Application of Remote Sensing and GIS Technology to the Study of Desertification of Arable Lands in North Shaanxi, China

Mushtak Talib Jabbar  HU Guangdao  ZHANG Zhenfei

ABSTRACT The policy of the Chinese government concerning the horizontal expansion of the cultivated land through the reclamation of desert soils result in a total increase of 665.985 km² during the period 1987-1999 in North Shaanxi. This increase is less than the loss in arable land by urbanization. The accelerated rate of change in agricultural areas calls for more rapid surveys of urbanization and loss of arable land. Remote sensing has a number of advantages over ground-based methods for such surveys. The multi-scale concept of remote sensing data help us study the problem in four towns. Several maps were produced to analyze the situation of urban coverage in different times. The evaluation of the status, rate and risk of urbanization are based on an accepted average of urban increase as 2% of population growth per year.

KEYWORDS urbanization; population pressure; arable land; desertification; remote sensing; GIS

CLC NUMBER P208

Introduction

Desertification has severely affected industrial and agricultural production as well as people’s lives. It has become an important factor restraining the sustainable economic and social development of western regions of China. One of the serious processes of desertification is the degradation of fertile, productive soils. Degradation takes many forms which may be described qualitatively or quantitatively. According to the magnitude, rate and geographical location the quantitative forms can be reversible or, in practical and economic terms, irreversible. In arid and semi-arid areas, the latter form includes mostly urbanization. Urbanization does not always mean desertification. Its long-term detrimental effects occur when it is made haphazardly; particularly in the absence of land use maps. The loss is even more drastic when this urban development is undertaken on the account of irrigated productive arable soil, such as the case in China. There are 13 cities in Shaanxi province with an urban population of 9.365 8 million including non-agricultural population 4.899 2 million whose percentages of the total population and non-agricultural population have been raised from 25% and 61.9% in 1990 to 27.3% and 62.4% in 1997 and the urbanization rate in 1997 was 27%. The application of remote sensing and geographic information system in the study of urban development has started since the 1940s by using the panchromatic aerial photographs for determining the urban area. The progress in photography by using color and false color films made it possible to study the human aspects of urban development. The progress of image processing techniques made the satellite image data fruitful in studying the field of urbanization, for example, CHEN Guangwei used computer implement-
ted techniques for landsat MSS and TM data to estimate and analyze major terrain features in China\textsuperscript{[2]}\textsuperscript{[2]}. The current research attempts to study generally the urban encroachment against the fertile land of the Yulin, Jinbian, Hengshan and Mizhi cities in North Shaanxi.

1 Location of the study area

Since the encroachment of urbanization is dangerous only in the arable land of Yulin, Jinbian, Hengshan and Mizhi municipalities, the study areas were chosen within these regions. The study areas include large cities, towns and some small villages, covering from 109° 00' E to 110°00'E and from 38°40'N to 37°20'N. The area is 158 km long from north to south and 87 km wide from east to west, and the total area is 13 746 km². The area is located in a typical transitional zone within the Mao Wusu desert area (Fig. 1).

Fig. 1 General location of the study area

2 Methodology

2.1 Satellite data and preprocessing

Two Landsat TM and ETM scenes in 1987 and 1999 for Yulin and Jinbian, respectively, were used for the land cover change detection (Table 1). The TM sensor consists of detectors, which produce signals proportional to the average amount of light reflected from an area 30 m × 30 m, which is the geometrical resolution of a Landsat TM sensor. Raw digital images usually need to be corrected for geometric deformation due to the variation in vertical velocity of the sensor platform, for variations in scan speed and in the sweep of the sensor’s field of view, earth curvature. The systematic errors are normally corrected at the receiving station. Random distortion need to be corrected by the analyst through selection of sufficient number of ground control point (GCP’s) with correct coordinates.

| Location | Data satellite | Mission-sensor | Receiving station |
|----------|----------------|----------------|------------------|
| YULIN    | 24 October 1987 | Landsat-5 TM   | Beijing          |
|          | August 1999     | Landsat-7 ETM  | Beijing          |
| JINBIAN  | 1 September 1987| Landsat-5 TM   | Beijing          |
|          | October 1999    | Landsat-7 ETM  | Beijing          |

By using rectification algorithm image and/or vector, the column and row coordinates of the image can be fit for the Geodetic Datum WGS84 and map projection NUTM49 coordinate system built into the vector using the linear method and the chosen resampling method was nearest-neighbour which preserved original reflectance value (Table 2). Fifty ground control points were chosen on the images, primarily on clearly visible river. The points were spread quite evenly throughout the image, making a good control. Image software allowing for easy zooming to assist point selection that the points were registered in the header file of the image for coming rectification. Once all ground control points were compiled, error checking was used to gauge the efficiency of point used. The RMS errors for the linear method of rectification were examined with varying accuracies, all of them are approximately 0.6 m in displacement error\textsuperscript{[3-5]}.

| Corrected sense | GCP’s to map number scheme | Resampling nearest neighbor | RMS Geodetic map projection WGS84 NUTM49 |
|-----------------|---------------------------|----------------------------|------------------------------------------|
| 1987 sense      | 50                        | nearest neighbor           | 0.6                                      | WGS84 NUTM49                             |
| 1999 sense      | 50                        | nearest neighbor           | 0.3                                      | WGS84 NUTM49                             |

2.2 Digital analysis of satellite image

An estimation of increasing urbanization in Yulin, Jinbian, Hengshan and Mizhi cities was carried out. The estimation was performed on a twelve-year interval by using computer imple-
mented techniques for digital image processing of landsat TM satellite images, which cover the same area. By unsupervised classification technique and supervised classification technique the major land cover classes that exist in the image were recognized, without prior knowledge of what they might be. They are useful for determining the spectral class composition of the data prior to detailed analysis by the methods of supervised classification. Cluster classifications search for cluster of pixels with similar reflectance characteristics in multi-band image\(^6\). In this study a cluster classification module from the ER mapper software was used. First a false color composite image (FCC) was produced from band 7, 4 and 1. As the intention was to recognize major land cover classes, a broad generalization level was chosen, revealing 6 classes in the two images. The used software includes some computer programs, namely categorical analysis (CA) and landsat categorical processor (LDCP) which categorize landsat digital reflectance and automatically calculated area of each category. The technique requires that the location of a number of training sets, represent areas of known features from ground true information be established in the data. The selection of training sets in the study area was made on the basis of the available topographic maps of 1 : 100 000, and 1 : 25 000, field observation, and visual interpretation of the landsat false color composite images. The (CA) program does the categorical analysis of the training sets and produces coefficients to allow categorization of the different features in the light of its multispectral response. The software is also capable of calculating the area of any categorical group out of any spectral band or of any combination of bands. To study the extension of urban space, we combined the traditional data (maps) with satellite images. 

2.3 Application of geographic information system

Arc/Info and ArcView systems were used to estimate the area of each study site. Topographic maps at scale of 1 : 100 000 were used. These topographic maps date to 1986 and 1995. The urban areas were allocated on the topographic maps and boundaries were exactly delineated on vectorazation by using Arc/Info software.

2.4 Monitoring of urban areas

The multi-concept of remote sensing is used in this study to satisfy different conditions of study sites. Small scale satellite images are suitable to monitor large area. They have the advantage that a single scene provides regional image to the interpreter. The use of large scale satellite image permits the delineation and analysis of smaller features. Topographic maps of scales range from 1 : 100 000 to 1 : 250 000 were used. The spatial analysis of component land covers gives the urban areas their physical recognition. A manual interpretation scheme was followed as a process, which is divided into a number of phases (e.g. map-reading, recognition and reduction) and resulted in the ultimate goal\(^5\).

2.5 Soil analysis

In order to have information about the soil characteristics of urban area, soil sample were collected. Also, previous studies of some soil profiles from the studied urban cities were analyzed. The evaluation of soils was based on measurements of soil color, organic matter content, total carbonate content, electrical conduc-
tivity, pH values and soluble cations and anions.

2.6 Evaluation of urbanization processes

The professional methodology of FAO (1979) and UNEP (1992, 1994) was taken as a guideline to evaluate the urbanization of North Shaanxi, China. The methodology was modified on the assumption that the accepted increase in the usual rate of population growth in most developing countries range from 1% to 2% per year. In urbanization the problems considered include the present conditions of the status, rate and risk. The suggested rating value for different aspects of urbanization is shown in Table 3.

| Desertification aspect | Assessment factor | Slight | Moderate | Severe | Very severe |
|------------------------|-------------------|--------|----------|--------|-------------|
| Status                 | Loss of fertile land within ten years, (% of inhabited area) | <20    | 20–30    | 30–50  | >50         |
| Rate                   | Increase in urban area per year. | 1–1.5  | 1.5–2.5  | 2.5–4.5 | >5          |
| Risk                   | Population growth (%) | <1.5   | 1.5–2.0  | 2.0–3.0 | >3          |

3 Discussion of results

3.1 Monitoring Urbanization from Satellite Images

Three sites have been studied using recent image satellite (Landsat TM) compared with topographic maps of earlier period. It was possible to delineate the boundaries of each study site. The high resolutions of the satellite images were quite helpful for the exact delineation of these boundaries. The statistical values of arithmetic mean and standard deviation (S, D) for the spectral reflectance of urban categorical groups in the seven bands of the used two Landsat TM images show a large variation. The ER mapper software performs the categorical analysis of the training sets and produces coefficients for categorization of the urban areas based on its multispectral response and show landsat categorized image flown in 1987 and 1999, respectively. Table 4 summarizes the differences in urban area of three sites between the years 1987 and 1999. The measurements make it possible to notice a significant increase of urbanization with respect to the time interval. The rate of increase ranged “from” “3, 23% to 4.50%”. The data reveal a significant increase in urban area with time. However, the magnitude of increase depends on the strategically significance of the location. Yulin in the north of Shaanxi province is considered as great economic and administrative center, the increase of urban area reached more than 4,600 2 ha during twelve years. The percentage increase in its urban area reached 54, 04% compared with its original coverage in 1987. Jinbian, Hengshan and Mizhi have a geographical extension smaller than Yulin. The high increase in urbanization (54.04%, 35.03%, 38.84% and 40.63%, respectively) is a clear indication of the great danger to the fertile cultivated land in north Shaanxi. This pattern of increase is mostly related to the socio-economic conditions. People tend to live where the administrations are concentrated. These trends are always on the account of the fertile cultivated land. Hence, the redistribution of administration and work opportunities must be considered in establishing new urban societies. These conditions might have their influence on people’s education and mentality which may help in following a civilized population policy.

3.2 Population increase

High population density is a very significant feature of Yulin and Jinbian; it applies great pressure on the land and other natural resources. The risk of population growth here is significantly higher than in neighboring cities. Local statistical data of the cities shows that the populations increase by 250% from 1949 to 1982. The population density rose from 18 pers. / km² in 1949 to 43 pers. /km² in 1982.
The farmland available for each person decreased by about 10%. A critical index of population pressure in different regions was provided during the conference of arid land resources and environment in 1977.

In this study total population growth rate increase from 7.95% to 9.25% during the period 1987–1999 in the Yulin, Jinbain, Hengshan and Mizhi. At present, the population density of Yulin County has exceeded this critical index. From now on, if the population increases by a rate of 8.5% annually, the total population of Yulin County will increase by 39% in 2050. Farmland per capita will decrease gradually. If forest damage and grassland changing to farmland increased together with the population, land desertification would become more and more serious.

### 3.3 Characteristics of soil and evaluation of urbanization

A great number of soil samples, representing urbanized area, were studied. However, one soil sample is shown here as an example to represent the soil characteristics of such areas (Table 5). The soil is characterized by clear subangular blocky structure. It is moderately saline to severely saline (Table 6). The soil samples can be classified as “vertisols, typic torrerts”. These samples occupy the alluvial flood plain and fall within classes I and II according to their suitability for cultivation.

| Depth/cm | Description |
|----------|-------------|
| 0-20     | Dark brown (10YR, 3/3) moist, clay weak sub angular blocky, firm, sticky, plastic, many fine pores, many fine root, moderate effervescence with HCL, diffuse smooth boundary. |
| 20-40    | Dark grayish brown (10YR, 4/2) moist, clay, strong sub angular blocky, firm, sticky, plastic, slickenside, many fine pores, many fine roots, moderate effervescence with HCL, diffuse smooth boundary, |
| 40-50    | Dark grey (10YR, 4/1) moist, clay, weak fine, blocky, firm, sticky, plastic, slickenside, many fine pores, weak effervescence. |

The obtained results from satellite image and topographic map were employed in the modified FAO/UNEP professional methodology (1979, 1992, and 1994) to evaluate the magnitude of urbanization (Table 7). The results show that the study areas are almost exposed to a very severe to severe status and rate of urbanization. All the study areas faced severe risk. These measures are based on the assumption that all urban expansion happened on the cultivated fertile land. Indeed, this assumption is mostly true because the creation of new urban societies in the desert is a recent policy started in the last few years. The estimation of the risk is based on a population increase of 10% per year. Following a more civilized population policy may reduce the future risk of urbanization. This can come from a detailed study of socio-economic behavior.
Table 6 Results of chemical analysis of soil samples

| Location | Depth/cm | pH | E.C /dsm⁻¹ | Saturation extract (meq/L) | Na⁺ | K⁺ | CO₃⁻ | HCO₃⁻ |
|----------|----------|----|-------------|----------------------------|-----|----|------|-------|
|          |          |    |             | Ca²⁺ | mg²⁺ |     |      |       |
| Yulin    | 0-20     | 7.1 | 1.5         | 3.0  | 4.2  | 6.5 | 0.3  | 0.00  | 2.9   |
|          | 20-40    | 7.3 | 1.2         | 2.3  | 3.3  | 7.4 | 0.2  | 0.00  | 3.1   |
|          | 40-60    | 7.4 | 1.0         | 1.8  | 3.6  | 7.3 | 0.2  | 0.00  | 3.5   |
| Jinbian  | No data  |    |             |      |      |     |      |       |
| Hengshan | 0-20     | 7.2 | 1.9         | 5.4  | 2.5  | 7.8 | 0.3  | 0.00  | 3.0   |
|          | 20-40    | 7.2 | 1.7         | 4.7  | 2.6  | 7.9 | 0.3  | 0.00  | 3.0   |
|          | 40-60    | 7.4 | 1.3         | 3.2  | 2.4  | 8.5 | 0.2  | 0.00  | 3.2   |
| Mizhi    | 0-20     | 7.9 | 4.9         | 6.4  | 2.9  | 9.7 | 0.5  | 0.00  | 3.2   |
|          | 20-40    | 7.9 | 3.7         | 4.9  | 3.8  | 9.7 | 0.3  | 0.00  | 3.5   |
|          | 40-60    | 8.0 | 3.3         | 3.8  | 3.4  | 8.9 | 0.3  | 0.00  | 3.9   |

Table 7 Evaluation of different Aspects of Urbanization

| Name of location | Status   | Rate | Risk |
|------------------|----------|------|------|
|                  | (1) Class| (2) Class | (3) Class |
| Yulin            | 57.75    | 4.50 | 2-3  |
| Jinbian          | No Data  | 3.89 | 2-3  |
| Hengshan         | 43.7     | 3.23 | 2-3  |
| Mizhi            | 67.73    | 3.38 | 2-3  |

Notes: (1) Loss of fertile land within ten years (% of inhabited area); (2) Increase in urban area per year; (3) Population growth (%).

4 Conclusions

It can be concluded that the cultivated areas in the Yulin, Jinbian, Hengshan and Mizhi cities are suffering from a serious problem of urbanization. This problem has caused an irretrievable loss of very fertile suitable land. The problem is characterized by a very severe status and rate and severe risk of urbanization. The construction of new urban cities in the desert and following a civilized population policy are the hope now for sowing the remaining fertile land from being lost. Also, this construction away from the cultivated land will protect more fertile lands to be scraped out for brick industry. This study demonstrates that remote sensing and GIS technology can play a great role in land desertification investigation, monitoring land change, evaluation of urbanization in the study areas, and as a tool for regional planning. The satellite image is very useful for monitoring and evaluating urbanization in cities.

REFERENCES

1. CCICCD (1997) China country paper to combat desertification. Beijing: China Forestry Publishing House.
2. Chen G W (1996) Land degradation approach methodology and practice. Beijing: Electronic Industry Press.
3. Dymond J R, Stephens P R, Newsome P F, et al. (1992) Percentage vegetation cover of a degrading rangeland from SPOT. *International Journal of Remote Sensing*, 13(11):1999-2007
4. Bausch W C (1993) Soil background effects on reflectance-based crop coefficients for corn. *Remote Sensing of the Environment*, 46:213-222
5. Dejong S M (1994) Derivation of vegetative variables from a Landsat TM image for modeling soil-erosion. *Earth Surface Processes and Landforms*, 19(2):165-178
6. Richards J A (1993) Remote sensing digital image analysis, an introduction. Berlin: Springer-verlag.
7. Gaston G G, Bradley P M, Vinson T S, et al. (1997) Forest ecosystem modeling in the Russian Far East using vegetation and land-cover regions identified by classification of GVI. *Photogrammetric Engineering and Remote Sensing*, 63(1):51-58
8. Collins W G, Bush P W (1996) The identification and classification of derelict land. *Journal of the Town Planning Institute*, 55:111-115
9. Ren Z B (1990) Remote sensing application on grass-land investigation. Beijing: Chinese Science and Technology Publishing Press.