Formation mechanism of eco-geo-environmental hazards in the agro-pastoral interlocking zone of northern China

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Abstract High sensitivity and distinct degradation characterize the eco-geo-environment in the agro-pastoral interlocking zone in northern China. Because of its specific natural conditions and human activities, this zone is easy to change and transfer between typical agricultural and pastoral environments. Several kinds of eco-geo-environmental hazards exist in the zone, such as land desertification, climatic disasters, endemic disasters, etc. The mechanisms of these eco-geo-environmental hazards include geotectonic processes in the Earth's history, and exogenic causes, such as the East Asia monsoon and irrational human activities. Both tectonic processes and exogenic causes act on the ecologically vulnerable environment, which makes the potential eco-geo-environmental vulnerabilities real hazards.

Key words Agro-pastoral interlocking zone · Eco-geo-environmental hazards · Ecologically vulnerable environment · Forming mechanism

Introduction

The agro-pastoral interlocking zone in northern China covers a wide area from the Hulunbeier League of inner Mongolia, south-westward, through the south-east part of inner Mongolia, the north sectors of Hebei and Shanxi provinces, and the Loess Plateau of northern Shanxi and the Eerdosi Plateau in the west (Fig. 1). An agro-pastoral interlocking zone has existed since the mid-Pleistocene in northern China. Farming and stock raising have been interlinked and frequently alternated within the zone (Chengping and Jiyu 1995). High sensitivity and low bearing capacity characterize the eco-geo-environment in this agro-pastoral interlocking zone (Feng 1993). This vulnerable ecosystem can be extensively disturbed by exogenic causes (including natural and man-made). The ecology will be weakened and the resistance to disasters will be reduced. Serious eco-geo-environmental hazards will directly threaten human life, belongings of the inhabitants and the sustainable economic development in the zone (Lansheng and Xiuqi 1997). Therefore, it is very important to study the mechanisms that lead to eco-geo-environmental hazards in order to effectively prevent them and to rationally manage the vulnerable environment.

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Eco-geo-environmental hazards

Several kinds of eco-geo-environmental hazards occur in the agro-pastoral interlocking zone of northern China because of irrational exploitation by man (Jie and Nianfeng 1995). This includes rapid land desertification, frequent climate disasters, severe water and soil losses, high endemic rate water source depletion, landslides, mud and rock flows, and silting up of reservoirs and ditches.

Land desertification

Land desertification, called "Earth cancer", is considered a worldwide fatal eco-environmental hazard. It is threatening the survival and development of the whole human race (Feng 1993). China is one of the countries that has the most serious land desertification problem, which covers vast areas. The land area affected by desertification in China is $\sim 3.33 \times 106\ km^2$, and a population of 3.33×10^6 will become victims of the hazard. The direct economic lose amounts to 1.96×10^{10} Chinese Yuan each year. The desertification has mostly occurred over the agro-pastoral interlocking zone in northern China. According to the Land Desertification Prevention and Control Pact of the UN, land desertification is a process of soil degeneration caused by numerous factors including climatic change and human activities in arid, semi-arid and moist–arid regions (moist index of 0.05–0.65). In the agro-pastoral interlocking zone of northern China, land desertification consists of sandy soil desertification, salinization, water and soil loss and prairie degeneration.

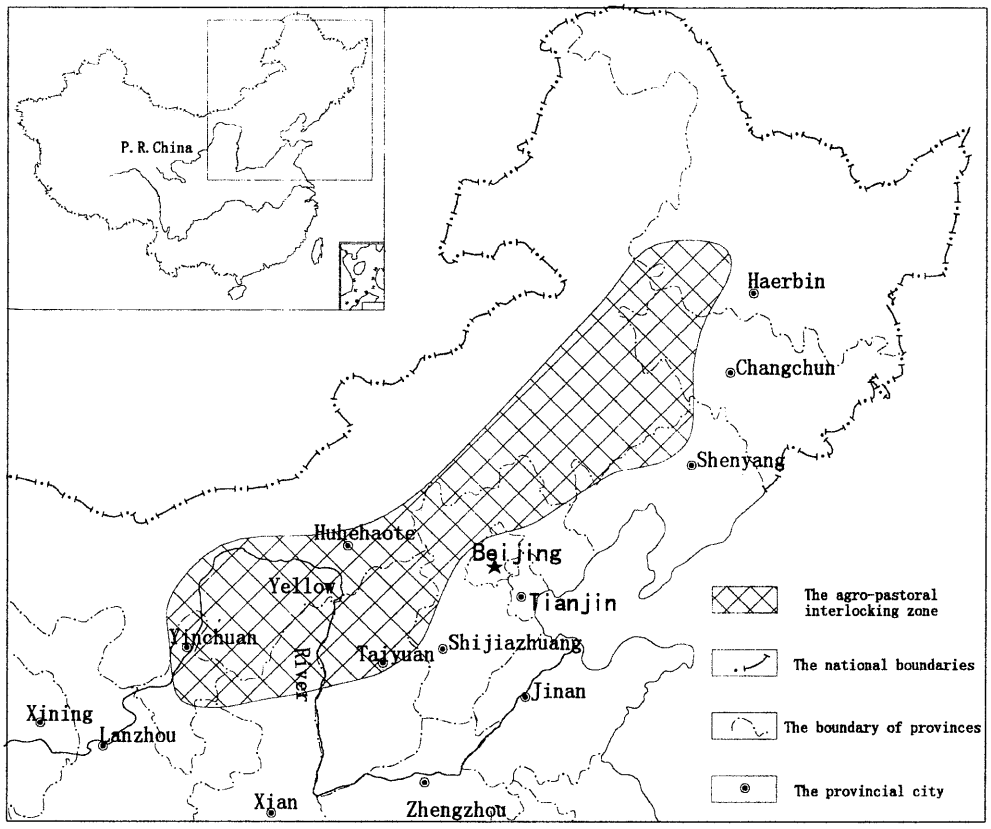

Fig. 1
Agro-pastoral interlocking zone of northern China

Sandy soil desertification

More than 90% of the sandy soil desertification in China is concentrated in the northern agro-pastoral interlocking zone. The area of sandy desertification is 1.6×10^5 km^2; the area of potential sandy desertification is 1.5×10^5 km^2 (Zhenda 1997). Violent sandstorms and severe sandy desertification have become fatal hazards to mankind. For instance, a super strong, black sandstorm took place in north-west China on 5 May 1993, which damaged 3.0×10^4 ha of farmland, destroyed 5.0×10^3 ha of seedlings, buried 1.48×10^2 km irrigation channels, 1947 livestock died or were lost, 87 villagers suffered misfortune, and the direct loss of 3.4×10^7Chinese Yuan just in Jingtai county. According to a survey, the sandy desertification area extended from 1.10×10^5 km^2 in the mid-1970s to 1.27×10^5 km^2 in the mid-1980s. Sandy desertification areas increased from 52.75 to 45.3%. The average increase in sandy desertification was 1.4793×10^3 km^2/year, and a 1.39% annual increase in the agro-pastoral interlocking zone (Zhenda 1997).

Land salinization

Increasing land salinization is also a serious eco-geo-environmental problem. It not only affects output and quality of crops but also causes land desolation. The land salinization area is 2.0×10^6 ha in the arid north-west of China and 2.43×10^6 ha in the Songnen Plain of north-east China.

Water and soil loss

Water and soil loss in China has mostly occurred in the Loess Plateau and the upper and middle reaches of the Yellow River. The most serious areas are located in the ravine regions of loess hills and altiplano. The average soil erosion loss is $0.5–1.0 \times 10^4$ tonnes/km^2 per year, and this can reach $2–3 \times 10^4$ tonnes/km^2 per year in some districts. Agro-pastoral working conditions are destroyed by serious water and soil loss: the farmland is ruined, the soil washed away, fertility decreased, and reservoirs and ditches silted up. Because the Yellow River flows across Loess Plateau areas, serious water and soil loss not only influences economic development but also endangers humans who live in the Loess Plateau areas, and the middle and lower river basins.

Frequent climatic disasters

Drought frequently occurs and affects the agro-pastoral interlocking zone in northern China, Historically, a drought occurred once every 3 years (Xinnian 1998). A drought that lasted half a year occurred once every 5 years. A drought that lasted all year and completely ruined the harvest occurred once every 10 years in the 320 years, from 1629 to 1949 in north-western Shanxi province. Fateful droughts have occurred 15 times in 37 years from 1934 to 1970 in the Yulin region of Shanxi province. The frequency of drought was 23.8% during 1934–1970, but increased to 33.3% from 1970 to 1990 in the Songnen Plain of northern China. Drought intensity

also greatly increased. Rainstorms in which the rainfall is >100 mm have occurred 37 times in the whole Loess Plateau since 1949. Eleven of them took place in the 1950s with an average rainfall of 147 mm and a maximum rainfall of 258 mm. Seventeen of them occurred in the 1960s with an average rainfall of 156 mm and a maximum rainfall of 422 mm. Nine great rainstorms occurred between 1970 and 1977 with an average rainfall of 345 mm and a maximum rainfall of 1400 mm. This is a result of eco-geo-environmental degeneration and causes eco-geo-environmental hazards.

High endemic diseases

Eco-geo-environmental problems mostly take place in the agro-pastoral interlocking zone of northern China, and include arsenic toxicosis in the bend of the Yellow River in inner Mongolia, endemic fluorosis in the western plain of Jilin province, Kaschin–Beck disease in Yongshou county of Shanxi province, and Keshan disease in Keshan county of Heilongjiang province (Jie and Nianfeng 1995). These problems all endanger human life and health in the zone.

Other hazards taking place in the agro-pastoral interlocking zone are the drying-up of riverheads, landslides and mud-rock flows, silting-up of reservoirs and ditches, land surface subsided, and pollution of the eco-geo-environment.

Mechanism of formation

The eco-geo-environmental hazards are caused by both the tectonic process, such as neotectonic movement, and by exogenic causes such as the East Asia monsoon and irrational human activities in the agro-pastoral interlocking zone. They act together on the vulnerable eco-geo-environment, and result in maladjustment of the ecosystem structure, destruction of the eco-balance and the occurrence of eco-geo-environmental hazards.

Vulnerability of the eco-geo-environment

The eco-geo-environment is characterized by its hypersensitivity and vulnerability in the agro-pastoral interlocking zone of northern China (Xinnian 1998). The climate of the semi-humid continental monsoon gradually changes to the climate of a typical semi-arid continental monsoon from the north-east to the north-west in this zone. Its annual average air temperature is 2–8 °C and the annual rainfall is 235–450 mm in most regions. The original landscape was all forest steppe and grassland. The original vegetation cover is not well preserved because of the combined influence of vulnerable natural conditions and irrational human activities.

The ecosystem is very unstable under the influence of natural and human factors. Drought and waterlogging are alternate and frequent. The eco-geo-environment is highly sensitive and degenerates easily in the zone.

High sensitivity

Sensitivity reflects the relationship between the disturbance and response. Eco-geo-environmental sensitivity is the degree of response of the eco-geo-environment and its composite elements to external disturbance. The sensitivity depends upon the stability of the internal structure of the regional ecosystem. There are two aspects of high or low eco-geo-environmental sensitivity. The first is the interval between the response of the ecosystem and external disturbance. The shorter the interval, the quicker the speed, and the higher is the eco-geo-environmental sensitivity. The second aspect is the consequences of the eco-geo-environmental change caused by the external disturbance. The stronger the response, the greater the eco-geo-environmental change, and the greater the eco-geo-environmental sensitivity.

By the standards mentioned above, the interlocking zone is an area with high sensitivity. As an example, the Keerqin Prairie, which had high-quality meadows in the 1950s, has since become seriously eroded as a result of irrational land reclaiming, overgrazing, cutting firewood, etc. The meadows are accelerating towards land desertification and salinization. The grazing grass is just 10–30 cm high. Poor quality grass is increasing and edible grass is decreasing. The bearing capacity of the meadows for breeding livestock is rapidly declining.

The degenerative trend

The trend of eco-geo-environmental degeneration is a result of the direction and intensity of eco-environmental change, which is caused by external disturbance. Its occurrence depends on two factors. One is the stability of the internal structure of the ecosystem. An unstable internal structure is likely to cause environmental degeneration. The other factor is the intensity of the stress on the ecosystem from external sources. Heavy external stress is likely to accelerate ecosystem degeneration. The degenerative trend indicates an imbalance in the internal structure and a decrease in eco-function of the ecosystem.

As a result of irrational human activities, the biomass and bio-diversity of the ecosystem in the agro-pastoral interlocking zone have clearly declined: fluctuations in bio-productivity are raised, surface coverage has decreased, soil fertility is reduced, and the soil structure is destroyed. The deterioration of the soil is demonstrated by the strongly blown sand, severe sandstorms and the gradually increasing aridity. All of them aggravate the threat of land desertification (Dianfa and Nianfeng 1999). The Keerqin Prairie, which is located in a semi-arid climatic zone, had an original landscape that was sandy light forest steppe with abundant plant and fauna communities, a stable structure and evident hierarchies within ecosystems, with high vegetative cover and grass yield. The Earth's surface was mostly covered with thick, solid and resilient sod that could endure trampling. Over the last 100–200 years the eco-environment has suffered significant destruction and land desertification has become serious. A sandy landscape with mobile dunes has ap-

peared. The secondary vegetation cover is poor compared with the original plant cover. The shrub layer is intensively developed, the arbor layer has basically vanished and the herbage layer is gradually degenerating. The psammophytes and xerophils have replaced the original vegetation. As a result of eco-geo-environmental degeneration, the types of community and ecosystem structure have become simpler, and edible grass yields have been greatly decreased (Dianfa Nianfeng 1999).

Tectonic processes

The tectonic mechanisms that cause eco-geo-environmental hazards refer to the geotectonic movements in geohistory. They have established a particular geomorphological pattern and a vulnerable geological strata in the agro-pastoral interlocking zone of northern China.

The major geomorphological units in this zone, including the south-eastern margin of the inner Mongolia Plateau, the northern Hebei upland, Yin Mountain, the Loess and the Eerdosi Plateau, lie basically in the second terrace in Chinese geomorphology. The special geomorphological pattern and climatic conditions have determined the eco-geo-environmental vulnerability in the agro-pastoral interlocking zone (Dianfa Nianfeng 1999).

The geomorphological pattern provides potential energy for water and soil loss, land desertification and salinization. The high potential energy of the Loess Plateau and the inner Mongolia Plateau results in river erosion and water and soil loss. The neotectonic movement directly affects the hypsographic and geomorphologic patterns, which encourage the land salinization of the Songnen Plain in north-east China (Dianfa Nianfeng 1999).

According to the vulnerable soil types, the agro-pastoral interlocking zone of northern China can be classified into two regions: the loess-overlain region and the sand-overlain region.

The Loess Plateau is a typical loess-overlain region, it covers a vast area, and has great thickness and a deep influence on the eco-geo-environment. Loess is a kind of the Quaternary earthy deposit with a homogeneous texture. It is easily eroded by water and wind because of its loose structure, holes and crannies, well-developed vertical joints, and rich soluble material. These characteristics result in an extremely unstable surface structure. The severe erosion and water and soil loss carves the landform of the Loess Plateau into ravines. The barren soil significantly restricts plant growth because natural fertilizers such as N, P and K are carried away along with water and soil. In addition, irrational human activities have further aggravated the vulnerability of the soil structure. The sand-overlain regions (including areas with an underlying sand layer) exist from the Eerdosi Plateau eastward to the inner Mongolia Plateau, through Keerqin Prairie, and north-eastward up to the Hulunber League of inner Mongolia. They are characterized by a rich sand source, barren soil and the vulnerable structure of the Earth's surface. They form a substantial foundation for sandy desertification in these regions.

Exogenic causes

The exogenic mechanisms that result in the eco-geo-environmental hazards include the East Asia monsoon and irrational human activities. Their joint effects turns potential vulnerability into real hazards (Dianfa Nianfeng 1999).

East Asia monsoon

The activity of the East Asia monsoon has been a link that has controlled the spatial and temporal evolution of the climate and environment since the Quaternary (Huairen and Qing 1985). The Qinghai-Tibet Plateau's uplift had an important effect on climatic change in Asia and even the northern hemisphere in the late Cenozoic. It enlarged the climatic discrepancy between the east and west of China. The Qinghai-Tibet Plateau, a heat source in summer and a cold source in winter, has been an important driving force for the climatic change in the northern hemisphere since the late Cenozoic. It has strengthened the fluctuations of cold and warm climates, and the alternation of dry and wet climates. It favors the continuation of the winter and summer monsoons. However, it has caused drought in northern China because it removed the Siberian high-pressure ridge to about 45°N from about 30°N. The agro-pastoral interlocking zone of northern China has the following features of climate because of the intense influence of the East Asia monsoon.

1. Although there is little rainfall in the zone, most of it falls in rainstorms that frequently cause severe calamities. The amount of rainfall varies and is distributed very disproportionately in various seasons. With the Loess Plateau as an example, the rainfall in the summer and autumn seasons accounts for ~80% of the year's total rainfall, and this can vary annually from 7 to 36%, but usually varies between 20 and 25%. However, monthly rainfall can vary between 40 to 140%. In general, variations in rainfall are low in the rainy season but high in the dry season. A rainstorm with high-strength rainfall not only reduces the utilization ratio of the precipitated water and triggers water and soil loss, but is also a major driving force of the eco-geo-environmental hazard itself (Qiyou and others1995).
2. There is a long yearly dry period in the agro-pastoral interlocking zone of northern China, with little rainfall and high rate of change. In dry years or seasons, water in the soil evaporates quickly. The loose and bare soil becomes much more susceptible to wind erosion. Grass for grazing grows poorly and does not completely cover the surface. According to statistics, 30 serious droughts have occurred between 1838 and 1980 in the Eerdose Plateau, with an average occurrence rate of once every 4 or 5 years (Shuying 1994).
3. Wind not only activates stabilized dunes but is also a driving force for removing them. It has been observed that wind with an average speed of 5 m/s can move sand grains on dynamic or semi-immobile sand dunes. The yearly average wind speed is 3–4 m/s with an average of 4–5 m/s in spring in the agro-pastoral interlocking zone. Speeds can reach 29 m/s. As a conse-

quence, in the Eerdose Plateau, the mobile sand dune can advance 5–7 m each year. Semi-immobile sand dunes can advance 2–3 m each year, and in a windy year they can advance >10 m (Shuying 1994).

Irrational human activities

Human activity is an important external stress, and is steadily increasing (Nianfeng and others 1999a). Its influence on the eco-geo-environment has became stronger through history, especially in the last 100 years. Human beings, while conquering and rebuilding nature for their survival and development, have also done many detrimental things (Dianfa and Nianfeng 1999). The destruction of the eco-balance, the degeneration of the eco-environment and many severe eco-geo-environmental hazards are just some of the examples (Nianfeng and others1999). Poverty is one of the main causes for the eco-geo-environmental degeneration in the agro-pastoral interlocking zone of northern China. Its economy and productivity lag behind other regions with a rapid growth of population. The natural resources are exploited in a plundering and destroying mode. Extensive cultivation and inefficient management, heavy grazing, and denudation result in ecosystem degeneration and frequent eco-geo-environmental hazards. In this area, land desertification, destruction of grassland and fixed dunes make up 45% of the area, heavy grazing meadow makes up 29%, gathering firewood makes up 20%, and industrial plants and mine buildings make up 6%. Zhenda (1997) concluded that, "land desertification results from vulnerable eco-environment acted by irrational human activities." The process of land desertification by humans is ten times faster than that of natural processes (Aimin and Longjun 1997). Poverty limits farmers' ability to reform their barren farmland and the local government cannot carry out projects to improve their eco-environment either. The poor quality of the basic agro-facilities reduces the capability of resisting natural disasters.

Population growth increases the stress on land and the environment (Hui 1995). Farmers have no choices but to use the grassland for more food. Most farmers are unable to exploit natural resources in a reasonable mode because of lack of education (Baoxiu 1997).

Some societal factors, such as the frequent alternation of political power, successive wars, unsteady policies and inefficient management, contribute to eco-geo-environment degradation (Zhizhu and Yijuan 1997).

Up to the 17th century, the eco-geo-environment of the Songnen Plain of north-east China was well-kept because very few dwellers lived on hunting and grazing there. Large numbers of immigrants arrived there after 1902 because the Qing Dynasty permitted pioneering, and humans started the process of rebuilding nature. Although they cut trees and cultivated virgin soil, the bearing capacity of the eco-geo-environment was not exceeded. However, after 1949, "the Great Leap Forward" and "the Great Cultural Revolution" caused this zone to suffer serious eco-disasters. One-sided foodstuff production contravened the natural law of eco-geo-environmental evolution. Large-scale reclamation ignored the principles of land use. Undue centralization left the local government no choice but to choose a feasible land exploiting method (Taiyun and Guangting 1991).

"The public wealth tragedy" occurred because the right and obligation of "using, fostering and conserving soil" was not implemented (Dianfa and Nianfeng 1999). The grassland was overused for a long period. Ninety percent of the natural meadows in the west of Jilin province have now degenerated. With regards to forestry, the local government focuses on forestation rather than management. The survival ratio of trees is very low. The denudation and stealing of trees occurs frequently. The state has rented land to farmers, but without any mandate for land maintenance. The farmers are not held responsible for degenerating the soil. In fact, the government acquiesces in their plundering activities of the land (Dianfa and Nianfeng 1999). The low efficiency of a management system has accelerated sandy desertification because of the misuse or destruction of sandy soil (Zhizhu and Yijuan 1997).

In conclusion, the eco-geo-environmental hazards are a result of tectonic processes and exogenic causes. The tectonic processes have established the geomorphological patterns and the vulnerable soil base in the agro-pastoral interlocking zone of northern China. Acting on the vulnerable eco-geo-environment, the exogenic causes, such as East Asia monsoon and irrational human activities, turn potential vulnerabilities into real hazards.

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