

Chapter 2

The Loess Plateau

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The Loess Plateau (34°–40°N, 103°–114°E) is situated in the northern part of Central China (Fig. 2.1). It borders on North China Plain in the east, adjoins Qinghai-Tibet Plateau in the west, stands in the north of Qinling Mountains, and neighbors Inner Mongolia Plateau in the north. The Loess Plateau is a part of the dryland region in northwest China, with its altitude in the range of 800–3000 m, encompassing a vast expanse of 620,000 km². The Loess Plateau stretches over Shanxi province, northern Shaanxi province, Gansu province, northeastern Qinghai province, Hetao Plain, and Ordos Plateau of Inner Mongolia, and the western hilly land of Henan province—that is, 341 counties (cities) in seven provinces (or autonomous regions) (Fig. 2.2). The loess is perfectly arable due to its fine grains, loose texture, and high content of mineral nutrients. In fact, it is the cradle of the ancient Chinese civilisation, with a long agricultural history (over 6000 years) in its basins and river valleys. Standing between the developed eastern part and the less developed western part of the country, the Loess Plateau is one of the major regions selected for China's national eco-environment development programme.

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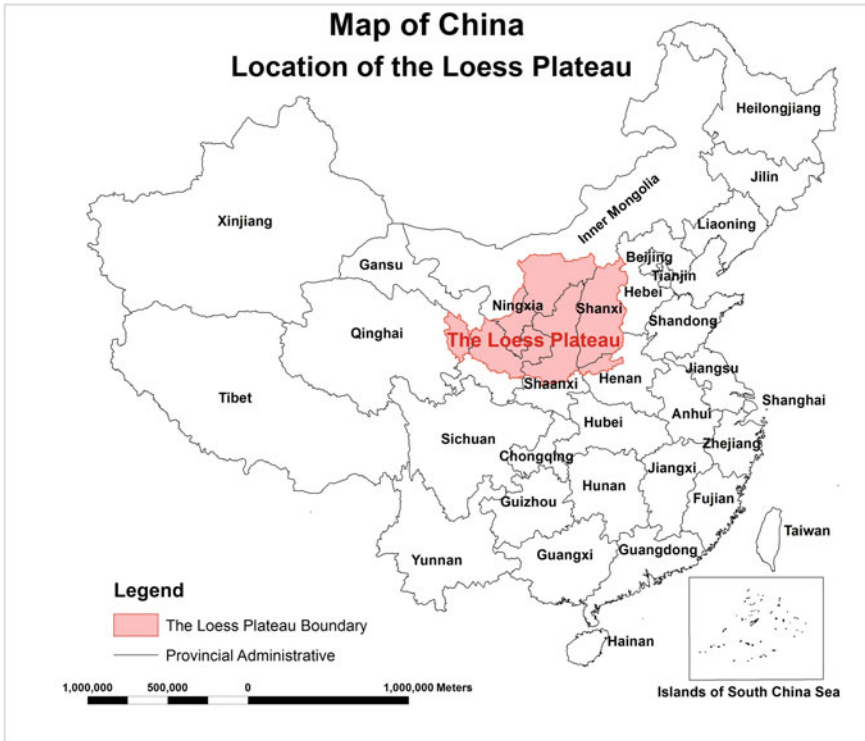


Fig. 2.1 The geographical location of the Loess Plateau in China

2.1 Geomorphology and Geology

The basic topographical pattern of the Loess Plateau emerged as early as in the late Mesozoic period. Its modern topographical features result from the tectonic movements and denudation during the Tertiary period and the loess accumulation and erosion processes during the Quaternary period. The large-scale sedimentation that started in the early fourth century brought Wucheng loess, Lishi loess, Malan loess, and Holocene loess in sequence of the original topographical pattern of the Loess Plateau. During that process, it went through multiple erosion and accumulation periods, giving birth to many river valleys and various landforms between these valleys. There are several classifications of the plateau's topography. For instance, Zhang and Qian (2009) based the classification on causes: tectonic features by erosion, denudation, denudation and accumulation, erosion and alleviation, accumulation, or accumulation by wind. Sheng and Ding (2002) divided the plateau's landforms into four major types: plain, tableland, valley, and mountain.

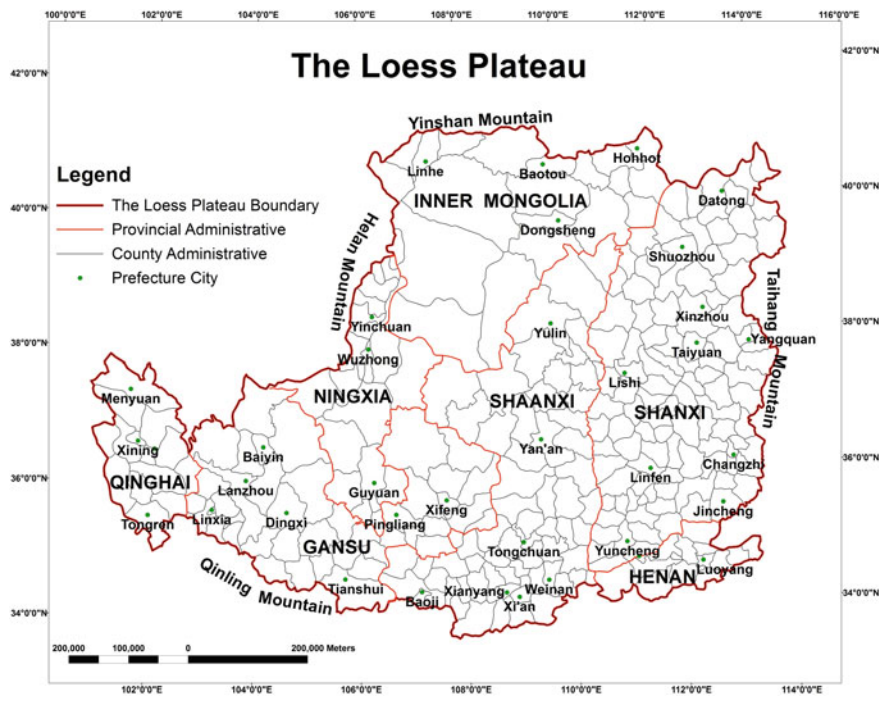


Fig. 2.2 The Loess Plateau boundary plan

Hu (2006) offered a general classification: hill, high tableland, terrace, plain, desert, and stony mountain. To sum up, the Loess Plateau area consists of three major topographical features—stony mountains, valley plains, and plateau hills (Fig. 2.3).

2.1.1 *Stony Mountains*

The Loess Plateau, both inside and in the surrounding areas, is dotted with many mountains of various sizes. These mountains affect the distribution and development of the loess topography. The soil erosion on the Loess Plateau is a natural process that occurs continuously and nowadays presents a tendency of acceleration under the influence of human activities (Liu 2005). Due to enduring soil erosion, the bedrocks along mountain ridges and valleys have been exposed, forming mountainous areas with a thin layer of soil. The valley bedrocks are mostly limestone, sandstone, and shale. In the eastern part of the Loess Plateau, there are many mountains of middle and high elevations. The mountains of middle and low

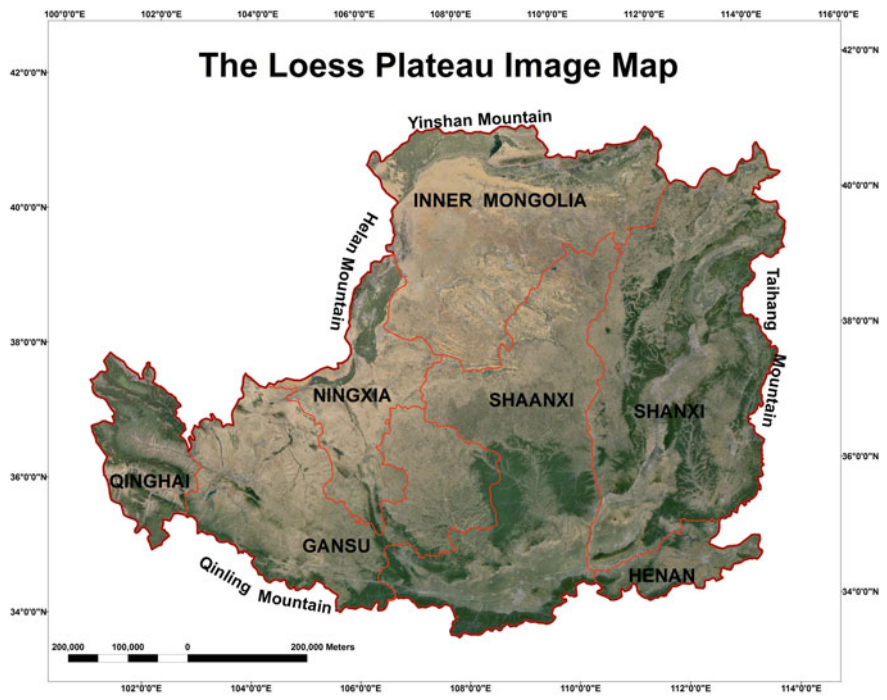


Fig. 2.3 The Loess Plateau image map



Fig. 2.4 Terrain of Liupan mountain in Ningxia Hui autonomous region

altitudes in central Loess Plateau are origins of many major rivers and thus form a number of watersheds. A typical example of such mountains is the Liupan Mountains (Figs. 2.4 and 2.5).



Fig. 2.5 Terrain of Liupan mountain in Ningxia Hui autonomous region

2.1.2 Valley Plains

Valley plains are a terrain with limited presence on the Loess Plateau, accounting for less than 15% of the total area. The Fenhe Plain and Weihe Plain, formed by the fault depression, constitute different levels of fluvial terraces and tablelands. Loess tablelands are a type of pedestal terrace under the influence of depression, which are distributed asymmetrically along the two sides of the river valley (Fig. 2.6). They are usually 10–20 m wide, with a layer of aeolian loess on the surface that can be over 100 m at maximum in thickness. The fluvial terraces in the Fenhe Plain and Weihe Plain are normally 20–30 m higher than the river level, with flat and broad surfaces—the largest width can reach 60–70 km. The Yellow River and its major tributaries have gone through a long process of erosion and cultivation, and in these processes, the fluvial terraces resulting from deposits of loess have become the major industrial and agricultural production bases in China (Liu 2005).

2.1.3 Plateau Hills

Plateau hills are the main topographic feature of the Loess Plateau region, accounting for over 60% of the total area (Liu 2005). Based on variations in paleo-geomorphology and erosive forces, the Loess Plateau hills can be divided into three parts. Lüliang Mountains are used as borderlines for division. The hilly region has its unique topographic features. For instance, the loess hills in the central Gansu region (the highest among the three hilly regions) have an altitude of



Fig. 2.6 Weihe Plain

1500–3000 m. In the north of this hilly region, the loess deposit is quite thin and the landform is featured by a combination of stony mountains and loess hills, while in the south, due to the higher rainfall and stronger erosion, the terrain is shattered (Fig. 2.7).

2.2 Soils

Loess is brownish yellow, loose, and relatively homogeneous in texture. It is aeolian, often silt loam or silty clay loam, as a result of wind deposit. The content of silt (particle diameter between 0.05 and 0.02 mm) is over 60% in loess. Loess soil has a strong vertical joint structure and soil cohesion relies mainly on calcium carbonate, which can be gradually dissolved if water permeates into soil. For this reason, loess is easy to break, collapses in water and thus highly erodible. The main soil types in the Loess Plateau include cinnamon soil, Lou soil, loessial soil, dark loessial soil, gray cinnamon soil, and sierozem (Table 2.1). With the exception of the stony mountainous areas, the thickness of the loess deposit is 50–80 m on average in most parts of the Loess Plateau; it may reach 150–180 m at maximum in some areas (Loess Plateau Scientific Expedition Team 1991).



Fig. 2.7 Terrain of the central Gansu area on the Loess Plateau

2.3 Water Resources

2.3.1 Rivers Characteristics

The main stream of the Yellow River in the Loess Plateau region has a length of 3000 km. At the transitional zone from more humid to more arid climate, there are many major tributaries of the Yellow River including Taohe River, Huangshui River, Zuli River, Qingshui River, Kuye River, Wuding River, Fenhe River, and Weihe River. The total drainage area of these rivers is 522,700 km², accounting for 84.1% of the overall Loess Plateau region (Loess Plateau Scientific Expedition Team 1991).

The annual natural runoff of the Yellow River is 58 billion m³/a. Four of its tributaries—Weihe River, Taohe River, Huangshui River, and Yiluo River—have an annual runoff of more than 3 billion m³. The Loess Plateau has thousands of ravines and gullies, more than 80% of which are dry and are usually plagued by mountain torrents and flash floods during rainstorms. In comparison with other regions of China, the Loess Plateau suffers from water shortage—the water amount per capita in the Loess Plateau region is only one-fifth of the national average—and the water availability for cultivated land is less than one-eighth of the national average. These facts make the Loess Plateau one of China's most water deficient

Table 2.1 Brief information on the main soil types (Yao et al. 2015)

Type	Distribution area	Physical property
Cinnamon soil	Under forest in semi-humid southeast of the Loess Plateau	Under natural vegetation, the soil normally contains 1–3% of organic matter. Where there are cultivation and farming activities, the organic matter content is usually below 1%. Hydromica and vermiculite are the main clay minerals, along with a slight amount of montmorillonite, kaolinite, and chlorite. Cinnamon soil has a well-developed argic horizon, thus can retain water and nutrients very well. It has a neutral or slightly alkaline reaction and is suitable for cultivating various crops. However, its organic matter content decreases sharply with cultivation; nitrogen and phosphorus contents are insufficient. Additionally, cinnamon soil in mountainous areas is often thin and has high content of rocks, not suitable for cultivation
Lou soil	Distributed on terraces, e.g., in the Fenhe Plain and Weihe Plain valley area, Guanzhong Plain	The clay content is 13–15%; the main clay mineral is illite in the upper layer, and illite and vermiculite in the lower layer. In general, the soil has a neutral or alkaline reaction, with a pH value of 7.0–8.5
Loessial soil	Widely distributed, particularly in the hilly and gully areas of northern Shaanxi, central and eastern Gansu, and western Shanxi, where soil erosion is severe	Weak soil forming process, soil profile presents uniform structure, strong lime reaction, with around 0.5% of organic matter content
Dark loessial soil	Mainly distributed in central and eastern Gansu, northern Shaanxi and northwestern Shanxi, with the greatest distribution in loess tableland	The soil layer is thick, normally 150–200 cm, with an organic matter content of 1.0–1.5%. The main clay minerals are illite and hydromica. Its pH value varies between 7.4 and 7.8
Gray cinnamon soil	Mainly distributed in Liupan Mountains, Lüliang Mountains, at an altitude of 1200–2600 m	The soil has neutral or slightly alkaline reaction. The content of organic matter is around 5% on average, and 10% at maximum
Sierozem	Limited distribution in the transitional area from grassland to desert	The content of organic matter is 0.7–1.5%. In terms of texture, clay accounts for 35–45%, with a variation of 10–20%. The main clay mineral is hydromica. Soil pH value is 8.0–9.5

regions. In terms of water resource per capita, Ningxia Hui Autonomous Region and Shanxi provinces rank the lowest in the loess region, which have only 200–400 m³ per capita. The Yellow River runs through Ningxia Hui Autonomous Region. The northern part of Ningxia Hui Autonomous Region is relatively flat; it is thus easier to build channels and divert water for agriculture. In contrast, the southern mountainous area of the province suffers from drought and water shortage due to difficulties in water diversion. In addition, Dingxi region, eastern part of Gansu, highlands of Weibei region, and hilly loess region of Shaanxi are places with scarce water resources (National Development and Reform Commission 2010).

2.3.2 Groundwater

Groundwater in the Loess Plateau region mainly includes pore water stored in loose rock structures, water in karst carbonate rocks, fissure water from crystalline rocks, pore, and fissure water from clastic rocks, pore, and fissure water from loess and underlying bedrocks. Pore water in loose rock structures is mainly distributed in the hilly areas and alluvial plains, totalling 19.63 billion m³/year, accounting for 56% of the region's total amount. Fissure water from crystalline rocks and fissure and pore water from clastic rocks is mainly distributed in mountains and flattened tableland areas, with the latter occurring in the hilly regions consisting of clastic rocks. Karst water is mainly distributed in mountainous areas, featured by large water quantity, good water quality, and easy accessibility, which accounts for 13% of the region's total resources. Fissure and pore water from loess and underlying bedrocks is mainly distributed in the expanse of hilly and gully regions, accounting for 7% of the region's total resources. It is obvious that with limited water resources, hilly and gully regions of the Loess Plateau suffer most from water shortage and poor water quality. Overall, the groundwater resources in the Loess Plateau approximate 33.6 billion m³, of which 86% is potable and covers 88% of the entire loess area. In terms of quality, most of the water is freshwater of high bicarbonate level and low mineralisation (Loess Plateau Scientific Expedition Team 1991).

2.4 Climate

2.4.1 Temperature

The Loess Plateau region is susceptible to monsoons. However, it is distant from the ocean (its eastern edge is 500–800 km away from the ocean), hence it has strong characteristics of continental climate (Zhang et al. 2007). The Loess Plateau has

three climatic zones in general: semi-humid climate in the southeast, semi-arid climate in the central part, and arid climate in the northwest. The lowest temperature appears in January, with an average temperature of below 0 °C, while the highest temperature appears in July, with an average temperature of 20–25 °C. The region is subject to dramatic temperature changes, the annual amplitude of temperature change is often over 25 °C in most parts and the amplitude has a tendency of increasing from south to north and from east to west. The ≥ 10 °C annual cumulative temperature is 2500–4350 °C (Liu 2005).

2.4.2 Precipitation

Rainfall in the Loess Plateau region is distributed unevenly over time and space. The average annual precipitation in the Loess Plateau region ranges from 200 to 600 mm. In the northern part, precipitation can be sometimes even less than 200 mm/a. Influenced by geographical location and topographic conditions, the average annual precipitation declines gradually from the southeast to northwest regions (Fig. 2.8). 50–70% of annual precipitation falls in July, August, and September and often in the form of heavy rainstorms. In addition, the interannual variations of rainfall are dramatic. The maximum annual rainfall can reach 1.5–2

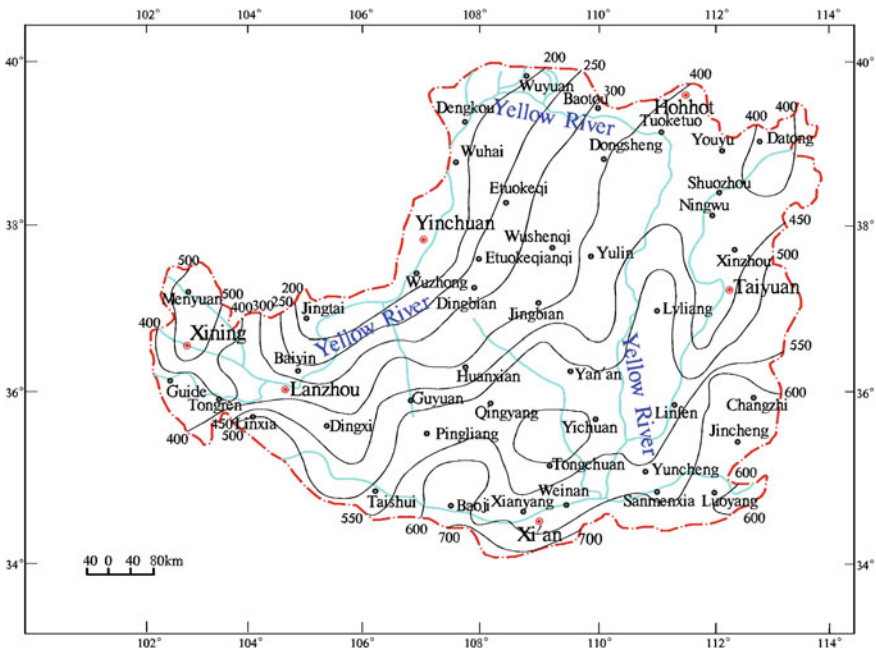


Fig. 2.8 Average annual rainfall isohyets in the Loess Plateau region (Liu et al. 2005)

times as much as the average annual rainfall, in most cases it is 1.5 times in the southeastern part and 2 times in the northwest (Huang and Li 1987).

2.4.3 Evaporation

The Loess Plateau's evaporation varies between 1000 and 2000 mm depending on the location—it is less than 1400 mm in southern Gansu, Liupan Mountains region of Ningxia Hui Autonomous Region, and south of the Weihe River in Shanxi; it is between 1600 and 2000 mm in Shanxi province, northern Shaanxi, most part of the Ningxia Hui Autonomous Region, and Gansu's Qilian Mountains region (Zhang et al. 2007).

2.5 Vegetation

The natural vegetation in the Loess Plateau has been destroyed for a long time. Therefore, to a certain extent, the existing vegetation does not fully reflect the true nature of vegetation zonality. Liu (2005) has divided the Loess Plateau into four vegetation zones: forest region, forest-steppe region, typical steppe region, and desert steppe region (Fig. 2.9). The covering area and vegetation features of each region are illustrated below.

2.5.1 Forest Region

The Forest Region is located in the southeastern part of the Loess Plateau. Broadleaved deciduous forests are the major forest types. The dominant species include *Quercus wutaishanica*, *Populus davidiana* Dode, and *Pinus tabulaeformis* Carr. There are also coniferous trees such as *Cunninghamia lanceolata* (Lamb.) Hook and *Platycladus orientalis* (Linn.) Franco. In addition, many other minor species such as *Koelreuteria paniculata* Laxm, and shrubs such as *Cotinus coggygria* Scop, *Forsythia suspensa* (Thunb.) Vahl, *Syzygium aromaticum* (L.) Merr. Et Perry, *Vitex negundo* Linn. var. *heterophylla* (Franch.) Rehd, *Ostryopsis davidiana* Decaisne, and *Lespedeza bicolor* Turcz also grow in this zone. *Quercus wutaishanica*, *Populus davidiana* Dode, and *Pinus tabulaeformis* Carr are the natural forests in this region. *Cotinus coggygria* Scop and *Forsythia suspensa* (Thunb.) Vahl are the region's typical shrubs, mostly distributed in low-altitude loess hills and tablelands. Major species for afforestation are *Pinus tabulaeformis* Carr, *Robinia pseudoacacia* Linn, *Paulownia fortune* (seem.) Hemsl, along with others like *Ailanthus altissima* (Mill.) Swingle, *Koelreuteria paniculata* Laxm,

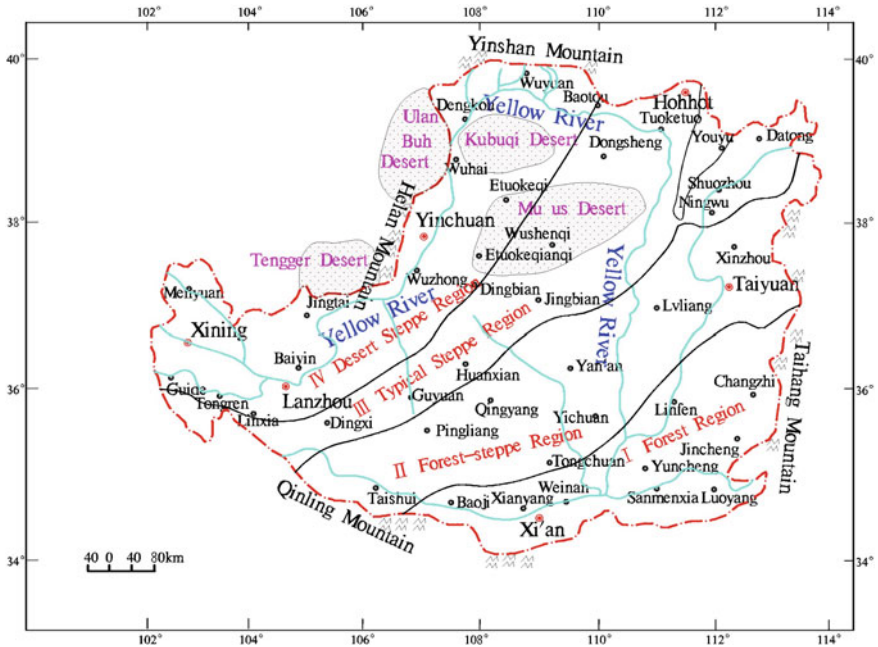


Fig. 2.9 Zonal distribution of vegetation in the Loess Plateau region (Liu et al. 2005)

Platycladus orientalis (Linn.) Franco, *Fraxinus bungeana* DC, *Morus alba* L, etc. (Loess Plateau Scientific Expedition Team 1991).

2.5.2 Forest-Steppe Region

This region covers the northern Huanglong Mountains, Ziwojing Mountains, and Liupan Mountains. Forests are formed mainly in high-altitude mountains, hills, and humid gullies. Shrubs are mostly mesoxerophytes and xerophytes, e.g., *Sophora moorcroftiana* (Benth.) Baker, *Prinsepia utilis* Royle, *Periploca sepium* Bunge, *Wikstroemia chamaedaphne* Meisn, etc. Mesoxerophytes are common in gullies and shady slopes, including *Syzygium aromaticum* (L.) Merr. Et Perry, *Spiraea fritschiana* Schneid, *Rosa xanthina* Lindl, *Ostryopsis davidiana* Decaisne etc. The environment in the loess hilly areas is getting drier (Cai et al. 2015). Steppe vegetation is becoming a dominant species, including *Bothriochloa ischcemum* (Linn.) Keng, *Stipa bungeana* Trin, *Lespedeza bicolor* Turcz, etc. In addition to natural vegetation, plantation is also carried out in this zone. Common afforested tree species are *Pinus tabulaeformis* Carr, *Robinia pseudoacacia* Linn, *Platycladus orientalis* (Linn.) Franco, etc.

2.5.3 Typical Steppe Region

Grass and shrubs are the dominant vegetation in this zone. The main grass species includes *Stipa bungeana* Trin, *Artemisia leucophylla* (Turcz. ex Bess.) C.B. Clarke, *Stipa capillata* Linn, *Thymus mongolicus* Ronn, etc.; while common shrubs species are *Caragana korshinskii* Kom, *Caragana microphylla* Lam, *Wikstroemia chamaedaphne* Meisn, etc. Shrubs used for plantation in this zone are *Hippophae rhamnoides* Linn, *Astragalus adsurgens* Pall, *Artemisia desertorum* Spreng, etc.

2.5.4 Desert Steppe Region

This region is located in the northern part of the Loess Plateau, bordering on the typical steppe region in the south. Among limited vegetation, *Stipa breviflora* Griseb is the most widely distributed one. Trees are rare in this region, only *Elaeagnus angustifolia* Linn, *Salix matsudana* Koidz, and *Ulmus pumila* Linn can be found. Compared to other regions, shrubs plantation covers a large area. However, it is still challenging to cultivate grass and shrubs in this zone due to the harsh conditions (Li et al. 2015).

2.6 Land Use and Agriculture Distribution

2.6.1 Current Status

It is estimated that 72.8% of the Loess Plateau region is affected by soil erosion. The annual sediment load into the Yellow River is 1.6 billion tons.a⁻¹. At the moment, the main land-use types are forestland (25.7%), grassland (25.4%), cultivated land (22.5%), orchards (1.9%), unused land (17.1%), and others (7.4%) (National Development and Reform Commission 2010).

2.6.2 Crop Farming

Wheat, maize, and millet are common grain crops in the Loess Plateau. Oil plants, cotton, beet, and tobacco are popular cash crops. The planting area of maize has been on the rise for years, and now takes the first place among all of the crops in terms of yield per unit area and total amount. Maize requires water and heat to grow. For this reason, maize is often planted in warm and humid valleys and flat areas, where the ≥ 10 °C cumulative temperature is >2800 °C, in some other cases also in mountainous areas (e.g., Taihang Mountains) where water is sufficient. Due

to the properties of drought resistance and barren tolerance, millet is a popular crop in this region, widely grown on relatively dry slopes in the semi-arid northern part of the Loess Plateau. In addition, sweet potato is a major product of central and southern districts of the Loess Plateau, while potato is popular in the northern district. Among oil plants, rapeseed, cotton seed, peanut, and castor are popular in the central and southern areas, whereas flax and sunflower mainly in the cold northern region.

2.6.3 Forestry

Due to long-term improper use, most of the natural forests have been destroyed, leaving only part of secondary forests, the main tree species of which are *spruce*, Chinese larch, Chinese pine, Chinese white pine, birch, aspen, oak, Oriental arborvitae, lacebark pine, hornbeam, *P. betulaefolia*, and *Ulmus macrocarpa*. Despite the significant increase in forest cover due to the implementation of afforestation, the forest cover in the Loess Plateau remains low because of the arid climate. The main purpose of forest development on the Loess Plateau is to control soil erosion and improve the environment, while addressing the regional timber, wood fuel, and other needs.

2.6.4 Orchard

Apple, jujube, pear, grape, peach, and apricot are the main fruit products in the region. In addition, dry nuts and fruits such as walnut and Chinese prickly ash (Huaajiao) are also preferred economic products for farmers. Jujube trees usually have a lifespan of over 100 years and are highly resistant to drought and infertility. By virtue of their well-developed deep root system and small canopy, jujube trees are suitable to be intercropped with other grains. By doing so, they are able to protect the soil from erosion and increase crop yield and income at the same time. For this reason, the jujube tree has become a popular species in the warm temperate area of the Loess Plateau.

2.6.5 Stockbreeding

In recent years, livestock breeding has been undergoing a booming development in the Loess Plateau region; its contribution to the gross regional agricultural product has risen from 10 to 25%. The primary and secondary varieties of animals for

breeding are different among regions. Herbivores such as cattle and sheep are most common in the northwest, with pigs as secondary choice; while pig farms are most common in the warm, humid central and southern parts, where cattle is the secondary option instead.

2.7 Ecological Problems and Risks

The Loess Plateau suffers from severe soil erosion resulting from special environmental conditions and intense human activities. The unique environmental conditions refer to drought, rainstorms, unfavorable topography, erodible soil, and sparse vegetation. As a consequence of unfavourable natural conditions, landslides, collapses, and flood frequently occur, leading to the degradation of natural resources (e.g., water) and damages of lives and properties. Apart from the natural conditions, the environment of the Loess Plateau is further deteriorated by irrational land use, such as deforestation, overgrazing, and intensified cultivation. The land productivity decreased significantly and the land cover/vegetation diminished rapidly resulting in further soil erosion. Soil erosion can cause loss of fertile topsoil, therefore nutrients (e.g., N, P, and K). Furthermore, sediments can quickly fill up dams that are built for flood control. This could lead to failure of dam performance, resulting in disasters like flash floods. Moreover, the trapped sediments in reservoirs and dams raise the river bed, creating a ‘hanging river’ and increasing risks of flood (Wang 1999).

The ecosystem of the dryland is vulnerable. The livelihood of the people and socioeconomic development in the Loess Plateau depend significantly on the ecosystem health and services. To remedy the situation, ecological restoration has been carried out (details are given in Chap. 3). However, various problems related to monoculture with exotic species occur, such as reduction in streamflow due to excessive soil water use, low survival rate of trees, unstable ecosystem, and loss of biodiversity. Given the dry environment of the Loess Plateau and the increasing demands for water and food due to population growth, the current land management cannot support the sustainable development of the region and provide adequate ecosystem services for the regional population. Therefore, a more innovative, efficient, and sustainable land-use system needs to be developed for the region.

2.8 Socioeconomic Conditions

2.8.1 Population

The Loess Plateau is one of the most densely populated regions in China (Yan 2007). According to the regional census in 2014, the permanent residents totalled

109 million, approximately 70% of which are rural population. The mean population density in the region is 170 pop/km², far exceeding the internationally recognized threshold of capacity (100 pop/km²) for dryland regions (Duan and Xu 1995). The total population of Shaanxi, Shanxi, and Gansu that live on the Loess Plateau accounts for 82% of the total regional population.

2.8.2 *Economy*

The gross regional product was RMB 4.92 trillion in 2014, with the primary, secondary, and tertiary industries accounting for 7.0, 50.3, and 42.7%. It is obvious that the secondary industry is dominant. They are mainly distributed in several large cities, such as Xi'an (Shaanxi province), Taiyuan (Shanxi province), and Lanzhou (Gansu province). The Loess Plateau region has abundant mineral resources and has undergone energy industry development including coal mining, petroleum and natural gas, and non-ferrous metal industry such as lead, zinc, aluminum, copper, molybdenum, tungsten, and gold, as well as rare earth. These industries are the driving forces promoting the regional economy.

Additionally, due to abundant sunshine and large temperature variations over the day, the Loess Plateau has an advantage of producing high-quality agricultural products. For example, it is the largest kiwi and second largest apple producer in China. At the same time, it is also a major growing district of high quality pears and jujubes, Chinese herbal medicine plants, and potatoes. With the exception of a few industrial cities, the Loess Plateau is mainly an agriculture dominated area. Nevertheless, its economy has the following features: (i) low economic growth compared to the national average; (ii) remarkable differences in development among areas within the region depending on quality of natural environment and availability of natural resource; (iii) underdeveloped agriculture, characterized by low crop yield and farmer income (Zhang 2005).

Recently, the Loess Plateau region has set its development goals and prioritized the goals for different areas. The ecosystem-related goals include provision of sufficient food, soil conservation, provision of water of high quality, and maintaining biodiversity. Despite rich land, energy, coal, mineral and other natural resources, its population carrying capacity is limited by severe water shortages and droughts. If Northwest China continues to implement the traditional model of development, it will be very difficult to solve the conflicts between economic development, resource conservation, and environmental protection fundamentally. It will also be very difficult to stop environmental degradation and environmental damage, thereby posing a serious threat to the sustainable development of Northwest China. Adjustment of the current land policy is required in order to achieve a more sustainable development of the region (Liu et al. 2012).

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