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Desertification assessment in China: An overview

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Abstract

Desertification, land degradation in arid, semi-arid, and dry sub-humid regions, is a global environmental problem. Accurate assessment of the status, change, and trend of desertification will be instrumental in developing global actions to prevent and eradicate the problem. As one of the most seriously affected countries, China has made great efforts to combat desertification. Although improvements have been made in some areas, degradation continues to expand and intensify throughout the entire country. Further land degradation assessments, such as assessments made by the Chinese Committee for Implementing UN Convention to Combat Desertification (CCICCD), will be necessary to ensure successful decision-making, to combat increasing desertification, and to implement Western strategies. This paper overviews the state-of-the-art desertification assessments on both the national and local levels. Also, two major problems facing the assessment of degradation—the uncertainty of baseline assessments and indictor systems and the misuse of remotely sensed data sources—are presented along with suggestions for possible solutions to these problems.

Keywords: State-of-the-art desertification assessment; Assessment baseline and indicators; Remotely sensed data sources; China

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1. Introduction

Desertification, land degradation in arid, semi-arid, and dry sub-humid regions, is a global environmental problem with political and socio-economic ramifications. There have been many attempts to assess the extent, nature, and rate of desertification on global, regional, and local levels (Thomas, 1997). These studies are instrumental in understanding desertification myths and in effectively fighting the destruction.

The earliest assessment can be dated back to Lamprey's research in central western Sudan, when he introduced the desert encroachment theory (Lamprey, 1975; Mainguet, 1994). Although this theory was criticized by fellow researchers (e.g. Hellden, 1988, 1991), nevertheless, Lamprey's research laid the groundwork for providing a process for measuring the desertification problem. Since the 1977 United Nations Conference on Desertification (UNCOD), there have been four sequential global desertification assessments by international organizations (Thomas and Middleton, 1994; Middleton and Thomas, 1998). Consequently, a provisional methodology for assessment and mapping of desertification was formulated (FAO/UNEP, 1984) and is now used for local and regional assessment and mapping (e.g. Dong, 1996; del Valle et al., 1997; FAO/UNEP/AGRIMED, 1998).

China, with extensive desertification and an underdeveloped economy, emphasizes remotely sensed assessment on both the national and local levels. These assessment results have helped correct misconceptions of desert encroachment, raised public awareness regarding the urgency of desertification control, and provided decision-makers with scientific data to more effectively control the degradation.

2. Present status of desertification assessment in China

2.1. Nationwide assessment

China began nationwide desertification assessment in the mid-1980s. Historically, China has focused on sandy desertification, which is caused by wind erosion (Zhu and Chen, 1994). Zhu (1985a) divided sandy desertification into four classes: potential, on-going, severe, and extremely severe (Table 1) This classification method was based on geo-morphological changes caused by blowing sand (such as sand dune and sand mound formations, sand cover, and surface coarseness), the percentage of change in relation to the total area, and the annual increasing rate of desertified land. These classifications have been broadly used in sandy desertification assessment (e.g. Dong et al., 1994; Wang et al., 2000) despite concerns about overestimates of the actual desertification area (e.g. Wu and Zhong, 1993).

Using his classification method and aerial photographs taken in China during the 1950s and the mid-1970s, Zhu (1985a) estimated the annual rate of sandy desertification as 1560 km^2. Using remote sensing (RS) data from 1975–1976 and 1985–1986, Zhu and Wang (1990) revised this estimate to 2100 km^2. This new estimate was derived by comparing typical areas selected from 66% of the total

Table 1
Typical criteria for sandy desertification assessment in northern China (Zhu 1985a, b)

Desertification intensity classification	Area (10^3 km^2)	Geo-morphological features	Proportion of land with geo-morphological feature of total area (%)	Annual increasing rate (%)
Extremely severe	34	Continuous mobile sand–dune matrix	>50	>3
Severe	61	Mobile sand–dune matrix interspersed with fixed and semi-fixed sand dunes	26–50	2–3
On-going	81	Shifting sand patch or dense shrub- or bush-mound everywhere, obvious surface deflation and coarseness	6–25	1–2
Potential	15.8	Spotted shifting sand points or deflation points	<6	<1

desertified land (Xinjiang Ugur Autonomous Region, Qinghai Province, and part of Gansu Province). During Zhu's (1985b) original assessment, he asserted that future desertified land change could be predicted by comparing the exponent increase in change of two arbitrary photos of RS data. Recently this theory was used to predict the impact of sandland change on carbon cycle in China (Qi et al., 2001). From the viewpoint of science, however, this prediction method is not considered reliable because of the differences in RS data used. Consequently, the corresponding results should be used with care.

In 1995 the former Chinese Science and Technology Committee initiated a project called the Sandy Desertification Assessment and Its Indicator System. Based on hundreds of expert questionnaires, sandy desertification intensities were classified as slight, medium, severe, or extremely severe (Wang et al., 1998). The main assessment indicators were bare sand ratio, vegetation coverage rate, and soil texture, and the importance of each indicator was calculated by the Delphi weighted method. The assessment methodology was validated from a case study in Lingwu County, Ningxia Hui Autonomous Region (Gao et al., 1998a,b). At the same time, on the basis of Zhu's (1985a) assessment method, Wang et al. (1998) divided sandy desertification into four classes: slight, moderate, severe, and very severe. Four main indicators included the (1) percentage of deflation land or mobile sand dunes, (2) annual mean expanding rate of deflation land or mobile sand dunes, (3) annual mean decreasing rate of productivity, and (4) change of vegetation coverage estimated by projection method.

Following the 1994 United Nations Convention to Combat Desertification (UNCCD), the Chinese Committee for Implementing UN Convention to Combat Desertification (CCICCD) organized a group of scientists to assess nationwide desertification. The group studied wind erosion, water erosion, frozen and melting processes, and soil salinization in addition to degradation by other driving factors. This study determined three desertification intensities (slight, medium, and severe)

Table 2
Assessment criteria of desertification caused by wind erosion (CCICCD, 1997)

Severity	Classification criteria
Slight	Vegetation coverage is more than 30%, no obvious blown sand activities and land surface is covered by fixed or semi-fixed sand dunes
Medium	Vegetation coverage is between 10% and 30%, blown sand activities are controlled significantly, and sand movement ripples exist on sand dunes
Severe	Gobi, sand dunes and sandland with less than 10% of vegetation coverage, denuded interdunes, denuded dune residuals, Yardang landforms, clay mounds and wind blowouts.

Table 3
Assessment criteria of desertification caused by water erosion[a] (CCICCD, 1997)

Severity	Annual mean erosion modulus ($t\,km^{-2}\,a$)	Annual mean soil loss thickness ($mm\,a^{-1}$)
Slight	1000–2500	2
Medium	2500–8000	2–6
Severe	>8000	>6

[a]With reference to criteria of soil erosion from the Ministry of Water Conservancy.

and the scientists formulated detailed assessment criteria for classification. Considering the significance of wind and water erosion, the scientists' assessment criteria were based on past research results and extensive experts' discussions (Table 2 and 3). Using a bioclimatic map drawn with the humid index, as defined by UNCCD (Ci and Wu, 1997), a desertification assessment map was compiled using field investigation and thematic map (TM) images. During cartography, only one degradation process was determined based on the processes occupying the largest proportion of the mapping units used.

The results of the CCICCD assessment identified the total desertification area in China as 2.622 million km^2. Desertification areas caused by wind erosion, water erosion, frozen and melting processes, soil salinization, and degradation by other driving factors were assessed as 1607×10^3, 205×10^3, 363×10^3, 233×10^3, and $214 \times 10^3\,km^2$, respectively. The reported areas of slight, medium, and severe desertification were 951×10^3, 641×10^3, and $1030 \times 10^3\,km^2$, accounting for 36.3%, 24.4%, and 39.3% of total desertification area, respectively (Fig. 1). Simultaneously, the annual expanding rate of sandy desertification was also estimated as $2460\,km^2$ from the 1980s to the mid-1990s (CCICCD Chinese Committee for Implementing Convention Combat, (1997)). Subsequently, the CCICCD method was further refined for desertification assessment and monitoring by the Chinese Desertification Monitoring Center, State Administration of Forestry (SAF, 1998).

Zhu (1998) and Zhu and Wu (1998) criticized CCICCDs final assessment data, however, claiming that it an exaggerated total desertification area in China by

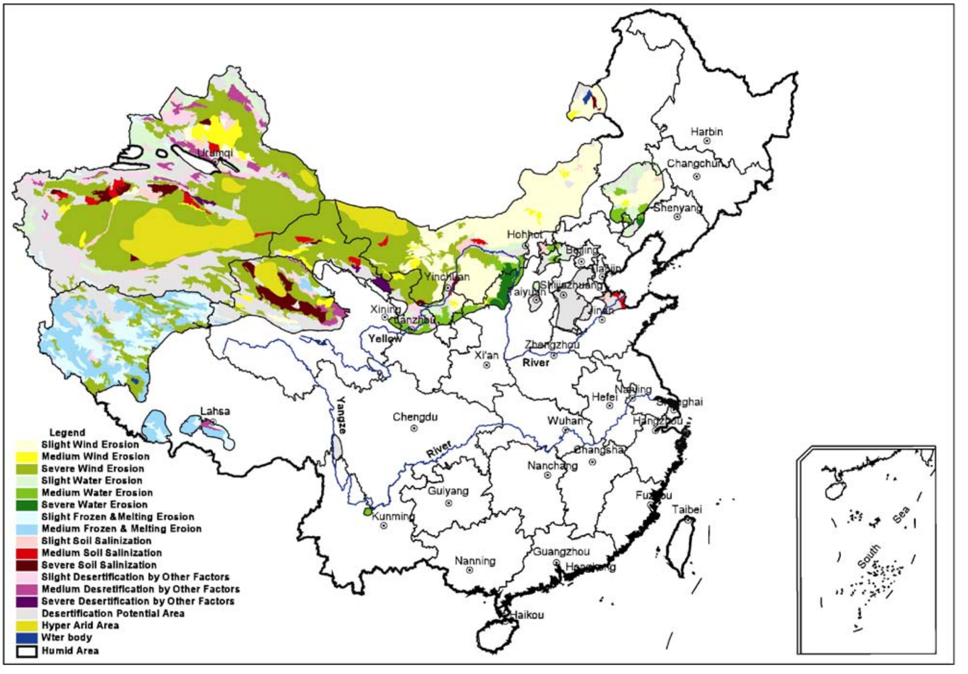

Fig. 1. Desertification distribution map in China, redrawn from CCICCD (1997).

including the deserts, and frozen and melting land into the assessment results. Also, Zhu and Wu insisted that land degradation in humid areas should be included in desertification assessment, as identified in the 1989 and 1994 ESCAP/UNEP documents. Accordingly, Zhu and Wu (1998) estimated that the desertification area was 861.6 thousand km^2, and the area of degraded water-eroded bad-land and rock slope-land in the humid area of southern China was 197.6 thousand km^2. A third estimate of China's desertification area was made by the United Nations Environment Program (UNEP). The estimate, based on Assessment of the Status of Human-Induced Soil Degradation in South and South–East Asia (ASSOD) conducted by the International Soil Reference and Information Center assessment, was published in the *World Atlas of Desertification* (Middleton and Thomas, 1998).

Fig. 2 compares these three assessment results. Due to differences in classification methods of bioclimatic zones, data sources, and assessment indicator systems, we cannot assert which assessment is the most accurate nor which coincides most closely with real conditions in China. What is clear, however, is that the CCICCD estimate is lower because it did not include the Qinghai–Tibet Plateau; Zhu's method of desertification definition and assessment is confusing; and the UNEP results are more unreliable due to its coarser scale and scarcity utilization of field data. At present the CCICCD assessment data have been cited in most official documents and literature because the data are consistent with the UNCCD definition and it was

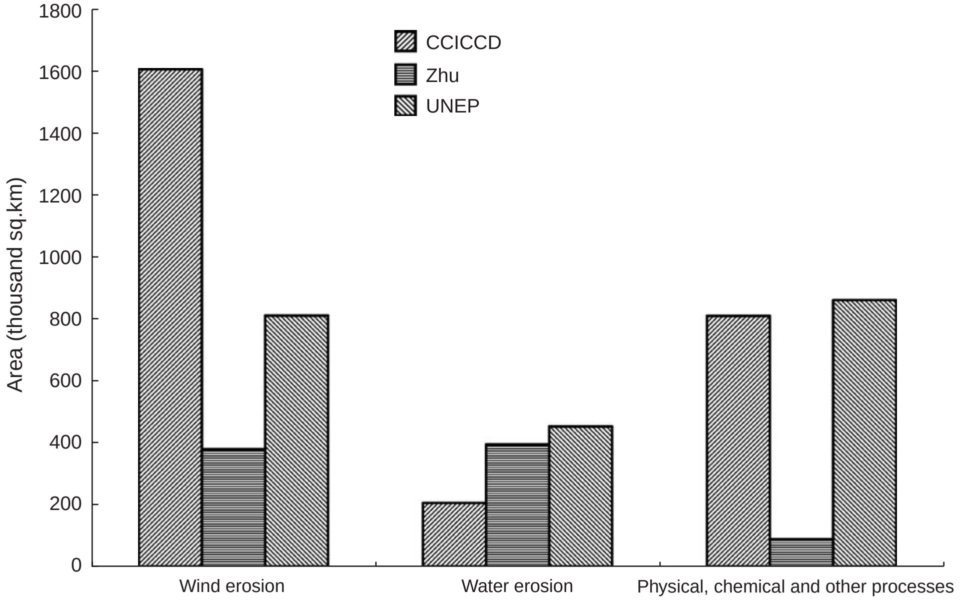

Fig. 2. Desertification assessment results from three data sources.

based on the use of extensive field data (e.g. Wang and Shen, 1998; Wang and Yang, 1999/2000).

2.2. Local assessment

Sandy desertification assessment on the local level was conducted around eight main deserts, four main sandlands, and their peripheral regions in China (Dong et al., 2000). Traditionally sandland refers to sand-covered land in semi-arid steppe that is characterized by dominantly physiognomic features of fixed or semi-fixed sand dunes (Fig. 3). The Ordos Plateau, especially the Mu Us Sandland, is a typical agro-pastoral mosaic zone in the semi-arid area of China. In this area, desertification dynamics very obviously coincided with human activities. Based on past data and the LANDSAT-based interpretation on mobile sand dune distribution, Luk (1983) concluded that desert expansion occurred in the Mu Us Sandland from 1953–1976, with peaks noted from 1959–1963 and 1971–1976. The total desert area and mobile sand dune area increased by 10% and 83%, respectively, and the annual mean expanding rate of the sandland was 6.4% or 460 km^2 from 1958–1971. Interestingly, two time-phase LANDSAT images (1974 and 1978) were interpreted during this research; however, no detailed data on desertification status were produced. Using TM images, Wu et al. (1997) calculated that desertification area decreased by 1936 km^2 in the Mu Us Sandland between 1987 and 1993. For this calculation, desertification intensities were classified into slight, moderate, severe, and very severe, and mobile sand dunes were excluded. However, when sandy desertification

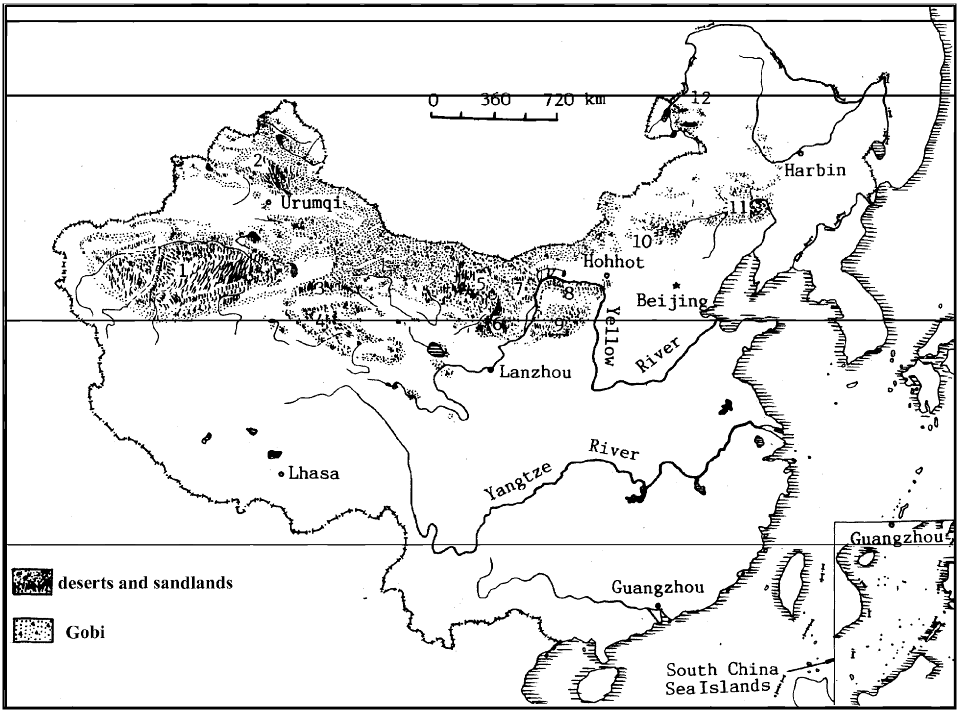

Fig. 3. Distribution map of deserts and sandlands in China, redrawn from Zhu et al. (1980): (1) Taklimakan Desert, (2) Gurban Tonggut Desert, (3) Kumtag Desert, (4) the Deserts in Qaidam Basin, (5) Badain Jaran Desert, (6) Tengger Desert, (7) Ulan Buh Desert, (8) Qubqi Desert, (9) Mu Us Sandland, (10) Otindag Sandland, (11) Horqin Sandland, and (12) Hulun Buir Sandland.

area was calculated, mobile sand dunes were included, which may cause confusion regarding classification and assessment. Afterwards, using aerial photographs in 1958, 1977, and 1993, Wu and Ci (1998) studied desertification dynamics in six typical areas of the Mu Us Sandland. The results showed that desertification was expanding in five typical areas from 1958–1977, in three areas from 1977–1993, and in four typical areas from 1958–1993. Although the speed of desertification expansion has slowed down, the expanding trend remains unchanged. Using NOAA/AVHRR NDVI satellite data, Runnstrom (2000) noted that on the Ordos Plateau from 1982–1993, irrigated farmland had higher productivity due to intensified cultivation and plantation of protective forests. Without corresponding rainfall, the rangeland had slightly increased productivity. However, Runnstrom did not conclude if northern China was winning the battle against desertification. Assessments have also been conducted in the Kerqin Sandland (Takeuchi et al., 1995); the Bashang Region, on the southern edge of the Otindag Sandland (Zhu, 1994); and the Minqin Oasis of Gansu Province, on the western edge of the Tengger Desert (Wang et al., 2000).

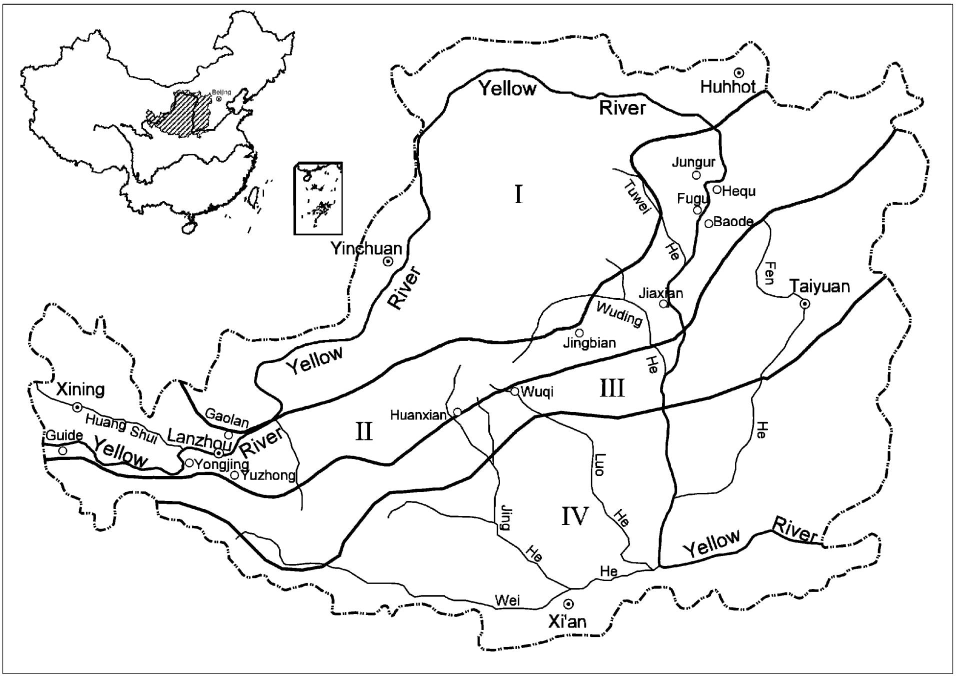

Fig. 4. Map of bioclimatic zones and location of typical counties for water erosion measurement on the Loess Plateau, redrawn from Tang and Chen (1990). (I) wind erosion belts in semi-arid warm temperate steppe and arid middle temperate steppe; (II) wind erosion and water erosion complex belt in semi-arid warm temperate steppe; (III) water erosion belt in semi-arid warm temperate forest-steppe; and (IV) water erosion and gravity erosion complex belt in sub-humid warm temperate broadleaf forest.

Assessment of desertification by water erosion has concentrated on the Loess Plateau. Soil erosion on the Loess Plateau has been regionalized into four belts: (1) wind erosion belt in the semi-arid steppe of warm temperate climates and the arid desert steppe of middle temperate climates; (2) wind erosion and water erosion complex belt in the semi-arid steppe of warm temperate climates; (3) water erosion belt in the semi-arid forest-steppe of warm temperate climates; and (4) water erosion and gravity erosion complex belt in the sub-humid broadleaf forest of warm temperate climates (Fig. 4). Water erosion intensities are typically divided into six classes according to standards set by the Ministry of Water Resource (MWR, 1997, Table 4). Accord to these standards, annual soil tolerance loss was estimated at 1000 tons km^{-2} (Chen et al., 1988). Among the four erosion belts, the second and third belts are the most serious soil erosion zones, with annual mean erosion rates of 6000–25,000 and 8000–20,000 tons km^{-2}, respectively (Tang and Chen, 1990). The annual mean erosion rates of northern Loess Plateau counties along the Yellow River and its branches are shown in Fig. 5. These sediment-loading estimates were based on data from a local hydrological station (Tang and Chen, 1990).

Table 4
Classification criteria of water erosion intensity (MWR, 1997)

Intensity	Annual mean erosion modulus ($t\,km^{-2}\,a$)	Annual mean soil loss thickness[a] ($mm\,a^{-1}$)
Negligible	<1000(500[b])	<0.74(0.37[b])
Slight	1000(500[b])–2500	0.74(0.37[b])–1.9
Moderate	2500–5000	1.9–3.7
Severe	5000–10000	3.7–5.9
Very severe	10000–15000	5.9–11.1
Extremely severe	>15000	>11.1

[a]Annual mean soil loss thickness is calculated based on the soil bulk density of 1.35 $g\,cm^{-3}$, for specific site, it can be calculated using in-site soil bulk density.
[b]Number in parentheses is applied in mountainous areas.

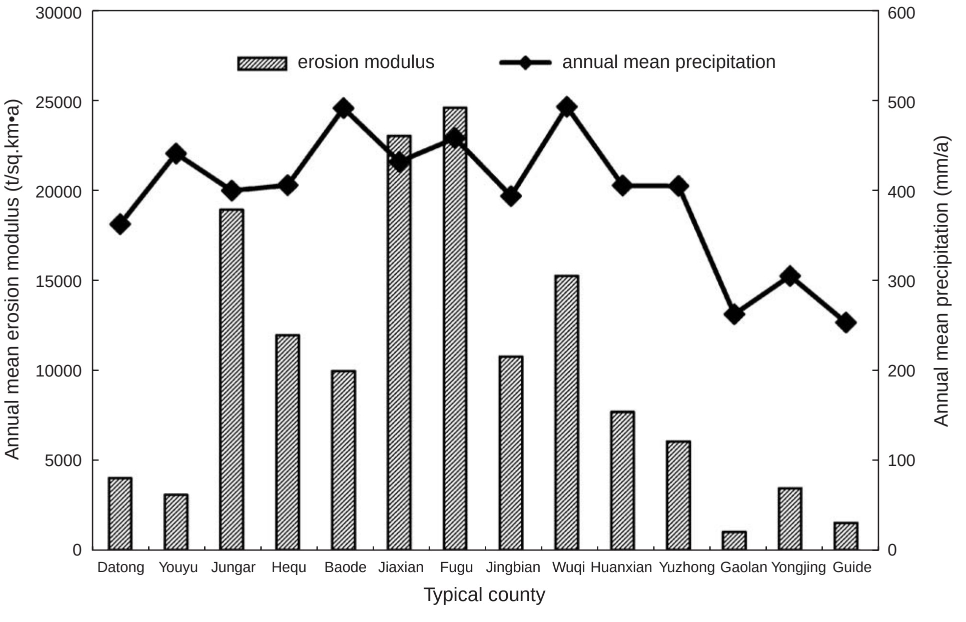

Fig. 5. Erosion modulus and annual mean precipitation in some typical counties of the northern part of Loess Plateau (arid and semi-arid areas) (drawn from the data of Tang and Chen, 1990).

3. Two major problems

To date, desertification in China had been assessed by many organizations and scholars, but some scientists argue that it is impossible to estimate desertification accurately due to the complex causes of and large areas of degradation in China (e.g. Fullen and Mitchell, 1994). Zha and Gao (1997) also attributed this impossibility to complexities of desertification definition, types, and degrees. This does not mean, however, that desertification cannot be assessed accurately in China. In fact, inaccurate assessment is the result of two urgent problems: (1) uncertainty of baseline assessments and indictor systems and (2) misuse of remotely sensed data sources.

3.1. Baseline assessment and indicator systems

Considering that desertification comprises not only land degradation processes but also its consequences (Mainguet, 1994), desertification assessment, like other evaluations of environmental changes, must be based on a definite reference point or baseline (e.g. Grainger, 1992, pp. 17–33). In general, the change in vegetation is the most direct indicator of land degradation. Grainger (1992, pp. 17–33) pointed out that the baseline for desertification assessment theoretically should be climatic climax vegetation in natural environments. In the FAO/UNEP methodology for desertification assessment (1984), the quantitative climax theory was used to determine the baseline for vegetation degradation assessment. However, in arid ecosystems with climatic variability, non-equilibrium ecosystems based on state-and-transition models are more predominant than equilibrium ecosystems based on the Clementsian succession model (Westoby et al., 1989; Oba, et al., 2000). It is impractical for researchers to determine an assessment based only on vegetation growth and changes because there are multiple stable states for vegetation in arid ecosystems. In China, very few literature addressed the non-equilibrium theory (Ho, 2001), and it is difficult to find related references to arid land assessment. Limited by available data and field experience in combating desertification, a relatively arbitrary time-dependent reference baseline was determined. Zhang and Yang (1999) suggested that the optimum alternative should be the physical conditions around 1949 as baseline for desertification assessment.

After a baseline has been established, an indicator system is required for assessment. Although many indicators were singled out on different scales, only several indicators are actually used for desertification monitoring and assessment. Hammond et al. (1995) recommended that both decision-makers and the public require a few highly aggregated indicators for environmental assessment, and these indicators should be easy to use, sensitive to stressors, and cost effective (Rubio and Bochet, 1998; Dregne, 1999, pp. 95–102).

Many indicator systems for desertification assessment were established following the 1977 UNCOD, and they have been used on the global, regional, and local levels (e.g. Berry and Ford, 1977; FAO/UNEP, 1984; Warren and Hutchinson, 1984; Guyot, 1990, pp. 295–297; Mouat et al., 1992, pp. 717–737; DeSoyza et al., 1997, 1998; Sharma, 1998). In China, some indicator systems (e.g. Zhu, 1985a; CCICCD 1997; Gao et al., 1998a,b; Liu and Ci, 1998; SAF 1998) have also been applied to coarse-scale desertification assessment. All of these indicators are synoptic, and the indicators can be determined directly by a combination of RS and field investigation. However, a community or patch-based fine-scale indicator system in combination with high-resolution data and ecological models has not yet been established. Recently FAO launched the Land Degradation Assessment in Drylands (LADA) program, which studies the biophysical and socio-economic components of desertification by using local information and scientific knowledge (FAO, 2002). As one of three pilot countries, in addition to Argentina and Senegal, China will establish an integrated stress–response indicator system under the guidance of FAO, which will promote participatory, decentralized, and fine-scale desertification assessment in China.

3.2. Data sources and their applications

In general, desertification assessment is undertaken by field-based and remotely sensed scales (FAO/UNEP, 1984). Because desertification occurs mostly in rural, remote, and underdeveloped areas, limited funds and technically proficient personnel shortage hinder field-based assessment of large areas. Different RS data, such as MSS, TM, SPOT, NOAA/AVHRR, Russian satellite Kosmos-1939, Indian Remote Sensing Satellite (IRS-IA and IB), and AVIRIS, have been broadly applied (e.g. Guyot, 1990, pp. 295–297; Kharin, 1990, pp. 179–238; Hanan et al., 1991; Tucker et al., 1991; Pickup et al., 1993; Sahai 1993; Okin et al., 2001) and been proven to be useful tools (Tueller, 1987; Thomas and Middleton, 1994).

During remotely sensed assessment, vegetation coverage and its change are easy to interpret from satellite images and are often considered preferred indicators (Tucker et al., 1991; Mouat et al., 1997; Weiss et al., 2001) rather than the best indicators of desertification. Vegetation coverage is influenced by climate change including short-term fluctuation (drought) and long-term variation (aridity), and it may take 30–40 years before a permanent change in vegetation coverage becomes evident (Dregne and Tucker, 1988). Hence, multi-temporal data will be the best choice to determine short-term vegetation fluctuation from long-term permanent change. At present, multi-temporal NOAA/AVHRR data are used in desertification assessment (e.g. Bastin et al., 1995; Tripathy et al., 1996; Weiss et al., 2001).

In China, aerial photography and TM images are often used for assessment either separately or in tandem (e.g. Ma et al., 1996; Wu et al., 1997; Gao et al., 1998a,b; Wu and Ci, 1998). Aerial photography is taken no more than once every 5–10 years for military purposes or national land-use surveys. Therefore, in recent years, TM images have been used more often because of their relatively high resolution and wide-range regional coverage. However, in the past the use of multi-temporal images has been economically unfeasible in China; hence, only a few snapshot images have been used for assessment. This may have contributed to error and uncertainty in many previous desertification-related studies in China (Runnstrom, 2000). For instance, the Mu Us Sandland assessment used a few snapshot images, but neglected the influence of climate fluctuation on seasonal and yearly vegetation coverage (Wu et al., 1997; Wu and Ci, 1998). If multi-temporal images were used, the Mu Us Sandland assessment may have been more reliable. Recent economic developments in China, however, have made the use of multi-temporal data, such as NOAA/AVHRR and SPOT4 vegetation imagery (e.g. Long, 2000, pp. 55–60; Sun et al., 2000, pp. 82–84) possible. Using increasingly available multi-temporal or multi-spectral remotely sensed data should minimize assessment errors in the future.

4. Conclusion

In the past 20 years, desertification assessment in China has laid the foundation for further scientific study. The assessment conducted by CCICCD provided background information for undertaking desertification control and initiating Western development strategies. Limited by the political system and intricate physical conditions, however, desertification assessment continues to be controlled by a top–down approach. Institutions play very important roles and assessment results are only available to academic researchers and government decision-makers. Despite the newly enacted Sand Control Law, local governments or institutions continue to be in charge of desertification monitoring and assessment, while local farmers and herders, who suffer from desertification effects and implemented desertification controls, are not mentioned in the law (SAF, 2001). Future assessment should include a participatory-based hierarchical framework and an early warning system for desertification.

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