Land Degradation Detection, Mapping, and Monitoring in the Northwestern part of Hebei Province, China, Using RS and GIS Technologies

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Abstract

Two algorithms (Tasseled Cap Transformation and NDVI) and GIS technique were applied for this study in order to detect, mapping, and monitoring the land degradation in the Northwestern part of Hebei Province, China, at county level, which covered by Landsat-5 TM image (124/32) during the period from 1987 to 1996. Thresholding was used to acquire the changed areas and produce the general change maps, which contains three classes: positive change, negative change, and no-change. The results indicated that the study area had an increase in the tasseled cap greenness positive change, tasseled cap wetness positive change, NDVI values, and decrease in tasseled cap brightness values, which means increase in the vegetation cover and the soil moisture during the study period. Laishui County had the highest values of the vegetation cover increase and the lowest soil bareness values. The results also revealed that there was a high significant relationship between the values of the tasseled cap greenness indicator and the NDVI indices for the study area. This study demonstrates the effectiveness of the remote sensing 'RS' and the Geographical Information System 'GIS' in detection, assessing, mapping, monitoring, and generating essential quantitative information on the land degradation at county level in the Northwestern part of Hebei Province, China.

Key words: Remote sensing, GIS, Change detection, Land degradation, Hebei, China

Introduction

Land degradation is a complex ensemble of surface processes (e.g. wind erosion, water erosion, soil compaction, salinisation, and soil water-logging). These can ultimately lead to "desertification". As the increasing world population places more demands on land for food production etc., many marginal arid and semiarid lands will be at risk of degradation. The need to maintain sustainable use of these lands requires that they be monitored for the onset of land degradation so that the problem may be addressed in its early stages. Monitoring will also be required to assess the effectiveness of measures to control land degradation.

The most typical and serious form of land degradation in China is desertification. Desertified land covers an area of 3.3 million km^2, accounting for 34% of the total territory or 79% of the entire arid land in China (Chen et al., 1996). Over 100 million ha of grassland, 7.7 million ha of farmland and 0.1 million ha of woodland have been affected by degradation (Sun et al., 1998). Desertified sandy land increased by 25,200 km^2 for the period from 1975 to 1987 about 40.5% of which was distributed in the semiarid agropastoral regions of northern China (Zhu and Wang, 1993). At present, desertification is spreading with an annual growth of 10,400 km^2, with 400,000,000 population affected. Annual direct economic loss caused by desertification is approximately 6,500,000,000 US Dollars (UNCCD, 2002).

The basic premise in using remote sensing data for change detection is that changes in land cover result in changes in radiance values, which can be remotely sensed. Techniques to perform change detection with satellite imagery have become numerous as a result of increasing versatility in manipulating digital data and increasing computing power. Image differencing procedure is to register simply two images and prepare a temporal difference image by subtracting the digital numbers (DN) for one date from those of the other. The difference in the areas of no change will be very small, and areas of change will reveal larger positive or negative values (Lillesand and Kiefer 1987).

The objective of this study is to detect, assess, mapping, and monitoring the land degradation risk in the study area in the northwestern part of Hebei Province, China, at county level using Remote Sensing 'RS" and Geographical Information System 'GIS' technologies.

Study Area

Hebei Province is situated in temperate and warm temperate zones**.** The study area extends between latitude N 39° 27' to N 41° 11', longitude E 114° 24' to 115° 55'. It covers an area of 20,828 km^2, accounting 11.1% of the total area of Hebei Province. Northern and northwestern parts of Hebei are located in the temperate continental monsoon climate zone. Cold and windy winters and warm and dry summers are the general characteristics of the climate. The annual average rainfall ranges between 300 mm and 600 mm (Ministry of Civil Affairs and Ministry of Construction, 1992). Most of the rain comes between May and August. Figure 1 shows the location map of the study area in the Northwestern part of Hebei Province, China.

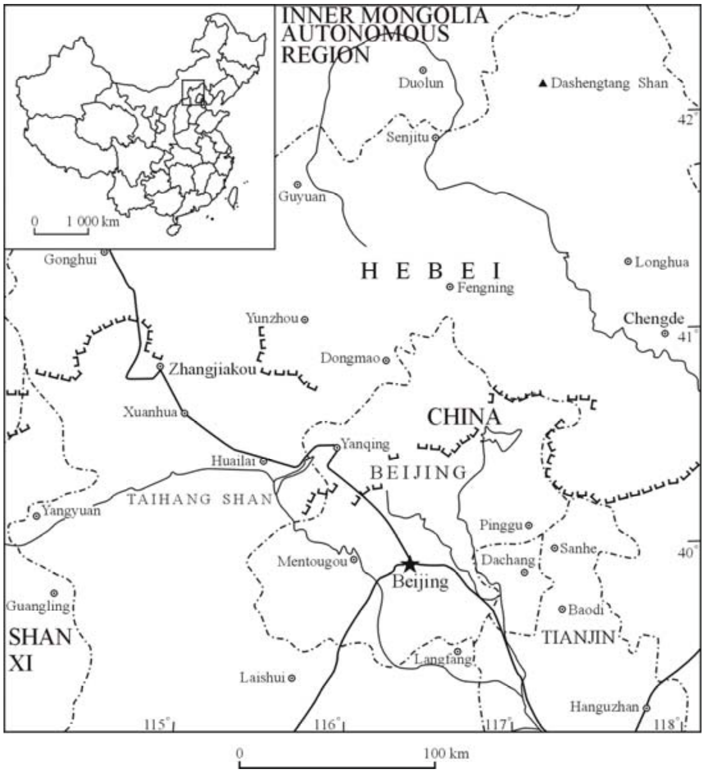

Figure 1. Location map of the study area in the Northwestern part of Hebei Province

Materials and Methods

Remote Sensing Data

A Landsat-5 thematic mapper (TM) imagery remotely sensed dataset (124/32) was assembled for this study, the period analysed was 1987 and 1996.

NDVI

The Normalized Difference Vegetation Index (NDVI) was initially proposed by Rouse et al. (1974). NDVI derived from the ratio of band 3 and band 4 in Landsat TM images data was applied for monitoring vegetation changes in the study area within the years of 1987 and 1996.

$$NDVI = (TM4-TM3) / (TM4-TM3)$$

Tasseled Cap Transformation (TCT)

Tasseled Cap transformation is one of the available methods for enhancing spectral information content of Landsat TM data. Tasseled Cap transformation especially optimizes data viewing for vegetation studies. Tasseled Cap index was calculated from data of the related six TM bands. Three of the six tasseled cap transformation bands are often used:

- Band 1 (Brightness, measure of soil).
- Band 2 (Greenness, measure of vegetation).
- Band 3 (Wetness, interrelationship of soil and canopy moisture).

The Tasseled Cap transformation provides excellent information for agricultural applications because it allows the separation of barren (bright) soils from vegetated and wet soils (ER Mapper, 1995).

Change Detection Methodology

Detection by image differencing (Lambin, 1994 and 1997) was adopted to detect the land cover change in our study complemented with visual comparison to distinguish and quantify the county-level change types. The procedures followed in our research are shown as following:

- Image to vector file rectification and image to image registration of the remotely sensed data using forty ground control points (GCP) whose ground coordinates were read from a vector file of the same scale for the same region. Accuracy with a RMS error of < 1 pixel (0.50 pixel) using the first model of polynomial function and Nearest Neighbor re-sampling method in datum WGS84 and projection UTM (50N).
- Tasseled Cap transformation (Crist and Cicone, 1984) on the TM images to convert the land cover information included in seven bands into three indicators: brightness, greenness and wetness, which respectively means the land bareness, vegetation vigor and soil moisture.
- Indicator differencing (e.g., NDVI, Greenness, Brightness, Wetness) between two different dates.
- Thresholding to acquire the changed areas and produce the general change maps which contain three classes: positive change, negative change, and no-change.
- Visual comparison to identify the types of land cover change (e.g., vegetation increase, land degradation) and creates detailed land cover change maps based on the previous general change map.
- Quantification of the land covers changes at county level by GIS technique.

Figure 2 shows the thresholding method to acquire the changed area using RS and GIS technologies for the study area in the Northwestern part of Hebei Province.

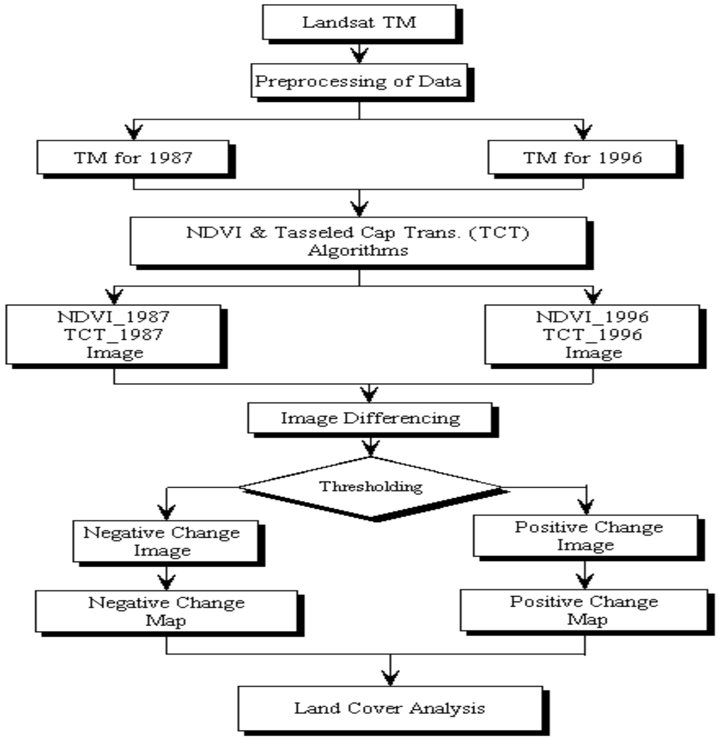

Figure 2. Flowchart of the land cover change detection method

Results and Discussion

Greenness Tasseled Cap Indicator

The results of the Greenness Tasseled Cap indicator were presented in table 1 and figures 3, 4. The results showed that highest greenness positive change (vegetation increase) was for Lai Shui County. It was 24.069% for the total area of the county.

The highest greenness negative change (vegetation degradation) value was for Chi Cheng County; it was 19.264% of the total area of the county. The vegetation cover increased by 17.462% of the total area of Lai Shui County in the period from 1987 to 1996; at a change rate 32.917 $km^2.yr^{-1}$. The overall greenness positive change (vegetation increase) in the district was 7.431% of the total areas, while it was 6.181% for the greenness negative change (vegetation degradation) over the whole district. The general average in the vegetation increase rate was 28.662 $km^2.yr^{-1}$, while was 23.842 $km^2.yr^{-1}$ for the vegetation degradation. The lowest percentage of no-change in greenness indicator was 76.171% for the total area of Chi Cheng County. The difference between the percentages for the greenness positive and negative changes was 29.009%, which means there is a vegetation increase in the studied area.

1.1.1 *Wetness Tasseled Cap Indicator*

The results showed that Chi Cheng County had the highest percentage (6.114%) of wetness positive change, while Wan Quan County had the lowest percentage (0.634%) for the total area of the county. Lai Shui County had the highest percentage of wetness negative change (3.830%) during the period from 1987 to 1996. The overall difference between the wetness positive and negative change was 1.642 % of the total areas of the counties in the region. The overall wetness positive change rate for the entire counties was 6.712 $km^2.yr^{-1}$, while was 3.259 $km^2.yr^{-1}$ for the wetness negative change rate. Table 2 and figures 5, 6 show the results of the wetness tasseled cap indicator.

Table 1. County-level Greenness Tasseled Cap indicator results of the Northwestern part of Hebei Province for the period from 1987 to 1996.

County Name	County Area	GN_P		GN_N		No-change		(GN_P)-(GN_N)	GN P rate	GN N rate
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	%	($km^2.yr^{-1}$)	
Chi Cheng (1/2)	**2,647.565**	120.856	4.565	510.034	19.264	2,016.675	76.171	-14.699	13.428	56.670
Wan Quan	**1,158.246**	99.502	8.591	11.021	0.952	1,047.723	90.458	7.639	11.056	1.225
Zhang Jia Kou	**405.414**	46.040	11.356	4.538	1.119	354.836	87.524	10.237	5.116	0.504
Cong Li (2/3)	**1,555.442**	37.168	2.390	227.259	14.611	1,291.015	83.000	-12.221	4.130	25.251
Huai An	**1,692.094**	83.782	4.951	26.388	1.560	1,581.924	93.489	3.392	9.309	2.932
Xuan Hua	**2,474.029**	141.923	5.737	50.193	2.029	2,281.913	92.235	3.708	15.769	5.577
Huai Lai	**1,855.068**	129.132	6.961	83.283	4.489	1,642.653	88.549	2.472	14.348	9.254
Yang Yuan	**1,838.358**	50.386	2.741	12.199	0.664	1,775.773	96.596	2.077	5.598	1.355
Wei Xian	**3,182.889**	235.979	7.414	138.719	4.358	2,808.191	88.228	3.056	26.220	15.413
Zhu Lu	**2,788.724**	306.705	10.998	142.507	5.110	2,339.512	83.892	5.888	34.078	15.834
Lai Shui (3/4)	**1,230.852**	296.252	24.069	81.325	6.607	853.275	69.324	17.462	32.917	9.036
Sum	**20,828.681**	**1,547.724**	**7.431**	**1,287.467**	**6.181**	**17,993.490**	**86.388**	**1.250**	**171.969**	**143.052**
								Average	**15.634**	**13.005**

Table 2. County-level Wetness Tasseled Cap indicator results of the Northwestern part of Hebei Province for the period from 1987 to 1996.

County Name	County Area	WT_P		WT _N		No-change		(WT_P)-(GN_N)	WT P rate	WT N rate
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2))	(%)	%	(km^2 yr^{-1})	
Chi Cheng (1/2)	**2,647.565**	161.862	6.114	31.998	1.209	2,453.705	92.678	4.905	17.985	3.555
Wan Quan	**1,158.246**	7.345	0.634	7.043	0.608	1,143.858	98.758	0.026	0.816	0.783
Zhang Jia Kou	**405.414**	11.507	2.838	5.837	1.440	388.069	95.722	1.399	1.279	0.649
Cong Li (2/3)	**1,555.442**	52.031	3.345	7.174	0.461	1,496.237	96.194	2.884	5.781	0.797
Huai An	**1,692.094**	16.766	0.991	14.819	0.876	1,660.509	98.133	0.115	1.863	1.647
Xuan Hua	**2,474.029**	39.950	1.615	21.313	0.861	2,412.766	97.524	0.753	4.439	2.368
Huai Lai	**1,855.068**	73.252	3.949	33.840	1.824	1,747.977	94.227	2.125	8.139	3.760
Yang Yuan	**1,838.358**	17.817	0.969	35.727	1.943	1,784.814	97.087	-0.974	1.980	3.970
Wei Xian	**3,182.889**	95.089	2.988	88.340	2.775	2,999.460	94.237	0.212	10.565	9.816
Zhu Lu	**2,788.724**	159.514	5.720	29.421	1.055	2,599.789	93.225	4.665	17.724	3.269
Lai Shui (3/4)	**1,230.852**	29.421	2.390	47.140	3.830	1,154.291	93.780	-1.440	3.269	5.238
Sum	**20,828.681**	**664.555**	**3.191**	**322.651**	**1.549**	**19,841.475**	**95.260**	**1.642**	**73.839**	**35.850**
								Average	**6.713**	**3.259**

1.1.2 *Brightness Tasseled Cap Indicator*

The result illustrated that the highest value of brightness positive change was in Cong Li County; it was 6.998% for the total area of that county, while the lowest value was 1.786% in Lai Shui County. The greatest percentage of brightness negative change was 11.321% of the total area of Xuan Hua County, while the lowest value was 1.240% in Lai Shui County. This county had the highest value (96.973%) of brightness no-change value.

The lowest negative difference value of brightness indicator for the study area was 8.379% of the total area of Xuan Hua County. The brightness positive change rate in the district within the period from 1987 to 1996 was 14.885 $km^2.yr^{-1}$, while it was 29.771 $km^2.yr^{-1}$ for the brightness negative change rate. Table 3 and figures 7, 8 show the results of brightness indicator.

Table 3. County-level Tasseled Cap brightness indicator results of the Northwestern part of Hebei Province for the period from 1987 to 1996.

County Name	County Area	BT_P		BT_N		No-change		(BT_P)-(BT_N)	BT_P Rate	BT_N Rate
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	%	(km^2 .yr^{-1})	
Chi Cheng (1/2)	2,647.565	118.069	4.460	179.504	6.780	2,349.992	88.760	-2.320	13.119	19.945
Wan Quan	1,158.246	32.058	2.768	106.098	9.160	1,020.090	88.072	-6.392	3.562	11.789
Zhang Jia Kou	405.414	19.010	4.689	26.811	6.613	359.593	88.698	-1.924	2.112	2.979
Cong Li (2/3)	1,555.442	108.853	6.998	106.949	6.876	1,339.639	86.126	0.122	12.095	11.883
Huai An	1,692.094	79.629	4.706	171.337	10.126	1,441.128	85.168	-5.420	8.848	19.037
Xuan Hua	2,474.029	72.801	2.943	280.091	11.321	2,121.137	85.736	-8.379	8.089	31.121
Huai Lai	1,855.068	48.040	2.590	183.688	9.902	1,623.339	87.508	-7.312	5.338	20.410
Yang Yuan	1,838.358	79.532	4.326	116.366	6.330	1,642.460	89.344	-2.004	8.837	12.930
Wei Xian	3,182.889	155.361	4.881	181.612	5.706	2,845.916	89.413	-0.825	17.262	20.179
Zhu Lu	2,788.724	68.428	2.454	239.934	8.604	2,480.362	88.943	-6.150	7.603	26.659
Lai Shui (3/4)	1,230.852	21.988	1.786	15.266	1.240	1,193.598	96.973	0.546	2.443	1.696
Sum	**20,828.681**	**803.770**	**3.859**	**1,607.657**	**7.718**	**18,417.254**	**88.423**	**-3.860**	**89.308**	**178.629**
								Average	**8.119**	**16.239**

Generally, there were a vegetation increase, soil moisture increase, and soil bareness decrease in the region during the study period. There were a higher positive change in the greenness indicator values, a higher positive change in wetness indicator values, and a decrease in the brightness indicator values.

1.1.3 *Normalized Difference Vegetation Index (NDVI)*

The results of the NDVI indicated that the highest value of NDVI positive change (vegetation increase) was 13.321% for the total area of Lai Shui County. The highest negative change (vegetation degradation) was 8.511% in Cong Li County. The highest positive net difference (between the positive and negative changes) was 9.813% for the area of Lai Shui County, while the lowest was 3.949% of the area of Cong Li County. The highest positive change rate was 23.932 $km^2.yr^{-1}$ for Zhu Lu County for the period 1987 to 1996. The highest value of NDVI negative change rate was 14.709 $km^2.yr^{-1}$ in Cong Li County. Table 4 and figures 9, 10 show the results.

From the statistical analysis, the result illustrated there was a highly significant correlation coefficient between Tasseled Cap greenness indicator and the NDVI at 99% confidence level. The other correlations between brightness, wetness, and the NDVI were weak. Table 5 shows the results of the statistical analysis.

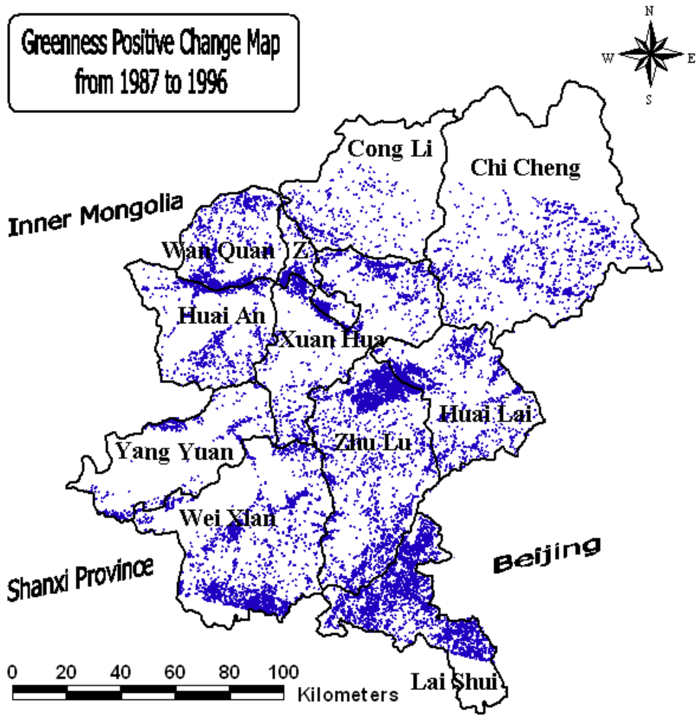

Figure 3. County-level Greenness positive change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

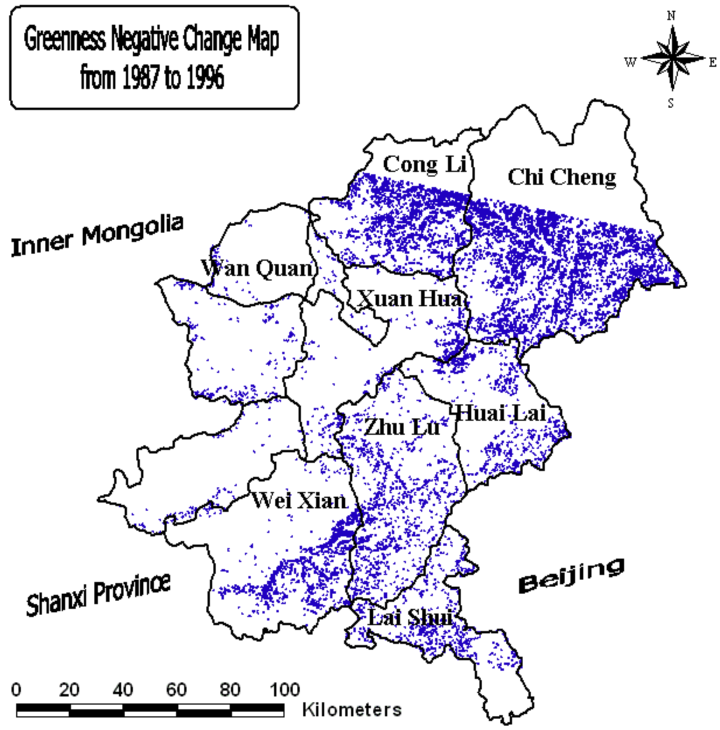

Figure 4. County-level Greenness negative change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

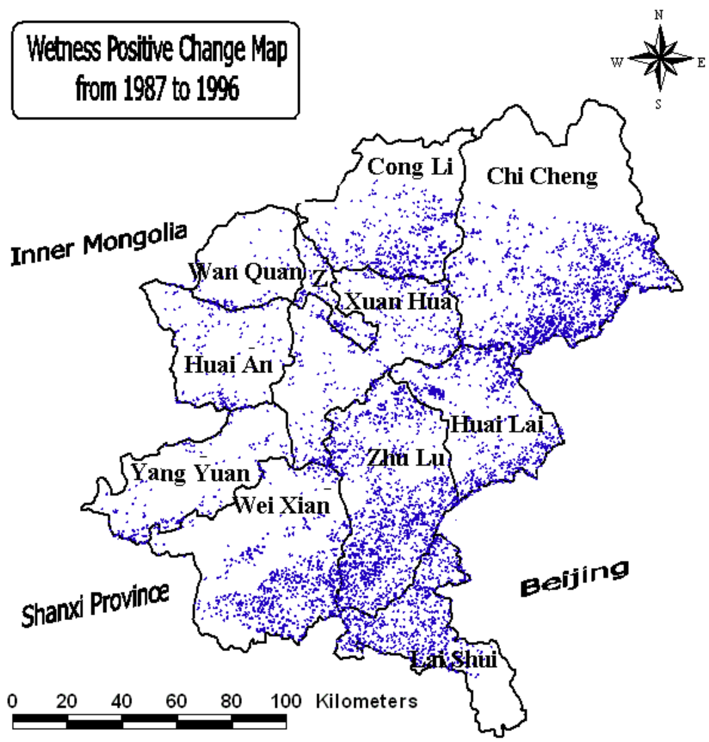

Figure 5. County-level Wetness positive change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

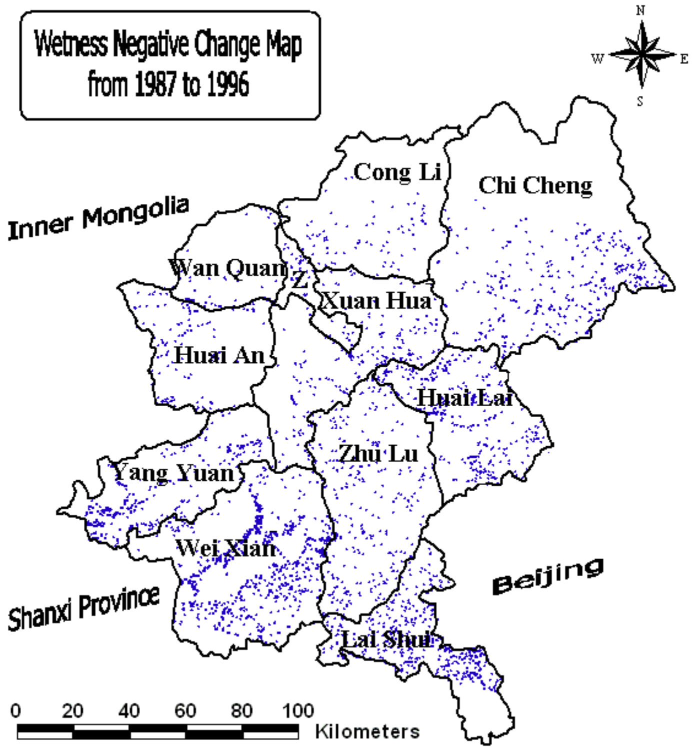

Figure 6. County-level Wetness negative change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

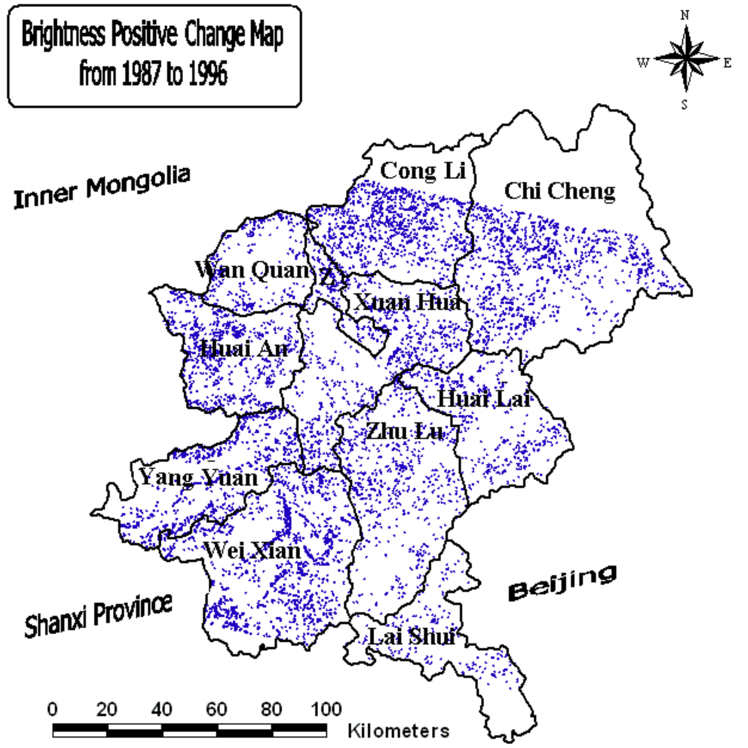

Figure 7. County-level Brightness positive change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

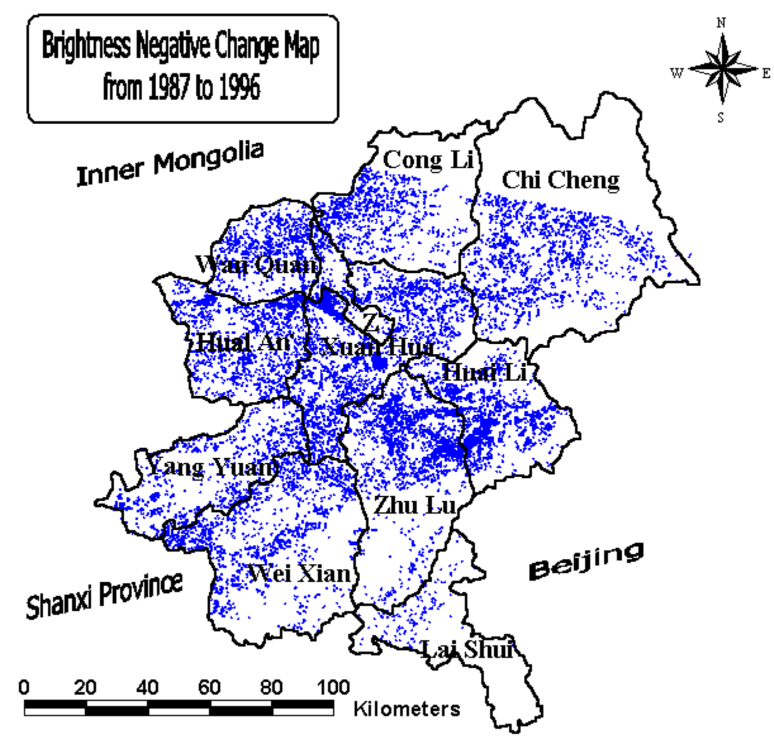

Figure 8. County-level Brightness negative change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

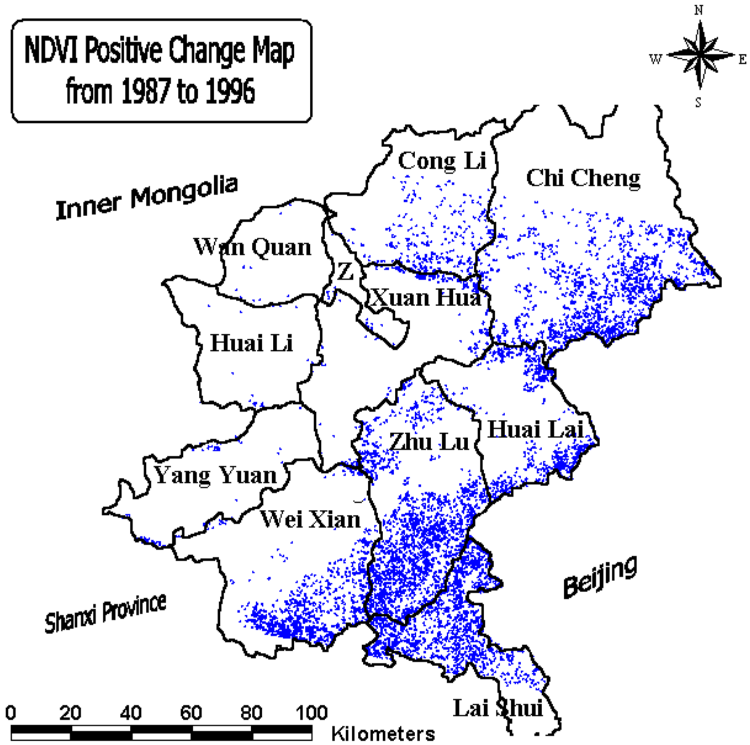

Figure 9. County-level NDVI positive change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

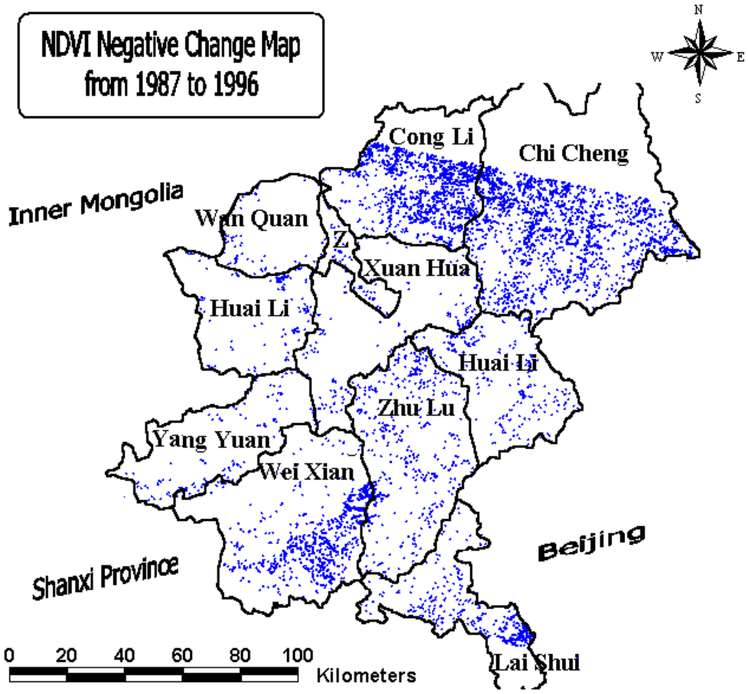

Figure 10. County-level NDVI negative change map of the Northwestern part of Hebei Province during the period from 1987 to 1996

Table 4. County-level NDVI results of the Northwestern part of Hebei Province for the period from 1987 to 1996.

County Codes	County Area	NDVI_P		NDVI_N		No-change		(NDVI_P)-(NDVI_N)	NDVI_P Rate	NDVI_N Rate
	(km^2)	(km^2)	(%)	(km^2)	(%)	(km^2)	(%)	%	(km^2 .yr^{-1})	
Chi Cheng (1/2)	2,647.565	35.849	1.354	69.814	2.637	5,189.468	98.005	-0.641	3.983	7.757
Wan Quan	1,158.246	0.839	0.072	6.667	0.576	1,150.740	99.352	-0.503	0.093	0.741
Zhang Jia Kou	405.414	2.079	0.513	5.483	1.352	397.851	98.135	-0.840	0.231	0.609
Cong Li (2/3)	1,555.442	40.166	2.582	132.384	8.511	2,162.949	92.612	-3.949	4.463	14.709
Huai Hua	1,692.094	3.242	0.192	12.361	0.731	1,676.491	99.078	-0.539	0.360	1.373
Xuan Hua	2,474.029	27.486	1.111	19.554	0.790	2,426.990	98.099	0.321	3.054	2.173
Huai Lai	1,855.068	71.518	3.855	25.021	1.349	1,758.530	94.796	2.506	7.946	2.780
Yang Yuan	1,838.358	7.032	0.383	12.414	0.675	1,818.912	98.942	-0.293	0.781	1.379
Wei Xian	3,182.889	113.031	3.551	95.482	3.000	2,974.376	93.449	0.551	12.559	10.609
Zhu Lu	2,788.724	215.392	7.724	54.078	1.939	2,519.254	90.337	5.785	23.932	6.009
Lai Shui (3/4)	1,230.852	163.963	13.321	43.184	3.508	1,023.705	83.170	9.813	18.218	4.798
Sum	20,828.681	680.597	**3.268**	476.442	**2.287**	19,671.64	**94.445**	**0.980**	75.621	52.937
								Average	**6.875**	**4.812**

Table 5. Correlation matrix and regression equations between the studied indicators for the Northwestern part of Hebei Province

Correlations Matrix				
	BT	**GN**	**WT**	**NDVI**
BT	1.0	0.084	0.003	-0.042
GN	0.084	1.0	0.144	0.704
WT	0.003	0.144	1.0	0.263
NDVI	-0.042	0.704	0.263	1.0
Regression Equations				
NDVI	NDVI= 9.31388+0.335838*(GN) R^2 =49.517 **			
GN	GN=51.3252+1.47445*(NDVI) R^2 =49.517 **			
**	There is a statistically significant relationship between the variables at the 99% confidence level.			

Conclusion

In general view, the study area revealed an increase in tasseled cap greenness indicator, tasseled cap wetness indicator, NDVI values during the study period from 1987 to 1996, which means that there was an increase in the vegetation cover and soil moisture. In the same time showed an decrease in the tasseled cap brightness indicator values, which points to decrease in the soil bareness. By other words, there was a decline in the land degradation in the region during the study period.

This study demonstrates the effectiveness of the remote sensing and GIS technologies in detecting, assessing, mapping, and monitoring the land degradation. The outcome of this type of studies represents a valuable resource for decision makers to guard against land acquisition, and for future development projects in the study area in the Northwestern part of Hebei Province, China.

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