safely during last fifty years, but it is accumulating massive potential energy. Many downstream sections of the Yellow River are clogged with silt up to 5 m to 10 m above its banks, and, in addition, because the river often runs dry, the problems facing the Yellow River are becoming more complex. The issue of flooding on the Yellow River has yet to be resolved and, on the contrary, is worsening and becoming more severe.

Siltation and sedimentation accumulation in reservoirs and water catchments countrywide is also very serious. A total of 997 reservoirs of various sizes were built before 1995 in Shanxi Province with a total water storage capacity of 3.23 billion $\mathrm{m^3}$. The water storage capacity has since decreased by more than 25% due to siltation. In Sichuan Province, there are 73,000 reservoirs and water catchments affected by an annual siltation accumulation of approximately 46.2 million m^3 that has resulted in the loss of 81.3 million ha of irrigation land. In the upstream area of the Yangtze River, approximately 10 billion m^3 of reservoir water storage capacity has been lost due to siltation and sedimentation. In Jiangxi Province, more than 9,000 reservoirs were clogged with silt, and as a consequence, 10.47 million m^3 of water storage capacity has been lost, equivalent to the loss of a medium scale reservoir. In the Songhuaba Dam in Kunming City, Yunnan Province, 52,000 tons of silt and sand flowed into the dam in the 1960s, 73,000 tons in the 1970s, 132,000 tons in the 1980s, and 175,000 tons in 1990s which has greatly reduced the service life of the dam. The renowned Sanmenxia Dam in Henan Province, China, could no longer function as designed due to sedimentation and it had to be completely reconstructed. Due to water erosion alongside the Danjiang River valley, the annual accumulation of silt in the Danjiangkou Dam became as high as 63 million m^3, equal to the loss of a medium scale reservoir. In Shaanxi Province, 192 reservoirs and dams with a capacity over a million m^3 of water storage were built before 1973, of which, 41 reservoirs and dams have become fully clogged due to sedimentation, while 40% of the effective water capacity in the remaining reservoirs and dams has been lost.

Theoretically, the volume of sediment transported from one watershed is not directly proportional to the volume of sediment lost by land surface erosion from that watershed. This is because the sediment that originated from soil erosion processes partially settled within the watershed and thus the sediment volume deposited at the outlet of watershed valley would be less than the sediment volume that originated from soil erosion. The ratio between the two volumes is usually called the “silt-sand transport ratio.” It is the criterion for measuring sediment transport from upstream erosion sites to a specified location downstream as a result of deposition. The ratio is usually less than 0.3. The silt-sand transport ratio of a specific watershed is influenced and determined by geomorphological and environmental factors, including the physical condition, scope, and location of the sediment source areas, topography, slope gradient, watershed landform, river course condition, vegetation land use patterns, and soil texture.

5.3 Fundamental water erosion control measures

Major water erosion control measures can be divided into three categories: biological measures, engineering measures, and tillage measures. Biological measures include reforestation, tree plantation, and the reintroduction of grass in water erosion regions to increase vegetative cover, block and store runoff, conserve water resources, regulate hydrological conditions, etc. Engineering measures refer to approaches that act to control water erosion by changing microtopography and microenvironment, as well as blocking and storing runoff, improving agricultural conditions, preventing soil erosion from occurring on terraces, fish scale pits, aclinic strip fields and siltation dams that act to reclaim crop fields. Tillage measures are primarily aimed to heighten crop yield and hold moisture within the soil by means of ploughing, loosening soil with hoes, and raking soil using traditional farming tools. Tillage measures include contour farming, furrow farming, contour strip intercropping, contour crop rotation, and level trenches. Different soil and water conservation measures vary not only in the manner in which they conserve soil and water, but also depending on different environmental conditions.

The advantages of engineering measures are characterized by their effectiveness over short time periods and their wider popularity. However, engineering measures require a massive investment and their service life tends to be comparatively short compared with other measures. Biological measures can rehabilitate ecological environments and control soil erosion at the source of origin. However, they are restricted by a lack of hydrothermal conditions, particularly moisture conditions, and have a limited survival rate. The effectiveness of tillage measures is also limited because they can only control soil erosion on a limited scale. When applying soil and water conservation measures, it is important that appropriate measures are selected specific to local conditions. Moreover, the operation of integrated management approaches must also be applied.

5.3.1 Small watershed management

Experience in successful soil and water conservation projects during the past few decades was developed from the implementation of integrated management to small watersheds that play an important role in controlling water erosion. Small watershed integrated management, developed for small watersheds of a particular size, is a soil and water conservation measure developed scientifically based on the size and configuration of the watershed to provide a comprehensive framework for the effective protection of land resources within these small watersheds. Appropriate cultivation and careful development and land use are promoted for the sustainable development of agriculture, forestry, animal husbandry and other agricultural activities. The central issue for small watershed management is the allocation of soil and water conservation measures which are primarily in the form of land use adjustment and conversion. The main objectives, however, focus on the steady improvement of ecological effectiveness and the growth of economic benefits of watershed systems.

Experiments in the operation and comprehensive management of soil and water conservation within small watersheds were initiated in the 1950s, but it was not until the pilot projects of the early 1980s that the measures became popular and were extended on a large scale. During the last two decades, more than 3,000 small watershed and river systems have been effectively controlled and rehabilitated in the Loess Plateau region. Consequently, the volume of loess silt and sand flowing into the Yellow River has been greatly reduced and the ecological environment of the Loess Plateau region has been remarkable improved by means of this rehabilitation.

As a successful strategy for water and soil conservation, the guiding ideology and implementation of small watershed management have also experienced development and improvement. During the early and mid-1980s, watershed management was focused on accumulating further knowledge and experience. Due to limitations of knowledge and the level of technology at the time, the objectives of small watershed management were primarily focused on the preservation of water and the conservation of soil. A series of suitable control measures were used depending on the topographic and landform features of small watersheds and soil erosion mechanisms, to achieve the targets of storing runoff, floods, and rainwater. Measures included installing multilevel dykes while constructing catchments and storing all surface water inside these water systems. During this period, the Ministry of Water Resources setup 38 small basins in the middle reaches of the Yellow River as key experimental sites to explore the scientific aspects of protection systems. The main objective was to reduce soil erosion and less concern was paid to economic benefits. Thus, many watershed systems were effectively rehabilitated with remarkable efficiency, but economic benefits were ignored.

By the late 1980s, along with the national economic reconstruction, small watershed management was gradually redeployed in a form that included economic benefits. By means of integration of rehabilitation and development, economic benefit was targeted as one of the goals while implementing rehabilitation projects. Some small watershed basins and river systems were gradually rehabilitated with both ecological effectiveness and economic benefits in the Loess Plateau region during this new development stage. From then on, to avoid a traditional single benefit protective system, economic benefits were emphasized as priority targets in the rehabilitation of watershed basins and river systems. However, in the process of securing economic benefits, water and soil conservation efficiency was ignored. Moreover, unreasonably high economic benefit goals were set as targets, ignoring the production, supply, and marketing principles of market economics and as a result, the economic benefit targets were not achieved.

By the 1990s, along with the continuously expanding and developing of market economy in China, more concern and focus were paid to economic benefits in the rehabilitation and management of small watersheds. Since then, rehabilitation of small watersheds has been incorporated into the development of the small watershed economy. According to market demand and practical requirement, the rehabilitation and development of the small watershed basins were undertaken together by combining the responsible allocation of natural and social resources and the establishment of leading estate or pillar industries inside these small watershed basins. It is characterized by the use of valuable experience and technology to rehabilitate small watershed basins with the market itself reoriented to provide targets for the control and management of different parts of small watershed basins. At the same time, both maximum ecological efficiency and economic benefit are set as the decisive goals.

Due to continual changes in perspective in the guiding bodies, the selection and allocation of small watershed management measures have also undergone a continuous process of change and reorientation. During the early stages of implementation of small watershed management projects, engineering measures were extensively publicized and widely popularized to pursue a one-sided control effect. In the hilly gully area of the Loess Plateau region, in particular, soil loss from small watershed basins was effectively controlled by means of terrace construction, building slope trenches, and installing channels and dams. After an experimental period, it was found that the blocking and storage capacity of these engineering measures alone could not meet the necessary requirements for controlling water and soil loss following displacement from root sources. In situations where a severe storm event occurs and a dam collapses or terraces disintegrate and give way, further serious soil loss will undoubtedly occur. Due to these potential scenarios, biological measures and their effects in enhancing water and soil conservation were fully recognized.

A combined model incorporating both engineering and biological measures has gradually been developed and applied to the rehabilitation of small watersheds. It involves the construction of terraces on gentle slopes between gully basins. On steep slopes, grass and shrubs should be planted and check dams should be built. At the bottom of slopes, dams and catchments should be installed. Along with the selection and allocation of water and soil conservation measures, and with the constant pursuit of economic benefit, the percentages of cash crops and fruit trees that have been planted in the past ten years have increased significantly. With the introduction of a policy to revert sloping cropland back into forest and grassland (the ‘Grain for Green’ project), the structure of small watershed rehabilitation projects and programs will be continuously adjusted to raise and transform the productive values of agriculture and animal husbandry inside small watershed basins.

As a physical geographic unit, the small watershed is also a complete system on its own producing silt and transporting sand. Under the scouring force of rainfall and runoff, topsoil material flows away and is transported into gully ditches or trenches due to the impacts of splash, surface, and gully erosion, and then rushes into water channels and river courses from watershed outlets. With regard to small watershed basins, both the vertical movement of material from the top of the slope to the bottom of the gully and the horizontal movement of material from the gully head to the gully outlet are frequently occurring phenomena. The integrated management of small watersheds is aimed to efficiently utilize natural resources and effectively protect the natural environment.

The integrated management of small watersheds is aimed to use the laws of energy and material cycling to select appropriate land use patterns and continuously regulate and control the movement of materials and energy by human intervention. Precipitation causes soil loss by the impact of splashing on land surfaces that produces a scouring effect on the soil. At the same time, precipitation is the primary source of soil moisture which maintains plant growth. The basic principle of integrated management of small watersheds is to protect land surfaces from splash erosion and to reduce runoff erosion as much as possible through the application of various measures. It is also aimed to lessen or retard the movement and transportation of silt and sand by the regulation and redistribution of runoff in watershed basins. Small watershed basins in the Loess Plateau region display remarkable differences in geological and geomorphological features, land use, and socioeconomic aspects but are all part of a large control area. The features of this area can be generally summarized as: (i) hilly roof, slope and boundary, and gully slope and valley bottom areas; (ii) upland terrace and gully and sloping valley bottom areas; and (iii) rocky hill ridge and earth rocky hillside, loessial slope and ravine land; and other landscape components. It is important to note that different landscape components require different control models.

5.3.2 Small watershed management on the Loess Plateau

5.3.2.1 Hilly roof, slope, and boundary, and gully slope and valley bottom areas

The hilly roof, slope and boundary, and gully slope and valley bottom areas are the primary landscape types in the loess hilly region. Intercropping and rotation of crops and grass can be put into practice at the top of the hilly roof landscape type. Crop and grass rotation planting not only ensures the production of grain or cash crops, but also provides fodder and forage for livestock and domestic animals. The selection of crop species, grass, and shrubs must coincide with local conditions and be appropriate. At the same time, runoff harvesting projects, runoff blocking facilities, and runoff and rain-fed agricultural practices should be encouraged and developed.

Gentle sloping terraces can be constructed in the upper parts of hilly slopes to form the fundamental farmland strips to ensure adequate food availability for farmers. Alternating slopes and terraces separated by shrubs and grass can also be constructed to protect the land from erosion. Intercropping grass and shrubs on shady slopes can provide fodder and forage for livestock and domestic animals. Due to landform complexity and increased gradients, the lower parts of hilly slopes can be reverted into forest and grassland to establish a water and soil conservation belt. Fruit trees can be planted with an undergrowth of grass on the lower gentle hill slopes of hillsides exposed to the sun. Mixed plantings of trees and shrubs should be applied to shady slopes or areas with favorable rainfall conditions, and grass and shrubs should be planted on slopes of hillsides exposed to the sun. A deep rooting shrub shelterbelt should be planted to fix soil in place and/or conserve water or process fodder and provide fuelwood on peripheries or the edges of hill boundaries.

The optimum installation of an ecological economic zone on hilly and gully slopes is an important target for water and soil conservation. This zone should be reintroduced with vegetation and enclosed by fences. Trees and shrubs should also be reintroduced and grass and shrubs should be planted. At the foot of the slope, tree plantations should be incorporated because moisture conditions there are favorable, and shrubs and grasses should be replanted on the upper parts of the slope. Silt should be allowed to accumulate on, or should be transported to, valley bottoms where catchments or dams are installed to reclaim land for farming. People should be encouraged to practice high investment, high yield, and high efficiency intensive economic endeavors in valley and dam areas where silt has accumulated to promote a “virtuous cycle” (in contrast to a “vicious cycle”) inside small watershed ecosystems.

A large number of protection shelterbelts or tree networks can be planted on river courses to fix soil and conserve water in narrow and closed valley areas. In combination with the measures described above, reservoirs or catchments should be installed to block surplus flood water. An integrated system composed of blocking catchments and suitable components like crops, trees, and grass will therefore be formed at the various levels from the top of the slope to the valley bottom. This flexible system can reduce runoff and soil nutrient loss or make full use of limited precipitation to ultimately enlarge land productivity and ensure an optimum balance between ecological efficiency and economic benefit.

5.3.2.2 Upland terrace, gully slope and valley bottom areas

The primary landscape components in gully areas of the Loess Plateau region are the upland terraces, gully slopes and valley bottoms. Agriculture, forestry, and animal husbandry should be focused on throughout the terraces of the Loess Plateau, due to the high investment and high yield potential. At the same time, various water conservation facilities should be established to block runoff on upland terraces from flowing into the gully areas. On upland terrace slopes, shelterbelts should be installed first on the edge and periphery of the terraces to stabilize gully head areas. Concurrently, the ratio of agricultural land to forest and grassland should be decreased to accelerate improvements in ecological efficiency. Moreover, belts that increase ecological efficiency and economic benefit, such as forests and fruit tree plantations should be established. Gully slopes are the most complicated part of small watershed rehabilitation. The entire watershed has an increased moisture value that can lead to negative effects. In combination with skeleton projects, valley bottom shelterbelts to control scouring and erosion and other water and soil conservation treatments should be established to block runoff and accumulate silt and sand deposits.

5.3.2.3 Rocky hill ridges and earth-rock hillsides

The primary landscape components in the earth and rock mountainous region are the rocky hill ridges and earth rock hillsides, loessial slopes and ravine land. All hillsides in this region should be seized and trees and shrubs and water and soil conservation shelterbelts should be planted to restore vegetation cover. The ecological improvement of hillsides should be the primary objective in this region and large scale development should be limited. Loessial hill slopes with higher moisture contents should be rehabilitated by means of intercropping of crops and grass and by crop rotation. Grain production and livestock should be taken into account as well. Tree plantations, shrubs, and grass should be developed on sloping land greater than 15°. Animal husbandry and breeding industries should be developed while implementing water and soil conservation projects. Terraced fields with gentle slopes should be constructed in regions with scarce rainfall on sloping land of less than 15° while intercropping of crops and grass and crop rotation systems should be practiced. Diluvial valleys and gully bottoms distributed between the main gullies and piedmont foothills are covered with sandstone and gravel sediments, and the upper parts of open river courses, and the bottomlands are covered by a thin layer of loess sedimentation.

In areas with better moisture conditions, cash crops and nut trees should be planted on a large scale in conjunction with intercropping of forage and other grass to establish livestock breeding centers and cultivation stations. Runoff harvesting projects popularized in recent years not only bring about the hope of development of runoff agriculture in the Loess Plateau region, but also result in a new vitality for small watershed management.

The slope runoff harvesting projects being implemented in Loess Plateau region can change the effective distribution of precipitation because they can control the utilization patterns of water resources or change the regularity of occurrences and development of water and soil loss. According to studies by Qingbo Zeng, the silt and sand volume that flows into gullies along with runoff can account for more than 76% of total silt sediment runoff from small watershed systems. It is estimated that 77.8% of the gully erosion volume will be reduced when the slope runoff is isolated. If the runoff from slopes between gully areas can be effectively blocked and stored, erosion as well as silt and sand volume of the entire watershed system would be largely reduced. Moreover, harvesting slope runoff can reestablish land use patterns. Water restrictions will be alleviated to a certain extent when conducting water and soil conservation planning leading to productive, efficient, and strengthened water and soil conservation measures. Greater economic benefits and ecological efficiency can be obtained using the same natural resources due to an improvement in the land management systems. Therefore, as long as these environmental conditions are available, runoff harvesting technology should become popular in the Loess Plateau region.

Relevant research and experiments should be conducted to discover new approaches to reduce costs and establish sound and sensible integration planning. Like the implementation of the production responsibility system in rural areas, a new approach to implement watershed management by means of a household level contract policy has become widely adapted. This household level watershed rehabilitation policy is aimed to encourage local people to become involved in controlling soil erosion. Due to its suitability and flexibility in selecting appropriate land use systems, household level contracts used for small watersheds have created or enhanced the enthusiasm of people living in mountainous and hilly regions to conduct water and soil conservation projects. Good results are achieved because these contracts are fulfilled through the direct participation of the farmers. Long term consistency and stability of water and soil conservation policies should be encouraged and adhered to. By doing so, farmers will benefit from these development activities and guarantee their future interest in participation.

An integrated plan should be made prior the implementation of the household level contracts used for small watershed management to improve ecological efficiency through legislation and the recognition of the importance of stakeholder obligation. One-sided economic water and soil conservation interests should be strongly avoided while operating and implementing these projects. Moreover, short term and long term goals should be combined so that both economic benefits and ecological efficiency and sedimentation control accrue. Engineering and biological measures should be combined with tillage measures to control soil loss in small, incremental steps. Limited by available labor resources, the area of household-level small watershed management should guarantee the development and utilization of resources and reduce unnecessary risks. From the experience in Shanxi Province, a watershed area of 0.1 km^2 to 1 km^2 is acceptable for household level contracts to conduct small watershed management.

Unified planning and multi-household contracts should be encouraged for watersheds within larger areas. The household level contracts used for small watershed management can also be combined with wasteland (barren hills, barren slopes, barren beaches, and barren sandland) auctions. It needs to be feasible for contractors to use wastelands in conjunction with their interests to generate both economic benefits and general public interest in ecological efficiency. At the same time, central and local governments should strengthen scientific and technological inputs and provide technical assistance and necessary support to farmers and contractors to allow them to make further contributions to the successful implementation of ecological improvement projects (Li, 1989; He and Liu, 2008; Xue and Chang, 2008).

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