4 Sandy Deserts, Gobi, Sandlands and Sandified Land in Dryland

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In China, the areas of dryland and susceptible dryland (hyperarid area excluded) are 357.05 and 331.70 million ha, respectively (CCICCD, 1997;), and 263.62 million ha had suffered or were suffering from desertification, covering 12 main deserts and sandlands (Taklimakan Desert, Gurban Tonggut Desert, Kumtag Desert, the Deserts in Qaidam Basin, Badain Jaran Desert, Tengger Desert, Ulan Buh Desert, Qubqi Desert, Mu Us Sandland, Otindag Sandland, Horqin Sandland, and Hulun Buir Sandland.) (Zhu, 2006), in which majority is related to sand-covered land. In this chapter, we focus on the introduction of sandy deserts, Gobi, sandlands and sandified land in drylands.

4.1 General situation of sandy deserts, Gobi, sandlands and sandified land

China is one of the countries in the world most severely affected by desertification and sand encroachment (Zhu, 2006). The area of Gobi, sandy deserts, Gobi, sandlands and sandified land in China is about 1.688 million m^2, which covers 17.6% of the national territory. The drylands are mainly distributed in the interior basins and plateaus between 35°N and 50°N, forming a sandy desertification belt about 4,500 km long and up to 600 km wide. The western end is near the western Tarim Basin in Xinjiang, and the eastern end is on the western Songnen Plain. This vast region encompasses the three northern areas of China (northwest, north and northeast China). Isolated patches of sandified land are also distributed on the coastal, river and lake areas. Gobi is distributed in the high and cold area of the Qinghai-Tibetan Plateau (Fig. 4.1).

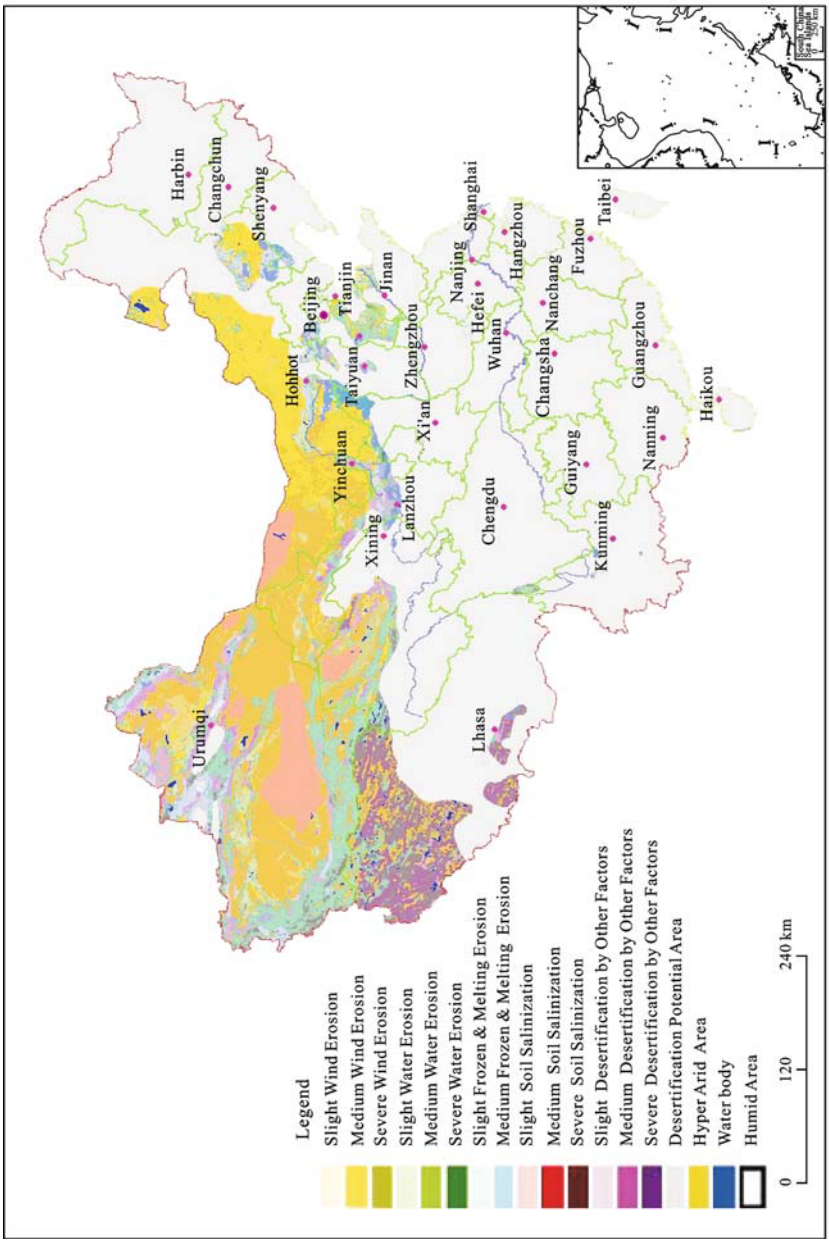

Fig. 4.1 Desertification distribution map in China (CCICCD, 1997; Yang et al., 2005, with permission from authors)

4.1.1 General distribution range of sandy deserts, Gobi, sandlands and sandified land

Sandy deserts, Gobi, sandlands and sandified land in different natural zones exhibit different manifestations of aeolian landforms.

North of the western desert region is the China-Mongolian boundary, to the south is the west end of the Yinshan Mountains, the Helan Mountains, Wuqiaoling Mountain, Qinghai Lake, west of Zhaling Lake and south of the Tianshan Mountains. This area contains several deserts including the Taklimakan, Kumtag, Qaidam, Badain Jaran, Tengger and Ulan Buh deserts. Its chief feature is the dry climate and recurring droughts. The average annual precipitation is below 250 mm and is extremely variable. Precipitation in some desert areas is only a few millimeters each year. The mobile dunes and longitudinal dunes are the most common dune forms on river banks, while in the sink area fixed or semi-fixed dunes are present, characterized by the high water table and the good vegetation growth.

North of the Tianshan Mountains in Xinjiang is the northeast sandy region, including the Gurban Tonggut Desert, Akkum Desert and Barikun Basin Desert. Although located in the arid zone belt, the seasonal distribution of precipitation is quite even, with snow occurring during winter and spring and rain in the summer. This moisture regime favors the development of fixed and semi-fixed dunes in this region.

Sandlands are also located in arid, semi-arid and dry sub-humid areas. Locations include the Songnen Sandland, Hulun Buir Sandland, Horqin Sandland, Otindag Sandland, Qubqi Desert, Mu Us Sandland, Ningxia Hedong Sandland, Qinghai Lake and Gonghe Basin. Here the wind-drift sand distribution is generally patchy, and the scale is small. Sand dunes are commonly interspersed with rivers, lakes and bogs. For example, there are dunes in the southeast of the eastern region, some paleochannels and floodplains on the Sanjiang Plain, Huang-Huai-Hai Plain and the middle and lower reaches Yangtze River Plain, as well as the seaside belt in some coastal provinces.

In summary, the sandy deserts, Gobi, sandlands and sandified land in China are broadly distributed, spanning many ecosystems and climatic zones. Their origin and the complexity of the landforms are unique in the world (Yang et al., 2008).

4.1.2 Distribution of sandy deserts, Gobi, sandlands and sandified land

Sandy deserts, Gobi, sandlands and sandified land in China (comprising 172,799,072 ha) are spread over 13 provinces or autonomous regions: Beijing, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Qinghai,

Gansu, Shaanxi, Ningxia, Xinjiang and Tibet. The seven provinces or autonomous regions with the largest areas of sandy deserts, Gobi, sandlands and sandified land are, from largest to smallest, Xinjiang, Inner Mongolia, Tibet, Gansu, Qinghai, Shaanxi and Ningxia. The total area of sandy deserts, Gobi, sandlands and sandified land in these provinces includes 96.40% of the sandy deserts in China. The total area in the other provinces, autonomous regions and cities is 6,288,566 ha (3.60%).

The "Three North" Shelter Forest Project area is the central area of sandy deserts, Gobi and sandland in China. The project area includes 13 provinces or autonomous regions, which contain 551 counties. Sandy deserts, Gobi, sandlands and sandified land are found in 322 counties in this area. The total area is 1.48 million ha, accounting for 84.5% of the total area of sandy deserts, Gobi, sandlands and sandified land in China.

In the Inner Mongolia-Xinjiang Plateau area, sandy deserts, Gobi, sandlands and sandified land are mainly located in the Tarim Basin, Junggar Basin, and Turpan-Hami Basin of Xinjiang, stretching eastward across Gansu's Hexi Corridor, then north through Ningxia, reaching the western regions of the Yellow River valley, and western part of Inner Mongolia, reaching into the eastern part of the steppe zone, through northern Shanxi to the west of Jilin. The total area of sandy deserts, Gobi, sandlands and sandified land in this region is 1,296,000 ha.

In the Qinghai-Tibetan Plateau, sandy deserts, Gobi, sandlands and sandified land are found mainly in the Qaidam Basin of Qinghai Nali area, the northern part of the great Qiangtang Plateau of Tibet, the river valley of the "three rivers" in eastern Tibet, and the northwest Sichuan Plateaus. There is also a patchy distribution of other arid areas. The total area of sandy deserts, Gobi, sandlands and sandified land is 334,200 ha.

In the eastern region, sandified land of the river, lake and coastal areas, covers 57,600 ha, including the Songnen Plain, Huang-Huai-Hai Plain, Yellow River, Yangtze River and its branches, and other river deltas. Sandlands in the coastal area is mainly located in the coastal plains and coastal beaches, including Liaodong Beach, Changli and Shanhaiguan in Hebei, the Jiaodong Coast, Dongtai and Dafeng in Jiangsu, Putuo in Zhejiang, Changle and Jinjiang in Fujian, Leizhou in Guangdong, Beihai in Guangxi, and the Hainan Island. Sandlands in this area covers 10,100 ha.

The total length of China's sandy coastline is 3,216 km (18% of the national coastline) and mobile dunes occur on 585 km (18.47%), semi-fixed dunes on 584 km and fixed dunes on 1,671 km. The provinces with the longest sandy coastline are listed in descending order as Hainan (23.26%), Guangxi (21.27%), Guangdong (21.55%), Jiangsu (14.55%), Fujian (9.95%), Liaoning (4.10%), Shandong (3.67%), Hebei (1.2%) and Zhejiang (0.35%).

Sandified land in lake areas occurs on lakeside plains and along the lakeshore in areas like Poyang Lake and Dongting Lake which are primarily associated with lakeside plains. The total area of sandified land in lake

areas is 108,020 ha (1.94%) in the humid and semi-humid region (Zhou et al., 2002).

Sandy desert and Gobi are mainly distributed in arid areas, sandlands are found in semi-arid and dry sub-humid areas and sandified land is found across all climatic zones from arid to humid zones in China (Yang et al., 2005).

4.1.3 Development trend and current situation of land sandification

Since the 1950s and 1960s, intense over-cutting and overgrazing have destroyed vegetation and caused the former semi-fixed and fixed dunes (sandland) to lose the protection of vegetation. The area of land degraded in this way totaled 3,294,293.5 ha (an increase of about 73,206 ha·a^{-1}). However, measures such as artificial reforestation, grass plantation and grazing bans have worked to restore the land productivity, improve the ecological benefits of sandstorm control, resist the spread of shifting sand and reduce damage from sandstorms, by gradually fixing some shifting sand and helping some semi-fixed dunes become fixed. The treated area is 6,168,013.4 ha (which equates to a restoration rate of about 137,067 ha·a^{-1}). Fortunately, now, the area where sandification is reversing is bigger than the area of sandification expansion in restoration areas. This shows that the area of sandification in these lands has reduced year by year, and that the land productivity is gradually being restored and improved. The physico-chemical properties of the soil in land where sandification has been reversed have not been essentially changed. The sandland ecological environment is still very fragile. If the vegetation is destroyed, the fixed sand will be become mobile again.

The sandification process is leading to a rapid increase in the area of newly sandified land, and is also causing the reactivation of fixed sand dunes. This means that more land will face the full impact of wind erosion, sand dunes will grow gradually and the productivity of the land will decrease and may even be completely lost. Eventually, the soil will be totally changed, leading to irreversible sandification.

According to the 1999 national desertification monitoring, the area of sandified land increased by 1,718,200 ha compared with 1994, which was an average rate of increase of 343,640 ha·a^{-1} (about 0.20%). This dynamic process mainly occurs in the 13 northern provinces and autonomous regions. According to case studies in 214 counties of 13 provinces and autonomous regions, the sandified land area increased by 149,590,981 ha. The areas of sandified land in Inner Mongolia, Gansu, Qinghai, Xinjiang, Tibet, Heilongjiang and Liaoning are enlarging at average annual rates of 0.86%, 0.08%, 0.21%, 0.003%, 0.2%, 0.2%, and 0.08%, respectively, whilst in Ningxia, Hebei, Shaanxi, Shanxi, Beijing, and Jilin there has been a slight decrease in the area of sandified land (generally less than 0.5%).

Sandification in Qinghai-Tibetan Plateau and Inner Mongolia-Xinjiang Plateau is increasing each year. The net rates of increase are 0.16% and 0.24%, respectively. For the 12 main deserts and sandlands, the Mu Us Sandland and the Horqin Sandland are reducing in area, and the others are increasing. In the Taklimakan Desert the yearly net expansion rate is 0.09%, the Gurban Tonggut Desert is 0.91%, Kumtag Desert is 0.001%, Qaidam Basin Desert is 0.05%, Badain Jaran Desert is 1.04%, Tengger Desert is 1.32%, Ulan Buh Desert is 1.78%, Qubqi Desert is 1.46%, Otindag Sandland is 1.84%, Hulun Buir Sandland is 0.67%, Mu Us Sandland is –0.03%, and Horqin Sandland is –0.65%.

4.2 Sandy deserts, Gobi and sandified land in Xinjiang Uygur Autonomous Region

The sandy deserts, Gobi and sandified land in Xinjiang can be found in 80 counties with a north-south area covering 1,200 km from 47°30′ N in the southern Altai mountains to 36°20′ N in the north of the Kunlun Mountain, and an east-west area covering 1,700 km from 96°21′ E near the border with Gansu Province and the China-Mongolian border to 75°50′ E connecting with the Kazakhstan desert.

4.2.1 Sandy deserts, Gobi and sandified land status and distribution

4.2.1.1 Type and area of sandy deserts, Gobi and sandified land

Xinjiang's sandy deserts, Gobi and sandified land areas cover 76,920,460.3 ha, of which wind eroded relic hill areas are 928,980.8 ha (1.21%), Gobi is 32,808,486.3 ha (42.65%), sandy deserts cover 34,929,174.8 ha (45.41%), and sandified land is 8,253,818.4 ha (10.73%).

Sandy deserts and sandified land cover 43,182,993.2 ha, of which mobile dunes are 32,116,354.4 ha (74.37% of the total area), semi-fixed sand dunes are 8,419,937.9 ha (19.50%), fixed dunes are 2,527,715.5 ha (5.85%); non-bioengineered control sand is 70,314.9 ha (0.16%), bare sand is 46,620.2 ha (0.11%) and sandified cropland is 2,050.3 ha (0.01%).

4.2.1.2 Distribution of sandy deserts, Gobi and sandified land

Xinjiang can be divided into four regions with total area of 67,465,844.0 ha (87.7% of total sandy deserts and sandified land areas). Patchy areas of sandy deserts and sandified land in the other parts of Xinjiang occupy 9,454,616.3 ha (12.3% of the total area).

(i) Sandy deserts, Gobi and sandified land in northern Xinjiang

The Gurban Tonggut Desert of the Junggar Basin is a desert in the northern Xinjiang arid zone. It covers six administrative prefectures, four cities and 36 counties. In this region, there are five main sandy deserts: the Gurban Tonggut Desert, Burqin-Haba River-Jimunai Desert, Fuhai-Fuyun Desert, Wusu Desert, and Takeermohuer Desert.

i) Gurban Tonggut Desert

The Gurban Tonggut Desert is located in the middle of the Junggar Basin, and is China's second largest desert. Its total area is 8,225,224.9 ha. There are 384,189.6 ha of mobile dunes, 3,592,253.9 ha of semi-fixed dunes, 802,629.4 ha of fixed dunes 1,795.0 ha of sandified farmland and 353.7 ha of bare sand, Gobi covers 3,374,436.6 ha (41.03%), and wind eroded relic hills are 66,751.5 ha (0.81%).

The Gurban Tonggut Sandy Desert consists of four main components. To the east of Qitai is the Huojingnielixin Sandy Desert located in the Junggar Plateau Corridor in a belt 220 km long and 40–50 km wide. The main body of the Gurban Tonggut Desert extends south of the three spring wadis. This desert is about 200 km long and 135 km wide. The Suobuguerbugelai Desert is located between the west bank of the Manas River and the east bank of Kuitun River. The Kuobubei-Akekumu Desert is located to the north of the three spring wadis.

The Gurban Tonggut Desert has a reasonable amount of precipitation, up to 70–150 $mm \cdot a^{-1}$, which falls mainly as snow. Snow falls on average about 30 days per year and the land remains snow covered for 100–160 days to a depth of more than 20 cm. Annual evaporation is 1,400–2,000 mm and the aridity index is 2–10. The spring rain promotes a vigorous growth of ephemeral plants and vegetation coverage is greater than 50%.

There are many plant resources in the desert, including *Haloxylon ammodendron*, *Ephedra distachya*, *Hedysarum scoparium*, *Calligonum mongolicum*, *Haloxylon persicum*, *Artemisia santolina* and many kinds of ephemeral plants such as *Portulaca grandiflora* and *Eremosparton songoricum*.

The Gurban Tonggut Desert has a fairly simple landform pattern, which consists of tree-like dune ridges in the middle and northern parts and honeycomb sand dunes in the south. The dune height is generally 10–30 m, the ridge height of the sand dune chains is 5–8 m, and the vertical sand dunes are about 20 m high. There are fixed and semi-fixed dunes with heights of 2–4 m at the edge of the desert.

ii) Burqin–Haba River–Jimunai Desert

Burqin–Haba River–Jimunai Desert is located in the northwest of the Junggar Basin, the west of Burqin County and both sides of the Irtysh River. Its total area is 858,898.0 ha, of which mobile dunes are 105,383 ha (12.27%), fixed dunes are 166,054 ha (19.33%), semi-fixed dunes are 202,356 ha (23.56%), Gobi is 366,215 ha (42.64%) and wind eroded hills are 18,890 ha (2.20%).

In this region, the Kumtag and Tazikumu Deserts are located at the tilt tableland of the northern foothills of Sawuer Mountain, and these deserts mainly consist of crescent shaped (or barchan) dunes and dune chains. The Tunkekumu and Akekumu Deserts are located on the hilly piedmont slope of the Altai Mountains and there are sand ridges 50 m high in the foothill belt.

The mobile dunes are on the piedmont pitch and the higher elevation terraces. Because of the northwest wind in the river valleys in winter and spring, snow cannot accumulate on the ground surface. Ephemeral plants that normally depend on snow-melt water cannot grow, and shrub survival is also difficult, making the sand dunes bare and quite mobile. Generally, the height is 10–20 m, with some as high as 50–100 m. Vegetation is sparse, with only a few *Phragmites communis*, *Phragmites communis* and *Allium mongolicum* on the windward and leeward slopes; *Calligonum* spp. on the windward slopes of the low mobile dunes, and *Artemisa arenaria*, *Stipa tianschanica* and *Inula aspera* on the flat interdunes. The fixed and semi-fixed sandy mounds of the Irtysh River terraces have a height of 3–5 m, and are covered with *Populus euphratica*, *Salix cinerea*, *Halimodendron halodendron* and *Atraphaxis jrtyschensis*.

iii) Fuhai-Fuyun Desert

The Fuhai-Fuyun Desert is located between the Irtysh and Ulungur Rivers to the east of Buluntuo Lake. It includes Fuhai Desert and desert between two rivers in the south of Fuyun County. The total area is 1,268,780 ha, in which Gobi covers in 1,195,862 ha (94.25%), fixed dunes cover 20,259 ha (1.60%) and semi-fixed dunes cover 52,659 ha (4.15%).

iv) Wusu Desert

The Wusu Desert is located to the northwest of the Junggar Basin, between the Guertu and Kuitun Rivers, and the southeast part of marshland around the Aibi Lake. Its total area is 786,380 ha, of which Gobi covers 566,481 ha (72.04%), mobile dunes cover 69,122 ha (8.79%), fixed dunes cover 70,070 ha (8.91%), and semi-fixed dunes cover 80,707 ha (10.26%). The sand ridges are generally 10–15 m high and some can reach 35 m high. The ridge tops are bare and *Haloxylon persicum*, *Calligonum mongolicum* and *Artemisia santolina* can be found on gentle west-facing slopes while on the leeward slopes there are many ephemeral plants such as *Semen trigonellae*. Ephemeral plants, desert lichens and desert shrubs can also be found on the low-lying sand ridges, and include *Haloxylon persicum*, *Artemisia vulgaris*, *Haloxylon ammodendron*, *Reaumuria soongarica*, and *Anabasis aphylla*.

v) Takeermohuer Desert

The Takeermohuer Desert is in the northwest of Huocheng County. It meets the old Huocheng city in the north, the bank of the Yili River to the south, and extends along the Yili River of Chabuchaer County. It consists of two desert patches, the Takeermohuer Desert and the Bajitai Desert. It covers about 40 km wide and 15–40 km long with the desert area covering 46,720 ha. The fixed dunes cover 11,380 ha (24.36%), semi-fixed dunes cover

34,408 ha (73.65%), and Gobi covers 932 ha (1.99%).

(ii) Sandy deserts, Gobi and sandified region in southern Xinjiang

This region is located in the Tarim Basin. The Tarim Basin is an enclosed inland basin, surrounded by mountains on three sides. It has an arid climate with great temperature fluctuations. It is one of the most arid regions in China. There are 40 counties in this region.

i) Taklimakan Desert

The Taklimakan Desert is located in the warm arid region with altitude of 800–2,500 m. The Taklimakan Desert, in the center of the Tarim Basin, is the largest mobile sandy desert in China. It includes the Kuluke Desert in the west of Lop Nor and the lower reaches of the Tarim River; the Alakumu Desert in the north Altun Mountain and south Qiemo River; the Tuokelake Desert; and the Buguli Desert in the delta plain of the Kashi River. The total area of the main body of the Taklimakan Desert is 41,088,083.9 ha. Mobile dunes cover 29,431,000.4 ha (71.63%), Gobi covers 6,035,567.1 ha (14.69%), abandoned cropland covers 135.3 ha, bare sand covers 13,444.5 ha (0.03%), and wind eroded hills cover 52,203.6 ha (0.13%).

In the Taklimakan Desert, the sand dunes are large with complex shapes and a general trend of low sand dunes (less than 25 m) near the desert margins, and high dunes (50–80 m) in the interior, with a few as high as 200–300 m. Using the Keliya River as a boundary, there are large, complex northeast-southwest sand ridges in the east, and barchan dunes, barchan dune chains and complex sand dune chains in the west. In the north of the Mazhatage Mountain, the sand dune types from north to south are sand mounds, barchan dunes and barchan dune chains, fish scale sand dunes and complex barchan dune chains. There are quaquaversal sand dunes and complex barchan dunes downstream of the Tarim River, the Keliya River and the old Tarim River bed, and there are pyramid sand dunes in the Qiemo-Yutian region.

Green corridors are formed by the rivers downstream of the Tarim, Niya, Hetian and Qiemo Rivers in the Taklimakan Desert, with many fixed and semi-fixed sand dunes located along them.

ii) Akebiele Desert

The Akebiele Desert is located to the east and south of Bositeng Lake, and consists of the Akebiele Desert and the Maertazining Desert, with a total area of 643,477 ha. Gobi covers 517,694 ha (80.45%), mobile dunes cover 64,712 ha (10.06%), fixed dunes cover 17,697 ha (2.75%), semi-fixed dunes cover 43,254 ha (6.72%), and abandoned cropland is 120 ha(0.02%). The Akebiele Desert is 75 km long and 3–10 km wide on average, and stretches from Ahongkailedi to the southeast of Bositeng Lake. The Maertazining Desert goes from the southeast to the north along eastern shore of the Bositeng Lake, and is 20 km long and 4 km wide on average.

Sand dunes to the southeast of Bositeng Lake are mainly pyramid shaped and ridge shaped with heights of 100–150 m. To the south of the lake the dunes are mainly barchan dune chains 40–150 m high and 1–2 km wide.

(iii) Kashun Deserts, Gobi and sandified region

The Kashun desert, Gobi and sandified region is located in the east of Xinjiang in the Turpan-Hami Basin of the eastern Tianshan Mountains, in the Kashun arid denudation mountains and the Lop Nor marshland in the southeast of Xinjiang. The area has an arid climate with little precipitation and frequent sandstorms due to scarce vegetation in the grasslands, low mountains, Gobi and deserts. Its administrative areas include Turpan and Hami, and include the Kumtag Desert and the Shanshan-Kumtag Desert.

i) Kumtag Desert

The Kumtag Desert is located in the eastern part of the Tarim Basin, and southeast of Lop Nor, north of Altun Mountain, in the east it extends to Dunhuang in Gansu Province. Its total area is 6,972,489.2 ha, of which Gobi covers 4,743.287.5 ha (68.03%), mobile dunes cover 1,559,325.4 ha (22.36%), and wind eroded hills cover 669,876.3 ha (9.61%).

This desert lies in an inland area with a hyper-arid climate, and the natural environment is extremely harsh with a mean annual precipitation below 10 mm. The desert was formed by deposition of materials blown from neighboring areas. The Kumtag Desert consists mainly of feather-like sand dunes, and pyramid and barchan dune chains. The relative height of the dunes is 100–200 m and the highest is 300 m, with the majority of these sand dunes located in a rocky mountainous region with an elevation of 1,250–2,000 m, and on ancient diluvial-alluvial plains.

ii) Shanshan-Kumtag Desert

The Shanshan-Kumtag Desert is located in the Turpan Basin, mainly in Shanshan County. Its area is 4,072,277 ha, in which Gobi covers 3,743,109 ha (91.92%), mobile dunes cover 221,859 ha (5.45%), fixed dunes cover 420 ha (0.01%), semi-fixed dunes cover 7,773 ha (0.19%) and wind eroded hills cover 99,116 ha (2.43%).

Dense sand dunes now cover the whole region except the center Youkelake rock area, formed by the combination of prevailing winds from the northeast and northwest and rich wind-eroded fine material from diluvium and deposition. In the north, the desert mainly consists of sand ridges, which are 15–20 m high, and pyramid sand dunes are formed in the south and northeast. The desert is very arid, and there are only a few plants such as *Tamarix chinensis* and *Alhagi pseudalhagi* at the edge of desert. The desert is mainly moving to the south, which is not damaging the Shanshan oasis.

(iv) Kunlun Mountain alpine deserts and sandified region

In general, the Kunlun Mountains are a desert and semi-desert mountain range with low precipitation and a dry and cold climate year round. The deserts and sandified region are concentrated in the Kumukuli Basin, and the administrative areas include the whole of Tashikuergan County, and mountain regions of Ruoqiang, Qiemo, Minfeng, Yutian, Cele, Hetian, Pishan and Yecheng counties.

The Kumukuli Desert, located in the Kumukuli Basin in the eastern

Kunlun Mountains, has a total area of 3,503,514 ha, in which Gobi covers 3,180,962 ha (90.79%), mobile dunes cover 190,361 ha (5.44%) and semi-fixed dunes cover 132,191 ha (3.77%). The elevation is 3,900–5,100 m, making this the highest desert in China. The Kumukuli Desert is an alpine desert, and has a cold, dry climate with annual precipitation of 240 mm, mainly falling in April, July and August. The annual mean temperature is 0–1 ℃. The prevailing wind is westerly (80% of the time), and the maximum wind speed can reach 8 $m \cdot s^{-1}$ in March and April. The desert plants are scarce, and common plants include *Oxytropis aciphylla*, *Salsola collina*, *Stipa* spp., and *Carex moocroftii*.

(v) Sporadic deserts and sandified land

The total area of sporadic deserts and sandified land in Xinjiang is 9,454,616.3 ha, of which Gobi covers 9,083,940.1 ha (96.08%), mobile dunes cover 90,402 ha (0.96%,), fixed dunes cover 64,103.8 ha (0.68%), semi-fixed dunes cover 158,373.5 ha (1.67%), non-bioengineered fixed sand covers 2,831.5 ha (0.03%), bare sandland covers 32,822 ha (0.35%) and wind eroded hillock covers 22,143.4 ha (0.23%).

4.2.2 Effects of sandification

(i) Changes to river flows and lakes

In the 1950s, Xinjiang had 52 lakes covering more than 5 km^2 each, and total lake area was 9,700 km^2. By the late 1970s, the lake area had declined sharply to 4,748 km^2. The famous Lop Nur, Manas, Aiding, and Taitema Lakes had dried up. The area of the Ulungur, Bositeng, and Aibi Lakes had also declined sharply. The amount of water in the Tarim River reduced year by year, and the Kashgar River ceased flowing into the Tarim River in 1990. In the 1950s, the Yarkant River had an annual water volume of 1.0–1.5 billion m^3 flowing into the Tarim River but as a result of dam construction in its upper reaches, no water has flowed into the Tarim River since 1979.

The annual mean water volume of the Hetian River flowing into the Tarim River was 1.1–1.2 billion m^3 in the 1950s but since the 1980s it has reduced to an average 0.8 billion m^3 with only 0.04 billion m^3 in one year. The Tarim River, the longest inland river in China, has been dry for more than ten years in the lower reaches from Daxihaizi, and in these areas, vegetation has declined, the sandification of "the green corridor" has become more serious and 160 km of river course has been buried by sand.

"The green corridor" of the lower reaches of the Tarim River is located between the Taklimakan and Kuluke Deserts, and is the second most important corridor from Xinjiang to Qinghai and inland, and is also another shortcut to the southern edge of the Tarim Basin. Its strategic position is very important. Before the 1920s, "the green corridor" had been prosperous. At that time, the water volume in the Tarim River was high, and there were abundant aquatic

plants along both banks. As a result of a change to the river course in the mid-1920s, the corridor habitat deteriorated. The Luntai Dam was constructed in the Layin River estuary in Weili County in 1952, and river water was forced to flow into Taitema Lake, restoring the corridor habitat. By the 1970s, construction of the Daxihaizi Reservoir reduced the flow of the Tarim River, and the groundwater level dropped rapidly, *Populus euphratica* forest degraded at a large scale, pasture became seriously degraded, and sandification developed rapidly in the corridor. In the Alagan region there were almost no blown sand events 100 years ago, and good quality natural pastures were common 40 years ago. After the Tarim River dried up in 1972, irrigation ceased and the area of abandoned farmland increased rapidly. Due to shrub over-cutting outside the farming area, the originally fixed and semi-fixed dunes reactivated and encroached on farmland in five farms. At the same time, part of the farmland was abandoned because of water scarcity, and the loose ground surface formed the sandified land. It is estimated that more than 8,600 ha of farmland was abandoned or left uncultivated, of which nearly 2,000 ha was buried by the shifting sand.

(ii) Degradation of vegetation and expansion of sandified land

The Tarim River area is China's largest and the most concentrated area of *Populus euphratica* forest. In the 19th century it was described as "dense trees make beautiful forest" and "flourishing forest". In 1958, the Tarim River watershed had 400,000 ha of *Populus euphratica* forest, but by the 1990s it was found that only 358,000 ha remained. In the Bayinguoleng region, about 10,000 t of *Glycyrrhiza glabra* was dug up each year, leading to the destruction of 110,000 ha of vegetation in the middle and lower reaches of Tarim River, and sandification of the area. The Hetian area suffers from a shortage of energy, so fuelwood was supplied from the *Populus euphratica* forest and desert forests. In just three counties (Hetian, Moyu and Luopu), fuelwood collection was 300,000 t each year, resulting in a large area of barren land.

(iii) Sandification of artificial oases

During development of artificial oases, people destroy the forest, exploit wastelands, and transform grassland into farmland. Because of the scarcity of water resources for irrigation, some arable land had to be abandoned soon after ploughing. Because of vegetation destruction and the vulnerable surface soil exposed to wind erosion, most abandoned cropland became sandified land.

The Hetian region, at the southern edge of the Taklimakan Desert, is a typical example of oasis agriculture in a sandy desert region. There are hundreds of pieces of oasis of different sizes which form an oasis belt about 600 km long from west to east. There is about a 2,000 km belt of wind eroded landscape and Gobi around these oases.

In Pishan County, for example, there are 53 pieces of oasis within a perimeter of 516 km. Here, the forest area is 1,340,000 ha, and the desert area is 11,669,000 ha. Because the oasis area is small and fragmented, and the surrounding desert vegetation has been almost destroyed, there is now no buffer

zone between the artificial oasis and the mobile desert. The invasion of shifting sand into the oasis has interfered with agricultural production and animal husbandry at the edge of the oasis and also adversely affected people's lives. Since 1949, about 28,000 ha farmland within the oasis area has been degraded. In mid-May 1986, a strong wind damaged more than 90% of the cotton fields including 50% of the fields in the area in the center of the oasis.

(iv) Disruption to industrial and agricultural production

Blown sand events are the biggest natural disasters in Xinjiang. For example, a cold air and sand-dust storm swept across more than 60 counties in 13 regions on April 9–11th 1979, and the wind force reached 8–9 on the Beaufort scale and as high as 12 in some areas. In eastern and southern Xinjiang, more than 30 counties were affected by the strong winds on May 17–20th 1986, 153,000 ha farmland was affected severely, 16 people died, 94,000 head of livestock died or were lost, and 800,000 trees, 3,000 telephone poles and nearly 2,000 houses were blown down.

The Turpan Basin has special topographical features and climate characteristics, and is one of the areas most seriously affected by sand-dust storm in Xinjiang. On April 24th 1984, a sand-dust storm destroyed 1,334 ha farmland in Turpan, affecting 17.6% of the sown area. The sand buried 69 qanats, obstructed 63,850 m of irrigation channels, killed 132 head of livestock, 90 houses collapsed, 88,000 m forest belts were buried by sand and 23,820 trees were blown down.

(v) Sand dunes reactivated and moving along the traffic lines

Road construction often destroys vegetation, causing the fixed and semi-fixed sand dunes to reactivate, which in turn endangers the roads. In the windy season of 1987, 95 road surfaces accumulated sand over a length of 100 km from Alagan to Luobuzhuang on the Kuruo highway, and six areas were completely buried by sand which seriously affected transportation.

At the southern edge of the Taklimakan Desert, a 350 km section of national highway No.315 from Qiemo to Ruoqiang is affected by serious shifting sand which endangers more than 40 km of this road. For example, about 17 km long between milestones 32 and 49, southeast of Qiemo County where the road is threatened by mobile barchan dunes that bury the road.

The Alakumu Desert moves from northeast to west, and forms several shifting sand belts which go straight to the nearby Cheerchen River. Barchan dunes and barchan dune chains move to the southwest with annual speed of 49 m and the mobile sand dunes have reached the highway in five places affecting 4.05 km of highways within Qiemo County. In the 180 km stretch from Qiemo to the Andier River, three mobile sand belts are encountered. There are mobile sands covering on the road surface in many places.

Soon after development, the Hami section of the Lanzhou-Xinjiang railway was seriously affected by sand movement. Since late 1970s, damage to the railroad from shifting sand has occurred again because the land surface and its vegetation were destroyed by digging licorice in the previously stable

Gobi on the both sides of the railway. When a strong wind occurs, sand-dust storms become more serious. On May 19–20th, 1986, a grade 12 wind (on the Beaufort scale) blew for 28 hours which led to serious sand accumulation in 59 places over a total length of 40.7 km with a sand volume of 74,918 m^3. Some equipment was destroyed and the railway transportation system was interrupted for two days, causing serious economic loss.

The railway is endangered by shifting sands in the Hami region, especially from Hexi station to Yaziquan station with total length of 259.9 km and 130.8 km from Yanquan to Hexi which comprises stone Gobi. All these areas are at risk from varying degrees of sand damage over a total distance of 226.1 km.

(vi) Dry and hot winds

The main crops in Xinjiang that suffer from dry and hot winds are wheat, cotton and corn. Because of the high temperature and high evapotranspiration rates, the plant root systems cannot meet the transpiration needs and the crop's physiological balance cannot be maintained. This leads to crop withering and atmospheric droughts. When the wind speed is $> 4\ m \cdot s^{-1}$ the damage is greater. These high wind speeds are common: in the Turpan Basin they occur, on average, 40 days per year; and in the Hami Basin they occur approximately 10 days per year. Therefore, dry and hot wind weather is one of main meteorological disasters that affect high value and stable crop production in this area. For example, in Tuokexun County, on June 4th 1978, a strong dry and hot wind blew for 20 hours over the whole county and about half the crop (1,000 t) was lost. The dry and hot wind is a widespread natural disaster in the Tianshan area in northern Xinjiang from May to August every year, where it causes damage during the crop growing season. Dry and hot wind can burn crop stems and leaves, cause seeds to wither and have the overall effect of decreasing yield. In July, 1989, Urumqi County, for example, 500,000 kg of wheat was lost because of the dry and hot wind.

Drought is also a common natural disaster in the northern Xinjiang deserts and sandified regior desert area. Especially during May and June, drought can cause extensive yield reductions to agricultural production. During 1960 and 1961, in the Yili, Tacheng, Bole and Changji regions, about 87,000 ha farmland was affected by serious drought; in the Miquan region, 929 ha was affected by drought in 1962, of which 392 ha suffered total crop failure; 5,179 ha was drought affected in Urumqi County also in 1962; in 1963 about 53,000 ha in the Altai, Yili and Changji regions were affected by drought; in 1974 the Altai and Tacheng area suffered from a drought affecting 80,000 ha, with a greater than 50% reduction in yield; in 1977 24,000 ha in Changji and Shihezi were affected by drought; in 1982, the Yili area was affected by drought covering an area of 67,000 ha, and reducing grain production by 50 million kg; in 1985 Yiwu County had a drought that resulted in the deaths of 9,331 head of livestock; and in 1989, drought in Balikun affected 14,000 ha and crop production was reduced by 20 million kg with a direct and

indirect economic loss of 25,000,000 RMB.

4.3 Inner Mongolia Autonomous Region

The Inner Mongolia Autonomous Region is located along the northern border of China, with the exception of the northern Da Xing'anling Mountains in the east of the autonomous region. The majority of the region is located in the center of the arid and semi-arid region. From west to east there are five major deserts, which are the Badain Jaran, Tengger, Bayinwenduer, Ulan Buh and Qubqi Deserts, and five sandlands which are the Mu Us, Otindag, Wuzhumuqin, Horqin and Hulun Buir Sandlands. There are also large areas of wind eroded sandified land north of the Yinshan Mountains. Some fragmentary sandified lands are also distributed around these deserts and sandlands. Desert and sandland region are the predominant eight leagues, four cities and 76 banners or counties covering a total area of 74,186,594.2 ha, or 62.7% of the total area of the autonomous region.

4.3.1 Present situation, type and areas of deserts, Gobi, sandland and sandified land

4.3.1.1 Types and areas of deserts, Gobi, sandland and sandified land

The total area of deserts, Gobi, sandland and sandified land in Inner Mongolia is 35,551,035.0 ha, of which deserts occupy 10,791,957.0 ha, accounting for 30.4% of the deserts, sandlands and sandified land in the region; Gobi occupies 6,541,908.0 ha (or 18.4%); wind eroded monadnocks covers 151,166 ha (or 0.4%); and sandlands cover 18,066,004.0 ha (or 50.8%). Within the deserts, sandlands and sandified land, the mobile dune area is 9,223,690.0 ha (25.9%), the semi-fixed dune area is 3,013,934.9 ha (8.5%), the fixed dune area is 11,666,627.6 ha (32.8%), abandoned farmland covers 4,404 ha (0.01%), and bare sand covers 4,949,304.5 ha (13.9%).

In the fixed and semi-fixed deserts, sandlands and sandified land, dunes fixed by trees cover 1,234,368.8 ha, (or 8.4%), dunes fixed by shrubs occupy 2,421,115.8 ha (16.5%), and dunes fixed by herbage cover 11,025,077.9 ha (75.1%). Of the fixed and semi-fixed dunes with trees, artificial forest is 744,495.8 ha, natural forest is 489,833.0 ha, and the air seeding area is 40.0 ha. In the areas of dunes fixed by shrubs, the artificial plantings are 778,277.0 ha, the natural plantings are 1,624,751.8 ha, and the air seeding area is 18,087.0 ha. In the herbage fixed and semi-fixed dunes, artificial plantings cover 229,507 ha, natural plantings cover 10,778,315.9 ha, and the air seeding area is 17,255.0 ha.

4.3.1.2 Distribution of deserts, sandlands and sandified land

Inner Mongolia has a vast territory with diverse natural and social conditions, and this diversity is also reflected in the distribution of land resources. The Inner Mongolian deserts, sandlands and sandified land can be divided into 4 regions according to the type of deserts, sandlands and sandified land, climate and landform conditions.

(i) West of Da Xing'anling Mountains, east of Helan-Zhuozi Mountains and north of Yinshan Mountains

In this region, the deserts, sandlands and sandified land area is 5,147,754.2 ha, occupying 14.5% of the total area of deserts, sandlands and sandified land in Inner Mongolia. In this area there are the Hulun Buir Sandland, the Wuzhumuqin Sandland, Otindag Sandland and the 12 banners wind eroded sandified area (also called the north Wumeng league area) in the north of the Yinshan Mountains. The total area of mobile dunes is 51,049 ha (1.0%), Gobi covers 2,023 ha (0.4%), and bare sand covers 1,439,512.5 ha (28.0%). In addition, abandoned farmland occupies 3,354 ha and wind eroded monadnock covers 132.0 ha.

(ii) Liaohe River Plain

The Horqin Sandland is located within the Liaohe River Plain which is south of the Da Xing'anling Mountains. The sandified land area is 4,820,873.0 ha, 13.6% of the entire deserts, sandlands and sandified land in Inner Mongolia. Fixed dunes cover 3,051,825 ha (63.3% of desertified land in this area), semi-fixed dunes cover 582,798 ha (12.1%), mobile dunes cover 420,244 ha (8.7%), abandoned farmland is 1,050 ha (0.02%), and bare sand is 764,956 ha (15.9%).

(iii) Ordos Plateau

The deserts, sandlands and sandified land area in this region is 5,818,400.0 ha, occupying 16.4% of the total deserts, sandlands and sandified land area in Inner Mongolia, the Mu Us Sandland and Qubqi Desert distribute in this region. Fixed dunes are the main landform type in the Mu Us Sandland with an area of 2,922,728 ha. Mobile dunes cover 710,409 ha, semi-fixed dunes cover 185,271 ha and bare sand covers 123,415 ha. The Qubqi Desert has a larger area of mobile dunes occupying about 907,426 ha, the fixed dunes cover 776,831 ha, semi-fixed dunes cover 167,528 ha, wind eroded monadnocks cover 3,604 ha, and bare sand covers 21,188 ha.

(iv) Alxa Plateau and west Wulanchabu Plateau, west of the Helan and Zhuozi mountains

This area encompasses the largest area of deserts and Gobi in Inner Mongolia. Deserts, Gobi, and sandified land account for 14,337,827 ha (40.3% of the deserts, Gobi, sandlands and sandified land area in Inner Mongolia). There are several sandy deserts: the Ulan Buh, Bayinwenduer, Tengger and Badain Jaran Deserts. Mobile dunes are the main landform type, followed by Gobi. Mobile dunes cover 7,051,734 ha (49.2% of this area), Gobi covers 3,665,496 ha (25.6%), semi-fixed dunes cover 1,542,180 ha (10.8%), fixed dunes

cover 1,313,754 ha (9.2%), wind eroded monadnocks cover 147,430 ha (1.0%), and bare sand covers 617,233 ha (4.3%).

The Badain Jaran Desert is the biggest desert in the Inner Mongolia. The geographic coordinates are 39°28′–40°58′N, 99°20′–100°08′E. The total desert area is 703,000 ha, the mobile sandy dunes have an area of 194,975.4 ha, the non-bioengineered sand control area is 118 ha, and Gobi covers 340,689.2 ha. The main characteristics of the Badain Jaran Desert are the large sand mountains, and the dense distribution of dunes. There are crescent sand dune chains around the big sand mountains, with a height of 20–50 m.

There are also fragmentary sandified lands located at the periphery of the main sandy desert regions, with a sandified area of 5,426,180.8 ha (15.3% of the entire deserts, Gobi, sandlands and sandified land area in Inner Mongolia). Gobi is the main landform with an area of 2,856,129 ha. It is mainly located to the west of the Ejina Qi in the Alxa League. Other landforms are fixed dunes occupying 373,677.8 ha (6.9%), semi-fixed dunes occupy 130,546 ha (2.4%), mobile dunes cover 82,828 ha (1.5%), and bare sand covers 1,983,000 ha (36.5%).

4.3.2 Effects of sandification

Damage caused by sandification is the main constraint in this region on economic development. Almost 50% of the poor people in Inner Mongolia live in deserts, Gobi, sandlands and sandified land areas and sandification threaten agriculture and animal husbandry, and also puts cities, villages, communication lines and water conservation systems at risk. About 3,000 km of railway pass through the deserts, Gobi, sandlands and sandified land region of Inner Mongolia and there are also extensive highways. The Wuda to Jilantai railway is 131.7 km long and the sand-damaged section is 89.7 km. Derailments occurred 22 times from 1967 to 1982 because of sand on the tracks. In the old city of Sunite Zuo Banner, more than 500 houses were buried, compelling the banner government to relocate. On May 5th 1993, 100% of the pastures of Alxa League were affected by a strong sand-dust storm which caused a loss of forage amounting to 1,320,000 t. This storm also buried or destroyed 35,000 ha crops, killed 8,000 head of livestock, buried more than 80 irrigation wells, damaged more than 100 sections of road and destroyed more than 200 livestock sheds and 100 houses. The direct economic loss from this storm was 176,000,000 RMB. The annual direct economic loss in the whole Inner Mongolia which is caused by blown sand disaster was estimated at 6,970,000,000 RMB.

Some areas, such as Ulan Buh Desert, suffered from shifting sand as early as the late 10th century A.D. In 981 A.D., during the North Song Dynasty, official records show that “the sand was 3 feet deep, the horse cannot go through, travelers all rode on camel”. In 1926, Mr. Feng Yuxiang built a road

from Yinchuan to Baotou which passed through Dengkou. The shifting sand was still 3–4 kilometers away from Dengkou town. After 1937, all the roads were cut off completely by the sand making them impassable to vehicles. The shifting sand has reached the river bank in many places, and by 1958, during construction of the Baotou-Lanzhou Railway; the railway was detoured to the east bank of the Yellow River at Bayangaole because of the shifting sand. During the 1950s the government established three farms in Ulan Buh Desert and attempted to develop agricultural production in this area. The shifting sand buried irrigation channels, roads and buildings. Also, the combination of poor soils and unreasonable water use led to widespread soil salinization and many production teams had to completely move out.

The Hulun Buir Sandland has better natural conditions than the Alxa Plateau area. However, human impacts and inappropriate development and management have caused grassland degradation and sandification, causing shifting sands to endanger the railways and roads. At the Heerhongde station on the Binzhou railway, several hundred meters of track are frequently covered by sand. Roads in the grassland are often buried by shifting sand and grassland is also often buried by shifting sand which has caused degradation to 880,000 ha of pasture. The quantity and quality of pasture in this area has decreased on a large scale. In the past 20 years, the upper 20–30 cm of the black soil layer in farmland surrounding Hailaer City have been eroded by wind, and many areas of farmland have become sandified. The annual yield decreased by 750 $kg \cdot ha^{-1}$, and some of the farmland has become wasteland. Some houses in Harigantusu, in the northwest of Chenbaerhu Banner have been buried and the people have been forced to leave. The northern wall of the town of Amugulang was buried in sand about 1 m thick. Therefore, damage by shifting sand has caused significant harm in this pasture region and combating further desertification is imperative.

4.4 Tibet Autonomous Region

The Tibetan Plateau is important as the headwaters of major trans-boundary rivers and as an ecological origin for China and South Asia. Eco-environmental issues caused by desertification on the Tibetan Plateau are extremely serious and they threaten and impact vast regions beyond the plateau. Should desertification develop further in the future on the Tibetan Plateau, this could have significant effects on regional economic development, and cause tremendous negative effects to the balance between the eco-environment and socio-economic development.

4.4.1 Bioclimatic zones of desertified land on the Tibetan Plateau

The Tibetan Plateau is a huge geomorphologic unit that is located at 26°50′–36°20′ N latitude, with an average elevation of about 4,500 m above sea level. Under the effects of atmospheric circulation, elevation and plateau topography (landform), a specific plateau monsoon climate occurs on the plateau. It is characterized by different temperature and moisture conditions varying from a warm, wet climate in the southeast to a cold, dry climate in the northwest part of the Plateau.

It is calculated that the total area of desertified land on the Tibetan Plateau is approximately 516,147.15 km^2, which include 42.84% of the total land area of Tibetan Plateau. Of these, the dry sub-humid area is 142,753.18 km^2, the semi-arid zone represents 264,082.66 km^2, and the arid zone covers about 109,311.31 km^2, representing 27.66%, 51.16% and 21.18% of the desertified climate zones of the Tibetan Plateau, respectively (Ci and Wu, 1997). The latent desertification land areas on Tibetan Plateau include all three climatic zones, as shown in Table 4.1 (Li et al., 2001b).

Table 4.1 Potential areas of latent desertification on the Tibetan Plateau

Climate zones	AZ	SAZ	DSHZ	SDO
Moisture indicators	0.05–0.20	0.21–0.50	0.51–0.65	0.05–0.65
Areas (km^2)	109,311.31	264,082.66	142,753.18	516,147.15
Percentage of total land area of the plateau (%)				42.84
Percentage of desertification-prone areas (%)	21.18	51.16	27.66	35.49

AZ: Arid zone; SAZ: Semi-arid zone; DSHZ: Dry sub-humid zone; SDO: Scope of desertification occurrence

The latent desertification land areas on Tibetan Plateau include: (i) North Tibet–Northwest Tibet; (ii) Pengqu Valley; (iii) the central part of the middle reaches of the Brahmaputra River; and (iv) the dry valley of the Jinsha River in Eastern Tibet.

4.4.2 Types of desertified lands on Tibetan Plateau

The desertified lands in Tibet can be classified, depending on cause, into four types: (i) desertification from dune movement and sand accumulation; (ii) water erosion; (iii) salinization; and (iv) freezing-thawing processes. Desertification caused by dune movement and sand accumulation processes is the main cause of desertification in Tibet.

4.4.2.1 Desertified land caused by wind erosion

Desertification caused by sand dune movement and sand accumulation affects the largest area of desertified land in Tibet and is widely distributed. The total area is 123,460.77 km^2 representing 67.24% of the total area of desertified land in Tibet. The level of desertification can be classified as: very severe, affecting 1,159.24 km^2 (0.94% of total sandy desertified area); severe, affecting 2,389.30 km^2 (1.94%); medium, affecting 58,169.38 km^2 (47.12%); and slight, affecting 61,742.85 km^2 (50.01% of the total area of sandy desertified land in Tibet).

4.4.2.2 Desertified land caused by water erosion

Desertification caused by water erosion affects the smallest area of affected land in Tibet and covers only 2,662 km^2 (1.45% of the total area). The very severely desertified area is 16.65 km^2 (0.63%); the severely affected area is 175.16 km^2 (6.58%); the medium severity affected area is 1,248.95 km^2 (46.90%); and the slightly affected area is 1,222.04 km^2 (45.89% of the total water erosion desertified area).

4.4.2.3 Desertified land caused by salinization

Salinized land is one of the causes of desertification in Tibet. The total affected area is 9,604.03 km^2 comprising 5.23% of the total area of desertified land in Tibet. The very severe salinized land covers 593.90 km^2 or 6.18% of the total salinized land area.

4.4.2.4 Desertified land caused by freezing and thawing processes on the Plateau

There are approximately 47,895.59 km^2 of desertified caused by freezing-thawing processes on the Tibetan Plateau, which comprise 26.08% of the total desertified land area on the plateau. Of the land desertified by freezing and thawing, the very severely affected land area is 101.11 km^2 (0.21% of its total affected land areas), with the medium and slightly affected land categories comprising the majority of the total area affected by this form of desertification. By analyzing the rate of development of this type of desertification and the percentage of land affected, it can be seen that under the prolonged effects of both regional climate warming, aridization and human factors, the area of desertified land on the Tibetan Plateau, caused by the dynamic pressure of freezing-thawing processes will be accelerated.

4.4.3 Driving force of desertification

4.4.3.1 Dynamic effects of increased temperatures and dry climate

The Tibetan Plateau is a region that is sensitive to environmental change and

its response to global warming is significant. During the last few decades the climate of the Tibetan Plateau has been affected by global change. Recently, the Tibetan Plateau has shown signs of a significant warming and drying trend brought about by rising temperature and a reduction of humidity, and this becomes an important driving force for the development of desertification.

From the 1950s to 1990s, the general characteristics of temperature change and rainfall variation on the Tibetan Plateau were increasing temperature and decreasing humidity. In most districts, precipitation decreased on a large scale while the temperature was higher (Li et al., 2001a).

4.4.3.2 Rainfall reduction and climate aridization

The historical record shows that the Tibetan Plateau has experienced a series of changes of alternating dry and wet periods. In recent decades the dry period has been longer and humid period has been shorter, with the climate tending toward aridization.

4.4.3.3 Soil erosion caused by water

The normal processes of desertification caused by water erosion, are driven by the rainfall and runoff in the affected areas causing of soil erosion. Interactive effects of rainfall and runoff are closely related to soil, vegetation and topography. Soils in the desertified areas of the Tibetan Plateau are mainly composed of newly formed skeletal soils such as cold desert soils and frigid desert soils. These were formed recently, mostly by physical weathering (efflorescence) because chemical weathering and other soil-forming factors are weak.

Slope gradient and topographic features are some of the other fundamental elements leading to runoff and soil erosion.

4.4.3.4 Human activities accelerating soil erosion

Inappropriate human activities are the driving force behind the acceleration of soil erosion. Human actions such as overgrazing, undue collection of fuelwoods and inappropriate construction and reconstruction increase the effects of water causing soil erosion.

4.4.3.5 Freezing-thawing processes affected desertified lands

In recent decades, under the effects of climate change, inappropriate human activities and rodent damage, the permafrost of the Tibetan Plateau is being degraded and large areas of desertified land have been caused by freezing-thawing processes (Fig. 4.2).

Climate warming has increased of the depth of seasonal melting layers, decreased the groundwater, increased soil aridity and the formation of freezing-thawing processes causing desertified lands.

Climate warming led to an increase in runoff flow, the freezing-thawing interface of permafrost melts causing land the surface to subside, break and

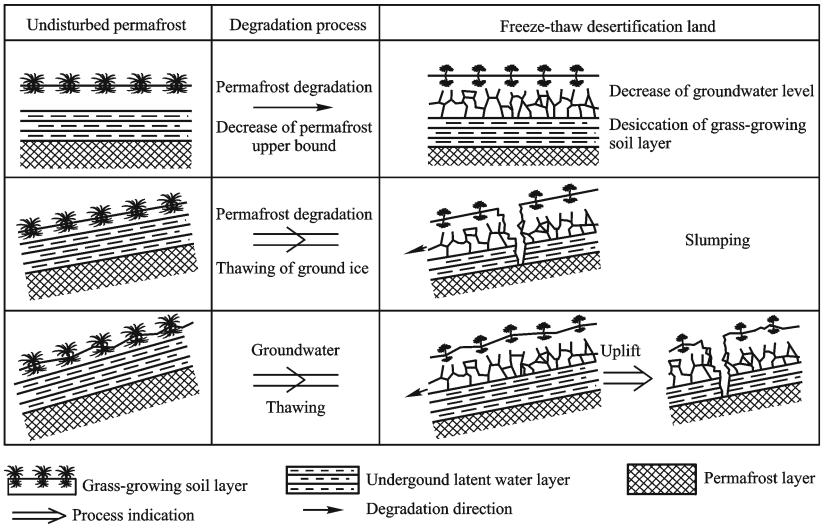

Fig. 4.2 Formation of desertification caused by freezing-thawing processes (Li et al., 2005, with permission from authors)

then form soil erosion.

Climate warming and increasing local temperatures accelerate the freezing-thawing processes which interacted through the overlapping of freezing and melting processes, thus expediting desertification (Li et al., 2004).

4.4.4 Hazards and pressures of desertification on the environment and development

The occurrence and development of desertification on the Tibetan Plateau has resulted in damage and destruction to the headwaters of important rivers, and the ecological origins of the plateau. The damage to the ecological environment has lead to harm and threats to human existence and caused significant economic loss and environmental pressure. Desertification is a huge obstacle to protection of the eco-environment and socio-economic development of the Tibetan Plateau.

4.5 Gansu Province

The distribution of deserts, Gobi and sandified land in Gansu can be divided into four geographical zones. The first zone is on the inclined plain north of the Qilian Mountains in the Hexi Corridor. There are a series of low lying areas within the low mountains and knolls which are affected by denudation and dryness. These areas are located at 37°01′–42°46′N and 92°12′–104°30′E, and include five prefectures, 20 counties and 171 townships in Hexi Corridor. The second zone is in the north of the Qingyang region, located at 36°13′–36°51′N and 106°22′–107°32′E, and including 12 townships of Huanxian County in the Qingyang region. The third zone is at the eastern end of Qinghai-Tibetan Plateau, located at 33°06′–34°23′N and 100°46′–102°29′E, and including four townships of Maqu County, in the northwest of the Gannan Tibetan Autonomous Prefecture. The fourth zone is the middle of Gansu and the north area of Jingyuan, located at 35°22′–37°15′N and 104°25′–105°16′E, and including 13 townships in the north of Pingchuan, Jingyuan and Jingtai counties.

4.5.1 Current situation and distribution of deserts, Gobi and sandified land

4.5.1.1 Type and area of deserts, Gobi and sandified land

The total area of deserts, Gobi and sandified land in Gansu Province is 11,669,064.0 ha, of which Gobi occupies 7,059,465.0 ha (60.50% of the total area); wind erosion and remnant earthen mounds (yardangs) cover 60,186.7 ha (0.52%); desert occupies 1,816,373.4 ha (15.56%) and sandified land covers 2,733,038.9 ha (23.42% of the total area).

In the deserts and sandified land areas, mobile dunes cover 1,967,412.8 ha (16.86%); semi-fixed sand dunes cover 1,027,267.8 ha (8.81%); fixed sand

dunes occupy 1,458,530.9 ha (12.51%); non-bioengineered controlling sands cover 4,686.3 ha (0.04%); abandoned farmland covers 15,588.7 ha (0.14%); and the bare sand area is 75,925.8 ha (0.65%).

Of the 1,458,530.9 ha of fixed sand dunes, those fixed by trees occupy 37,950.2 ha (2.60%); those fixed by shrubs occupy 376,271.0 ha (25.80%); and dunes fixed by herbaceous plants cover 1,044,309.7 ha (71.60%). Dunes fixed by human activities cover 114,003.6 ha (accounting for 7.82% of the fixed dunes) while naturally fixed dunes occupy 1,344,527.3 ha (92.18%).

Within the 1,027,267.8 ha of semi-fixed sand dunes, those fixed by trees, shrubs and herbaceous plants account for 34,893.3 ha, 183,205.6 ha and 809,168.9 ha (or 3.40%, 17.83% and 78.77%) respectively. The semi-fixed dunes fixed by human activities and natural processes account for 101,159.3 ha and 926,108.5 ha (or 9.85% and 90.15%), respectively.

4.5.1.2 Distribution of deserts, Gobi and sandified land in Gansu

(i) Tengger Desert

The west part of the Tengger Desert is in Gansu Province, while the eastern part of the Tengger Desert is in the Inner Mongolia Autonomous Region. The geographical coordinates of the Tengger Desert region are 37°01′–39°28′N, 101°41′–104°30′E, and the desert covers a total area of 2,642,000 ha, stretching across 50 towns associated with six cities, which cover Yongchang, Jinchuan, Wuwei, Minqin, Gulang and Jingtai counties. The Tengger Desert comprises 977,632.9 ha of mobile dunes, 247,676.8 ha of semi-fixed sand dunes, 414,851.6 ha of fixed sand dune, 896.7 ha of non-bioengineered controlling sands, 4,617 ha of abandoned farmland, 169,144.1 ha of Gobi, and 8,639.5 ha of bare sand. The sand dune heights range from 3 m to 10 m. The main soils are gray desert soils and gray brown soils. The ground water level is 10 m and the annual rainfall is 100 mm to 200 mm.

(ii) Kumtag Desert

This region mainly located in the southwest of Dunhuang County and includes eight villages and towns. The geographic location is 39°03′–40°56′N, 92°12′–94°56′E. The total area of desert is 3,593,000 ha, in which desert and sandified land area is 1,187,166.2 ha. Of the deserts, Gobi and sandified land, mobile sand dunes are 345,760.6 ha, semi-fixed sand dunes cover 21,729.4 ha, fixed sand dunes are 43,121.0 ha, abandoned farmland is 72.8 ha, and Gobi is 776,482.4 ha. The sand dune types include sand hills, sand piles, and sand ridges. Sand hills are the most common landform in this region, such as Mingsha Mountain in the south of Dunhuang County which has a relative height ranging from several dozen meters to more than one hundred meters, with the highest at 170 m. It is basically fixed. The prevailing wind directions are northeast, southwest and north. The groundwater is deep and with high degree of mineralization.

(iii) Deserts, Gobi and sandified land region in western Gansu Hexi Corridor

This region is located in the western part of the Gansu Hexi Corridor,

and includes the Yumen-Anxi-Dunhuang Oasis basin in the middle and lower reaches of the Shule and Heihe Rivers, and downstream of the Danghe River system. The geographical location is 38°14′–42°46′N, 93°46′–100°06′E, and includes 70 villages and towns. The deserts, Gobi and sandified land area is 15,583,000 ha, of which there are 396,388.7 ha of mobile dunes, 1,555.6 ha of non-bioengineered controlling sands, 60,186.7 ha of wind erosion remnant earthen mounds (yardangs), 5,569,312.0 ha of Gobi and 38,627.5 ha of bare sand. The deserts, Gobi and sandified land are dominated by a type of Gobi which concentrated in this region of Gansu Province. This vast region is one of the most seriously desertified regions in Gansu Province. With fierce changes in the climate and shifting sand flow, the Gobi is unstable, resulting in serious wind erosion and active desertification.

(iv) Deserts, Gobi and sandified land region in central section of Heihe River catchment of Gansu Hexi Corridor

The geographic location of this region is 38°30′–39°52′N, 99°23′–101°26′E, and includes 42 villages and towns which belong to five counties (Zhangye, Linze, Gaotai, Minle and Shandan). The total deserts, Gobi and sandified land area is 1,114,000 ha. There are 50,426.1 ha of mobile dunes, 91,757.0 ha of semi-fixed sand dunes, 33,770.4 ha of fixed sand dunes, 2,116.0 ha of non-bioengineered controlling sands, 47 ha of abandoned farmland, 203,837.3 ha of Gobi and 16,027.9 ha of bare sand. The terrain is flat with a rich water source in the Heihe River, which makes this region important for provision of food in the Hexi area. Due to meanders in the river bed, sand sources are exposed and many sand zones have developed.

(v) Deserts, Gobi and sandified land region in North Huanxian County

This region is located in the east of Gansu Province. The geographic coordinates are 36°13′–36°51′N, 106°22′–107°32′E, and the region includes 12 villages and towns. The climate is dry and the vegetation is sparse in this region. The total area of this region is 541,000 ha, in which 210,494.7 ha is desertified, occupying 38.91% of total area. There are 333.1 ha of mobile sand dunes, 76,170.3 ha of semi-fixed sand dunes, 123,139.4 ha of fixed sand dunes and 10,851.9 ha of abandoned farmland in this region.

(vi) Maqu deserts, Gobi and sandified land region

This region is located in the northwest of the Gannan Tibetan Autonomous Prefecture, at the eastern end of the Qinghai-Tibetan Plateau. The geographic coordinates are 33°06′–34°23′N, 100°46′–102°29′E. The region is bordered by Luqu County to the northeast; connects with Ruoergai and Aba counties of Sichuan Province in the southeast; neighbors Jiuzhi, Gande, and Maqin counties of Qinghai Province to the southwest and northwest; and adjoins the Henan Mongolian Autonomous County of Qinghai Province to the north. The Maqu deserts, Gobi and sandified land region encompasses four villages and towns, which are located in the east of Maqu County. It is a high and cold area with an altitude of 3,400–3,430 m in an ancient bed of the Yellow River. The total land area is 385,000 ha, of which 2,590 ha is deserts,

Gobi and sandified land, occupying 0.67% of total land area, and there are 1,896 ha of mobile dunes and 694 ha of fixed sand dunes.

(vii) Pingchuan-Jingyuan deserts, Gobi and sandified land region

This region is located in the north of Pingchuan and Jingyuan counties which are situated in the middle of Gansu Province, adjoining the Ningxia Hui Autonomous Region in the northeast, and bordering Jingtai and Baiyin counties in the southwest. Administratively, it includes four villages and towns of Pingchuan County (Baoji, Gonghe, Shuiquan and Wangjiashan) and four villages and towns of Jingyuan County. The geographic location is 35°22′–37°15′N, 104°25′–105°16′N, which means that this region is part of the connecting belt of the Longxi Loess Plateau and the Mengxin Plateau. There are interleaving gullies of various lengths and widths, resulting in fragmented and complex terrain in this area. Because of its location at the edge of Tengger Desert, where it is influenced by the atmospheric circulation around the Mongolian Plateau, the climate is dry. Furthermore, the grey calcium soil has poor structure and is easily eroded by wind. The total land area is 297,000 ha, of which 29,174.8 ha deserts, Gobi and sandified land, occupying 9.8% of this region. There is 181.0 ha semi-fixed sand dunes, 16,362.9 ha fixed sand dunes, and 12,630.9 ha of bare sand.

4.5.2 Effects of sandification

The Gansu deserts, Gobi and sandified land regions are characterized by vast territory and a sparse population, with water and plant resources suitable for raising livestock. In ancient times it was a fine animal husbandry region for semi-nomadic minority groups who followed a transhumance system of altitudinal migration to find water and grass. With the expansion of communication and prosperity derived from trade along the Old Silk Road, agriculture was promoted. More than two thousand years ago the Han Dynasty successively set up four counties (Wuwei, Jiuquan, Zhangye, and Dunhuang) in the Hexi area, developed agriculture and brought in people, which boosted the development of agriculture. However, thousands of years of inappropriate human activities, and especially in the past 50–60 years, poor cultivation practices, overgrazing and over-collection of firewood have caused a series of consequences, such as a deficiency of water resources, changing and drying of river courses, wind erosion and sand deposited, shifting sand burying infrastructure and so on, which have destroyed many towns and turned the oasis into a desert. The main effects of sandification are as follows:

(i) Shifting sand burying farmland

According to measurements made by the Minqin County forestry department, shifting sand moves 6–10 m each year in a southeast direction in areas where the desert vegetation has been destroyed. Since 1949, because of burial by shifting sand and serious sand-dust storms, approximately

127,000 ha farmland has been abandoned in oasis edge of Hexi region. By 1985 more than 3,300 ha of farmland had been buried by shifting sand.

(ii) Sand-dust storms causing human and livestock casualties

Strong sand-dust storms occur in the Hexi Corridor region. For example, on May 5th 1993 the area was subjected, to a force 12 gale that persisted for 60 hours. The sky became dark with flying sands and stones, crops were destroyed and people were killed or injured. The direct economic loss amounted to 162,000,000 RMB.

(iii) Wind erosion and sand blasting reducing agricultural output

Bare soil at the oasis edge and on some farms, especially those on sandy soil, is particularly susceptible to wind erosion. More than 20,000 ha of farmland have suffered a reduction in yield owing to wind erosion and sand blasting which has caused losses of more than 10,000,000 kg of grain and more than 15,000 kg of cotton.

(iv) Shifting sand in Gobi threatening the development of agriculture and animal husbandry

There is a large area of Gobi Desert in the west of the Hexi Corridor. When wind blows across the sandy ground surface, sand is removed from the land surface and enters the air current which leads to wind erosion; the transported sand materials are deposited when they encounter an obstruction. Sometimes the shifting sand can form a big sand dune, or even a sand hill. Such dunes move quickly, and can threaten farmland and pasture. According to county statistics, the effects of shifting sand on any farm can cause harm in the whole province desert region. The farmland suffering from shifting sand damage covers an area of 213,400 ha (43.4% of the existing farmland); while the affected pasture covers 4,063,700 ha (55.3% of pastureland). The number of villages affected by shifting sands are 4,366 (15.6% of the total villages); 713.9 km of railway are affected (52.6% of the total length); 2,813.9 km of highways (or 41.1% of the total length) are affected; and 8,749.8 km (or 37.1%) of canals.

4.6 Qinghai Province

Qinghai Province has a large deserts, Gobi and sandified land area. They can be found in eight counties, two cities and three towns. These deserts, Gobi and sandified land areas mainly include the Qaidam Basin, Gonghe Basin and Qinghai Lake and these are situated at 90°30′–101°05′E and 35°30′–39°00′N. The deserts, Gobi and sandified land stretches from the west of Mang'ai, to the eastern border of Mugetan's Huangshatou in the shape of a strip that is wider in the west and narrower in the east, with a length from west to east of nearly 1,000 km. The width from north to south is approximately 300 km. Patches of sandified land occur also in Maduo of south Qinghai, south of 35°30′N.

4.6.1 Current situation and distribution of deserts, Gobi and sandified land

4.6.1.1 Types and areas of deserts, Gobi and sandified land

The total area of deserts, Gobi and sandified land in Qinghai is 11,627,229.2 ha, of which sandy desert covers 27,140.0 ha (or 0.23%); wind eroded monadnocks cover 2,045,341.2 ha (17.59%); Gobi is 4,591,188.9 ha (39.49%); and sandified areas cover 4,963,559.1 ha (42.69%).

Of the 4,963,559.1 ha of deserts and sandified land, mobile sand dunes cover 1,825,052.9 ha (36.57%), semi-fixed dunes are about 1,236,864.4 ha (24.78%), fixed dunes are about 945,382.3 ha (18.94%); non-bioengineered controlling sands cover 40 ha; abandoned farmland covers 1,668.0 ha (0.03%); and bare sand is about 981,691.5 ha (19.68%).

Of the fixed dunes, those fixed by trees cover 20.0 ha and those fixed by shrubs are about 23,314.8 ha (or 2.47%), while those fixed by herbage plants are about 922,047.5 ha (97.53%). Dunes fixed by artificial plantings cover 87.4 ha (0.01%), while dunes fixed by nature is 945,294.9 ha, and accounts for 99.99% of the total fixed dunes.

Of the semi-fixed dunes, those fixed by trees cover 9,119.2 ha (0.74%), dunes fixed by shrubs cover 374,678.2 ha (30.29%), and those fixed by herbage plants occupy about 853,067.0 ha (68.97%). Dunes fixed by artificial plantings cover 149.5 ha (0.01%), while dunes fixed by nature is 1,236,714.9 ha, accounts for 99.99% of the total semi-fixed dunes.

4.6.1.2 Distribution of deserts and sandified land

(i) Qaidam Basin

The Qaidam Basin is in the northeast of Qinghai Province and is surrounded by the Qilian, Altun and Kunlun Mountains. It is an inland plateau basin and also the highest desert area in China. The total area of deserts and sandified land is 11,103,464.4 ha, with 1,535,797.6 ha of mobile dunes, 1,168.772.7 ha of semi-fixed, 916,262.7 ha of fixed dunes, the non-bioengineered controlling area is about 40 ha, abandoned farmland is about 1,668 ha, bare sand covers 852,206.3 ha, there is 4,583,375.9 ha of Gobi, and 2,045,341.2 ha of wind eroded monadnocks. The Qaidam Basin can be subdivided as follows:

Wutumeiren Sandified area. Starts from Gansenhu in the west, is connected with the northern foothills of Bokaleiketage Mountain, and the eastern Kunlun Mountains to the south, the eastern boundary is Dagele and the northern boundary is near the towns of Lenghu and Dachaidan. The length from west to east is approximately 500 km and the width from north to south is approximately 250 km. The total area of deserts, Gobi and sandified land is 3,415,293.0 ha, of which mobile dunes cover 846,373 ha (24.78%); fixed dunes cover 849,438.9 ha (24.87%); semi-fixed dunes cover 816,548.1 ha (23.91%); Gobi covers 802,618 ha (23.50%); abandoned farmland is about

400 ha (0.01%); and the bare sand area is about 99,915.0 ha (2.93%). The types of sand dune include crescentic dunes, chains of crescent dunes and sand ridges. The sand is moving about 5–10 m annually.

Lenghu sandified area. Includes the area west of Mang'ai town, the foothills of Qimantala Mountain, extends north from Altun Mountain and Danghe'nanshan Mountain, is connected to Zongwulongshan Mountain in Delingha in the east, and the southern boundary is close to the Wutumeiren sandified area. It is approximately 500 km long from west to east and 160 km from north to south. The lowest elevation is about 2,800 m and the highest elevation is about 5,798 m. The total area of deserts, Gobi and sandified land is about 5,101,169.0 ha, of which there are 393,626.4 ha of mobile dunes (7.72%); 2,045,341.2 ha of wind eroded monadnocks (40.10%); and 2,662,201.4 ha of Gobi (52.18%). Crescent dune chains and sand ridges are the main dune types and are about 5–25 m high. The dunes are moving at a rate of about 5–10 $m \cdot a^{-1}$, and in some places up to 10–20 $m \cdot a^{-1}$.

Tiekui sandified area. Starts from Dahala River in the west, and extends east near to Ela Mountain, the northern boundary is near Amunike and Buguote mountains, and the south is connected to Burhan Mountain. The lowest elevation on the sandified area is at Huobuxun Lake which 2,675 m above sea level and the highest elevation, in Yaladaze Mountain, is about 5,214 m. It has a typical cold region, plateau continental climate. It is approximately 300 km from west to east and 200 km from north to south. The total area of deserts, Gobi and sandified land is 2,587,002.4 ha, of which Gobi is 1,118,556.5 ha (or 43.24%), mobile dunes cover 295,798.2 ha (11.43%); semi-fixed dunes cover 352,224.6 ha (13.62%); fixed dunes occupy 66,823.8 ha (2.58%); non-bioengineered controlling dunes are 40 ha; and abandoned farmland is about 1,268 ha (0.05%). Crescent dunes, sand ridges and sand piles are the primary sand dune types, and they are moving at 5–10 $m \cdot a^{-1}$.

(ii) Sandified area in the Gonghe Basin

The Gonghe Basin is located at the southern part of Qinghai Lake. Its northern border is the south mountains of Qinghai, the southern border is Ela Mountain, a branch of the Kunlun Mountains, to the east is Xiqing Mountain and western boundary is connected with Qaidam Basin. It is administered by Gonghe and Guinan counties. The basin is approximately 280 km long from west to east, and 60 km wide from north to south. The total area of deserts, Gobi and sandified land is 321,251 ha, of which mobile dunes comprise 155,571.5 ha (48.43%), semi-fixed dunes cover 32,091.7 ha (9.99%), fixed dunes occupy 29,119.6 ha (9.06%), Gobi is 7,813 ha (2.43%), and the bare sand area is 96,655.2 ha (30.09%). The main dune landforms are crescent dunes, chains of crescent dune and sand piles. The desert is moving to the southeast with a speed of 7–12 $m \cdot a^{-1}$ for the 5–10 m high dunes, and 18–77 $m \cdot a^{-1}$ for the smaller dunes that are 2–5 m high. The highest speeds may reach 81 $m \cdot a^{-1}$.

(iii) Sandified area around the Qinghai Lake

This region extends north to the Datong Mountains, east to the Riyue

Mountains, south to Nanshan in Qinghai, and west to the Hala Lake valley. The altitude is 3,194–5,174 m and it has a high, cold, semi-arid grassland climate. The total area of deserts and sandified land is about 75,855 ha, of which mobile sand dunes comprise 32,955 ha (43.44%); semi-fixed sand dunes are 10,070 ha (13.28%); and the bare sand area is 32,830 ha (43.28%). The sand dune types are mainly crescent dunes, sand mountains, sand ridges and sandified land, with the highest sand mountain reaching up to 160 m. Qinghai Lake, which is oval-shaped, is the largest inland saline lake in China. It is approximately 108 km from west to east and approximately 60 km from north to south, with a perimeter of approximately 360 km and an area of 4,304.5 km^2. The elevation of the lake surface is 3,193.78 m. The lake has been affected by sand-dust storms and drought, and the lake level has fallen 10.53 cm every year from 1956–1986 and is still falling.

(iv) Maduo sandified land

This region is located in Maduo County and Maqin County of the Guoluo Tibetan region. The area of deserts and sandified land is 126,658.8 ha. Of which mobile dunes are 100,728.8 ha (79.53%) and semi-fixed dunes are 25,930 ha (20.47%). The main dune shape is undulating and ridge sand dunes.

4.6.2 Effects of sandification

4.6.2.1 Harming agriculture and livestock production

The shifting sands and sand-dust storms cause harm to agriculture and livestock production that reduces the area of arable land and also reduces the land's productive capacity. The frequency of disastrous sand-dust storms is also increasing. As a result of wind erosion, the sand flow spreads and the mobile sands bury land. Many fixed and semi-fixed sand dunes become destabilized and become shifting sand. At same time, wind erosion will remove soil organic matter and clay particles and the land will become poorer and have a coarser texture. During 1979–1983, shifting sand accumulated on arable land to a depth of 10 cm causing 6.7 ha farmland in Zhabuda Village of Shazhuyu Town to be abandoned. In Qinghai Province, there are about 213,000 ha of farmland affected by wind erosion to different degrees.

4.6.2.2 Burying buildings

There are hundreds of households in Shangqialigang Village in Shazhuyu Town of Gonghe County that were affected by shifting sand and they have been compelled to move four times within the past 40 years. In Geermu Farm the equivalent of 39,000 workdays are used cleaning up accumulated sand at the edges of fields and canals every year. The shifting sand in northwest of Dulan County is moving to the city at a speed of 8–12 cm every year, which will endanger the county seat directly.

4.6.2.3 Disrupting traffic

It is very common for shifting sand to accumulate on the road surface when sand flow stops or mobile dunes move forwards. Almost every year, and in any season, shifting sand buries roads. In May 1985, sand buried the railway to a depth of 70 cm deep in Fushaliang Region. The traffic was stopped 34 times in eight sections because of sand burying the railway. Four trains were obstructed in Fushaliang area in one night in May 1985. In March 1986, sand buried railway lines in Taoli Station at night and cargo train No.3461 was derailed on the third rail switch, which caused four oil tanks to catch on fire and one exploded. About 300 m of railway line were destroyed, three signal poles burned, 220 t of gasoline was burnt and traffic was interrupted for 15 hours and 45 minutes. The direct economic loss was more than 300,000 RMB.

4.6.2.4 Silted lakes and reservoirs

Shifting sand has threatened Qinghai Lake seriously for many years. The quantity of shifting sand and sediment going into the lake is 9,870,000 $t \cdot a^{-1}$, which has reduced the average depth of the lake from 37.5 m to 25.28 m. In past century, the water level has decreased by 12.22 m and the exposed area of lake bed reached 359.4 km^2. The famous Bird Island has become a peninsula.

4.7 Ningxia Hui Autonomous Region

Ningxia Hui Autonomous Region is located between the middle and upper reaches of the Yellow River and transitional belt between deserts and Loess Plateau. There are extensive deserts, Gobi, sandlands and sandified land in its central and northern parts, including the Mu Us Sandland, the Tengger Desert and fragmented pieces of sandified land within its 185 villages and towns of 13 counties.

4.7.1 Current situation and distribution of deserts, Gobi, sandlands and sandified land

The total area of deserts, Gobi, sandlands and sandified land in Ningxia Hui Autonomous Region is 1,235,773.9 ha, of which sandy desert covers 81,934.0 ha; Gobi is 208,404 ha (16.9%); and sandland is 945,435.9 ha (76.5%). Mobile sand dunes cover 206,884.9 ha (16.7%); semi-fixed sand dunes cover 233,471.3 ha (18.9%); fixed sand dunes cover 531,490.4 ha (43.0%); abandoned farmland is 55,402.8 ha (4.5%), and the non-bioengineered sand control area is 120.5 ha (0.01%).

Deserts, Gobi, sandlands and sandified land in Ningxia Hui Autonomous

Region can be divided into three parts: the Mu Us Sandland, the Tengger Desert and dispersive sandified land in the middle of Ningxia and the Yinchuan Plain.

Part of the Mu Us Sandland is located in northeast Ningxia. It includes most of Taole County, Yanchi County and Lingwu County with a total area of 1,047,378.5 ha, of which the sandy area is 735,024.2 ha, or 70.2% of the land area in this region. The area of mobile sand dunes is 118,961.2 ha (16.2%); semi-fixed sand dunes cover 217,636.7 ha (29.6%), fixed dunes cover 353,928.1 ha (48.1%); farmland is 42,442.9 ha and Gobi is 2,055.3 ha. The region is part of the area southwest of the Ordos Tableland, and common landforms are low mountain hills, low slope hills, wind eroded sand platforms, alluvial plains and lakes. The altitude is between 1,095 m and 1,600 m and has a central temperate zone arid climate. The main types of soil are Sierozem, aeolian sandy soil and small areas of loess and halomorphic soil. The main vegetation types on saline-alkali soils are *Glycyrrhiza glabra*, *Artemisia* spp., and *Cynanchum* spp. The other main vegetation types are *Glycyrrhiza uralensis*, *Caragana* spp., *Artemisia* spp., *Oxytropis aciphylla*, *Sophora alopecuroides* and *Peganum harmala*.

Part of the Tengger Desert is located in the northwest of Zhongwei County with the Yellow River as its boundary. Its total area is 177,273.0 ha, of which deserts, Gobi and sandified land occupy 124,047.0 ha, accounting for 70.0% of total land area in this region. Within the deserts, Gobi and sandified land, the mobile sand dunes area is 61,287.0 ha (49.4%); semi-fixed dunes cover 9,155.0 ha (7.4%); fixed dunes cover 50,838.5 ha (41.0%); Gobi covers 2,493.0 ha (2.0%); non-bioengineered controlling sand is 114.5 ha (0.1%); and abandoned farmland is 159.0 ha (0.1%). Its climate is arid with annual mean precipitation only 170 mm. The main soil types are brown calcic soil, meadow soil, swamp soil, saline meadow soil and takyr solonetz. The main vegetation types are *Caragana korshinskii*, *Hedysarum scoparium*, *Agriophyllum arenarium*, *Oxytropis aciphylla*, *Artemisia* spp., *Cynanchum komanovii*, *Nitraria tangutorum*, *Carex duriuscula*, and *Calystegia hederacea*.

There are also many scattered and different types of sandified land in Ningxia with a total land area of 1,530,510.7 ha, of which sandified land comprise 376,702.7 ha, accounting for 24.6% of the total land area.

4.7.2 Effects of sandification

The main effects of sandification are the shifting sands that threaten farmland, villages and houses, as well as destroying infrastructure. The surface of some land becomes exposed gravel under the action of wind, and areas of grazing land become sandified land which means that the grassland livestock carrying capacity is decreased. According to the historical data, Shapotou which means "sand starts here" used to be a flourishing town on the ancient road from

Ningxia to Lanzhou. Due to the Tengger Desert moving southward, many towns were buried. Sand dunes can be more than 100 m high in this area, and form a band that is 10 km long from east to west with the southern end near the Yellow River. Sand-dust storms events occur on average for 200 days each year, which causes parts of Zhongwei County to face serious sand-dust storm damage. Losses of land because of sand-dust storms account for 198.3 ha of farmland and 1,814.5 ha of grassland, and have affected 668 villages, 122 km of railway, 875 km of highway and 1,912 km of canals. The annual economic loss is 61.07 million RMB.

4.8 Shaanxi Province

The sandlands and sandified land of Shaanxi province is most common in Yulin and Yan'an in the north of Shaanxi. This area includes the southern part of the Mu Us Sandland (the northern part is in Inner Mongolia), and extends south to the loess hilly sandy area and the "shayuan" in Dali County at the intersection of the Luohe, Weihe and Yellow Rivers. 199 villages and towns in 14 counties are affected by sandification.

4.8.1 Distribution of sandlands and sandified land

The total area of sandlands and sandified land in Shaanxi province is 1,462,803.5 ha, accounting for 7.1% of the total land area. Mobile dunes occupy 144,609.5 ha (9.9%); semi-fixed dunes cover 303,257.5 ha (20.7%); fixed dunes cover 1,004,286.6 ha (68.7%); abandoned farmland is 1,919.3 ha (0.1%); farmland transformed from sandy wasteland is 2,676.9 ha (0.2%); and bare sandland is 6,053.7 ha (4.1%).

Of the fixed and semi-fixed dunes, 122,815.1 ha are fixed with trees, 624,468.6 ha are fixed with shrubs (47.8%) and 560,260.4 ha are fixed with herbage plants (42.8%). Of the dunes fixed by trees, 121,630.6 ha are artificial plantings, and natural forests cover 1,184.5 ha. The shrub fixed dunes comprise 581,993.3 ha of artificial plantings, 19,789.1 ha of natural forest, and 22,686.2 ha of air seeding. The dunes fixed by herbage plants comprise 166,208.9 ha of artificial grassland, 166,208.9 ha of natural grassland and 166,208.9 ha of air seeding.

In the total area of sandlands and sandified land in Shaanxi province, the Mu Us Sandland area and the loess sandy area account for 1,438,454.7 ha (or 98.3% of the total area of sandlands and sandified land in Shaanxi province). The remaining sandified land is in Dali and comprises 24,348.8 ha (or 1.7% of the total).

In the Mu Us Sandland in Shaanxi province, mobile sand dunes cover

144,609.5 ha (or 9.8% of the total area of the Mu Us Sandland); the semi-fixed dunes cover 297,660.7 ha (20.3%); the fixed dunes cover 988,211.50 ha (67.6%); and abandoned farmland is 1,919.3 ha (0.13%).

4.8.2 Effects of sandification

The strong wind in the sandlands and sandified land leads to wind erosion and causes sand flow. It destroys crops and pastures and buries farmland which is the main negative effect on the production of agriculture, forest and animal husbandry. According to historical data, in 413 A.D., Helianbobo of the Daxia Dynasty founded a capital, named Tongwancheng in Baichengzi on the northern side of Wuding River, which is now located in the north of Jingbian County. At that time, this region was next to a clean river with only a small sandy hill. During the Ming and Qing Dynasties, both sides of the Great Wall were covered in sand without any farming. In the one hundred years preceding the founding of the People's Republic of China, mobile sand spread more than 50 km south of the Great Wall. About 140,000 ha of farmland has been buried by sand and only 410,000 ha farmland is left, most of which is also surrounded by sand dunes. There are 260,000 ha of degraded grassland, and eight towns and 421 villages have suffered from sand-dust storms reducing residents' quality of life.

Prior to 1993, 220,000 ha of farmland, 6,027,000 ha of grassland, 110 villages (about 30% of the total villages in the sandy region), 71 km of railway, 1,659 km of highway (about 38% of highways in the sandy region), and 808 km of canals (about 66% of the total canals in the sandy region) had been affected by shifting sand in Mu Us Sandland, loess sandy area and Dali Shayuan region.

4.9 Other provinces and cities

In addition to the seven provinces discussed above, sandland and sandified land are also located in other regions including Beijing, Tianjin, Hebei, Shanxi, Liaoning, Jilin and Heilongjiang.

4.9.1 Beijing

Sandland and sandified land in Beijing are located in 129 towns in 11 counties and is mainly distributed along the river basins of the Yongding, Chaobai and Wenyu Rivers. Of these, the Yongding River basin has the largest area of sandland.

4.9.1.1 Area of sandland and sandified land

The total area of sandland and sandified land in Beijing region is 58,012.2 ha, of which, the bare sand area is 42.9 ha. Of the stabilized sandland, sand dunes fixed by trees cover 50,508.3 ha (87.13% of whole sandified land).

4.9.1.2 Distribution of sandland and sandified land

The sandland and sandified land of Beijing can be divided into five regions:

(i) Sandland and sandified land along the Yongding River

There are five sand strips as well as the modern riverbed of the Yongding River. The sand source is mainly from the old and new Yongding River beds. The prevailing wind direction is northwest in winter and the minor wind direction is from the north. Blown sand weather is the main hazard in this region.

(ii) Sandland and sandified land along the Chaobai River

The total area of sandland and sandified land along the Chaobai River is 6,917.5 ha and all of it is fixed. The main wind direction is northerly (northeast and northwest) in the Wenyu River basin. Dust days occur 40% to 50% of the time during sandy weather and days when suspended particles occur are recorded as 5–45% of days.

(iii) Sandland and sandified land in the Dasha River area of Huairou and Miyun Counties

This area is located between the Chaohe, Baihe and Yanxi rivers and turns to the south along the Baihe River to Niulanshan. It includes four towns in Huairou County and six towns in Miyun County. The total area of sandland and sandified land is 4,775.3 ha, and all is fixed. The sand particles are very coarse, especially in the front of the mountains, where surface sand and gravel are common. Wind is not very strong here because of its location in front of mountain. There was a high rate of vegetation coverage in the past but this has been destroyed in recent years.

(iv) Sandland and sandified land at Kangzhuang in Yanqing County

The wind is comparatively strong in Yanqing Basin, especially south of Kangzhuang region. Because of diluvial deposits in front of the piedmont and erosion, the land surface is a gravel Gobi formation and the lower area is a fine earth plain.

(v) Sandland and sandified land at Nankou in Changping County

This area is located in the wind corridor of Kangzhuang-Badaling-Nankou. The mean wind speed is 6 $m \cdot s^{-1}$ in spring and the wind has a strong erosion capacity. Its sandland and sandified land area is 635.8 ha and all are fixed.

4.9.2 Tianjin

Tianjin has five suburban counties and three districts along the coast with a

total area of 1,092.680 ha. Sandland and sandified land are located in 43 towns of Jixian, Bodi, Wuqing, Beichen, Xiqing and Dongli counties and districts with area of 181,276.5 ha, of which the sandland and sandified land area is 25,695.2 ha, or about 2.4% of the area of Tianjin.

Sandland and sandified land in Tianjin are mostly distributed along the river banks. There are 4,690 ha along the Jiyunhe Canal, 3,082 ha along the Chaobai River banks, 3,093 ha in the catchment of Qinglongwan, 1,557 ha in the Beiyun River catchment, 11,430 ha along the Yongding River, 1,351.2 ha along the Zhanghe, Zhouhe and Linhe Rivers, and 492 ha in the Xinkai River catchment.

4.9.3 Hebei Province

In Hebei province, sandland and sandified land are located in 78 counties of 11 prefectures and includes 1,503 towns, or 41.2% of the total number of towns in the province. Among the counties with sandland and sandified land, 12 are located in northwestern part of the province, including 137 towns, and 66 are located on the plains, including 1,366 towns.

There are 2,931,174.8 ha of sandland and sandified land in Hebei Province. Considering the geographical location, landform type and causes of sand encroachment, sandified land in Hebei Province can be divided into two regions, the northwest sandified land region and the plains sandified land region.

The northwest sandified land region includes 137 townships in 12 counties associated with Zhangjiakou City and Chengde City. The total area of sandified land is 1,552,279.8 ha, of which the mobile sand dune area is 38,117.8 ha (2.46%); the fixed sand dunes are 831,251.8 ha (53.55%); abandoned farmland is 267,288.8 ha (17.22%) and bare sandland is 415,621.4 ha (26.77%).

The plains sandified region includes 1,366 townships of 66 counties, and the total area of sandified land is 1,378,895 ha.

4.9.4 Shanxi Province

In Shanxi Province, sandified lands are mainly located in the north and northwest of the agriculture and pasture transition zone. Sandification along the Great Wall is common. The sandified land area in Shanxi Province ranges from the north of Shanxi Province to the west, bordering with Shaanxi Province and Inner Mongolia. The length from east to west is 300 km, the width from south to north is 230 km and this area has the shape of an inclined long strip. The geographical coordinates of this area are 110°56′–114°32′E and 38°39′–40°44′N. The administrative area involves 249 townships of 18 counties and three cities of Datong, Shuozhou and Xinzhou.

The total sandification area in Shanxi Province is 785,284 ha. Mobile sandified land has an area of 2,273 ha (or 0.3% of the total sandification area); semi-fixed sandified land covers 271,452 ha (34.6%); fixed sandified land covers 390,945 ha (49.8%); and abandoned farmland is 120,615 ha (15.4%).

In Shanxi Province, fixed sandified land covers nearly 50% of the total sandified land. This demonstrates that great achievements have been made in past years in combating desertification. Sandified lands cover about 29.0% of the land in those townships identified in sandification counties, and of the sandified lands, fixed and semi-fixed sandified land comprises 84.4%.

In the counties of Pianguan, Shenchi, Wuzhai, Baode and Zuoyun, all of the sandified land is fixed or semi-fixed. Most of sandified lands have been well controlled, primarily by forestation.

4.9.5 Liaoning Province

Sandland and sandified land in Liaoning Province involves 197 townships of 18 counties. According to the topography and the cause, sandland and sandified land in the province can be divided into three parts: the Horqin Sandland, sandland and sandified land along the Liaohe and Linghe River systems and sandland and sandified land along beaches.

The southern edge of the Horqin Sandland is located in the north of Liaoning Province between 121°50′–124°00′E and 42°25′–43°30′N. Its northern area connects with Inner Mongolia and the central Horqin Sandland, the eastern edge is at the Zhaosutai River, the southern boundary adjoins the sandland and sandified land along the rivers, and the western boundary is the Raoyang River. The Horqin Sandland has the shape of a long, narrow belt extending from west to northeast.

Sandland and sandified land along the rivers is located at the northwest of Liaoning Province, and is concentrated along the Laogu, Benghe, Xiushui, Yangximu, Liuhe, Raoyang, Xihe, Mangniu and Daling Rivers and the plains among the rivers. The geographical coordinates are between 119°15′–122°35′E and 39°30′–42°50′N.

Coastal sandland and sandified land are distributed along the coast of Liaodong Bay on the Bohai Sea from Suizhong in the west to Wafangdian in the east, in a narrow, horseshoe shaped band between 119°50′–122°29′E and 39°30′–41°9′N.

4.9.5.1 Type and area of sandland and sandified land

The total sandland and sandified land area in Liaoning Province is 328,747.2 ha (or 13.6% of the total land area). Mobile sand dunes cover 2,735.1 ha; semi-fixed sand dunes occupy 27,016.4 ha; fixed sand dunes are 295,768.6 ha; abandoned farmland is 2,487.1 ha; and bare sandland is 740 ha.

Sandland and sandified land fixed by trees cover 236,820.2 ha, those fixed by shrubs are 5,759.8 ha, those fixed by herbage plants are 53,188.6 ha. The artificial plantings occupy 235,078.3 ha and the area of natural plantings occupy 60,690.3 ha.

4.9.5.2 Distribution of sandland and sandified land

(i) South edge of the Horqin Sandland

This region is in the northern area of Liaoning Province and includes 26 townships in three counties of Zhangwu, Kangping and Changtu. The total sandland and sandified land area is 130,479.7 ha, of which mobile sand dunes are 1,150.6 ha, semi-fixed sand dunes are 18,670.6 ha and fixed sand dunes are 109,343.9 ha.

(ii) Sandland and sandified land along the river in the Liaohe and Linghe River system

This region is located in the northwest of Liaoning Province centered in the Liaohe and Linghe River system. It includes 112 townships in 11 counties of Jianping, Beipiao, Fuxin, Zhangwu, Yixian, Heishan, Xinmin, Liaozhong, Faku, Kangping and Taian. The total sandland and sandified land area is 164,101.7 ha, of which mobile sand dunes are 715.1 ha, semi-fixed sand dunes are 7,210.8 ha, fixed sand dunes are 155,114.1 ha, abandoned farmland is 321.5 ha and bare sand is 740.0 ha.

(iii) Coastal sandland and sandified land along Liaodong Bay

This region is located along the coastal beaches of Liaodong Bay on the Bohai Sea and includes the six counties of Suizhong, Xingcheng, Lianshan, Longgang, Panshan and Wafangdian. The total sandland and sandified land area is 34,165.8 ha, of which mobile sand dunes are 869.4 ha, semi-fixed sandland is 1,135.0 ha, fixed sandland is 31,310.4 ha and abandoned farmland is 851.0 ha.

4.9.6 Jilin Province

In Jilin Province, sandlands are located at the southwest of the Songnen Plain; in the corridor linking the east Liaohe River and Xiliaohe River which is part of the eastern Horqin Sandland; and the southern area of the Songnen Sandland. The eastern boundary approximately follows the line from Tuanjie of Lishu County to Lianhuashan of Gongzhuling City to Jubao of Changling County to Halahai of Nong'an County to Xiaojia of Fuyu County, and is adjacent to other provinces at the south, west and north. Geographical coordinates are between 122°06′–125°51′E and 43°18′–46°19′N. The administrative region includes 179 townships in the 13 counties of Tongyu, Shuangliao, Zhenlai, Taonan, Taobei, Qianguo, Changling, Qian'an, Fuyu, Lishu, Da'an, Gongzhuling and Nong'an.

4.9.6.1 Sandland type and area

The total area of sandlands is 494,107.8 ha, occupying 12.33% of the entire land area of Jilin Province. Mobile sand dunes occupy 109.0 ha (0.02%); semi-fixed sand dunes cover 16,433.6 ha (3.33%) and fixed sand dunes cover 477,565.2 ha (96.65%).

Of the fixed sand dunes, 430,758.9 ha (90.20%) is fixed with trees, 5,102.8 ha (1.07%) with shrubs and 41,703.5 ha (8.73%) with grasses. Vegetation of artificial origin occupies 370,669.5 ha (77.62%) with vegetation of natural origin occupying 106,895.7 ha (22.38%).

Of the semi-fixed sand dunes, 5,377.1 ha (32.72 %) is fixed with trees, and 11,056.5 ha (67.28%) with grasses. Artificial plantings cover 6,955.1 ha (42.32%) and natural plantings cover 10,478.5 ha (63.76%).

4.9.6.2 Distribution of sandlands

(i) Songnen Sandland

The Songnen Sandland has an area of 222,763.3 ha, which is comprised of 109 ha (0.05%) of mobile sand dunes, 12,267.4 ha (5.51%) of semi-fixed sand dunes, and 210,386.9 ha (94.44%) of fixed sand dunes.

The landform in the Songnen Sandland is relatively smooth as it is a sand covered alluvial plain with an altitude between 120–200 m. It features alternating sandland, farmland, grassland and lakes. The sandland is in a belt that consists of parallel sand ridges and swales, in the form of an arc to the south. The dune size decreases from east to west as the land becomes a gentle plain. There are also some scattered sand dunes in other places.

(ii) Horqin Sandland

The area of the Horqin Sandland in Jilin Province is the eastern edge of the Horqin Sandland, and is situated on the west side of the province mostly distributed to the east and west of the Liaohe River Plain. The geographical coordinates are 122°06′–124°38′E and 43°18′–45°03′N, and include 79 towns of the seven counties. The total area of sandland in this area is 271,344.5 ha, of which the semi-fixed sand dune area is 4,166.2 ha (1.54%) and the fixed sand dune area is 267,178.3 ha (98.46%).

The landform in the Horqin Sandland is relatively smooth, with sand covering an alluvial plain at an altitude between 120–200 m. The key landform in the sandland is a sand belt consisting of parallel sand ridges and swales. The sandland terrain can be divided into gentle plains, isolated sand dunes and complex sand ridges.

4.9.7 Heilongjiang Province

Sandland and sandified land in Heilongjiang Province is located at the eastern edge of a long stretch of blown sand in North China. The geographical location

is 122°10′–125°10′E and 45°30′–48°30′N. The region includes 105 townships of nine counties.

The total area of sandland and sandified land is 378,635.7 ha, of which mobile sand dunes occupy 1,198.9 ha (0.32%), fixed sand dunes cover 364,968.4 ha (96.39%), and abandoned farmland covers 3,580.0 ha (0.95%). sandland and sandified land are mostly located in the southwest semi-arid alluvial plains of the lower reaches of the Nenjiang River and cover an area 165 km wide and 400 km long along Nenjiang River tending from northeast to the southwest.

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