

Environmental Change Monitoring — A Case Study in the Region of Yinchuan, Ningxia, China

Weicheng Wu

PRODIG/Ecole Pratique des Hautes Etudes, 191 Rue St-Jacques, 75005 Paris, France
Tel.: +33 1 44 32 14 88 Fax: +33 1 43 29 63 83 E-mail: wuwc@univ-paris1.fr

1. INTRODUCTION

Change monitoring by remote sensing has been one of the environment research foci since 1960s, when Verstaappen used aerial photographs to measure the coastal evolution (Wu *et al.*, 2002b). Other two widely applied tools occurred in the last decade are Geographical Information System (GIS) and Global Positioning System (GPS). These three techniques, termed “3S” in the 1990s and recently replaced by “geomatics” or “geoinformatics”, have played an important role in the researches in environment. A recently occurred hotspot is the human-environment interaction modelling which aims at understanding the driving forces and mechanism of the environmental evolution based on GIS and linear/non-linear statistic analysis (Lambin, 1994, Mertens *et al.*, 1997; Wu *et al.*, 2002a, 2003 and Wu 2003a and b). This paper summarises such an interdisciplinary research by linking environment evolution with human activity, taking the region of Yinchuan, Ningxia, China, for example.

The study site, administratively located in the north part of Ningxia and surrounded by Inner Mongolia on the east, north and west, is one of the arid regions in northwest China (figure 1). It consists of a half of the Helan Mountains and most part of the Yinchuan Plain. The annual precipitation ranges from 78 to 295mm, annual evaporation from 1473 to 2318mm and annual average temperature from 8.2°C to 9.6°C in the recent decades (Wu *et al.* 2002a). The analysis on meteorological data in the past half century indicates that the annual temperature has been increasing and precipitation decreasing. The climate has been getting dryer and warmer. Since 1999, the Chinese government has inaugurated a middle to long term development strategy on the northwestern regions in China. The region of Yinchuan becomes one of the critical areas. It is thus of importance to undertake an interdisciplinary research on the evaluation of the environmental changes due to human activities and provide a monitoring prototype and useful references to the local governments for their sustainable development planning and environmental management. The initial study result has been reported in the conference Map Asia 2002 (Wu *et al.*, 2002a). This paper presents a more profound analysis on the relative subject as a continued part of the former.

Multitemporal remote sensing data (Landsat TM dated Sept.20, 1987, Sept.17, 1989, and ETM Aug.12, 1999), county-level socio-economic and meteorological data and software such as PCI, ER Mapper, SYSTAT/SAS and ArcView GIS were utilised in this research.

2. METHODOLOGY

As mentioned above, the method adopted in the change monitoring is precisely shown in figure 2.

3. CHANGE DISCRIMINATION

The procedures to distinguish the changes shown in figure 2 are depicted as follows:

(1) Image-to-image registration

The remotely sensed data (TM1987, 1989 and ETM1999) were geometrically corrected by the topographic maps on the scale of 1/200,000 to 1/300,000 in the datum WGS84 and projection UTM (48) using polynomial model (3rd order) and bilinear re-sampling. The RMS error of the image-to-image rectification comes between 0.53 and 0.58 pixels.

(2) Atmospheric correction

A completely image-based approach was introduced for atmospheric correction based on the researches of Crist *et al.* (1984a, 1984b and 1986a) and Chavez (1988 and 1996).

Chavez proposed a DOS (dark-object subtraction) model (1975, 1988) and its ameliorated version — COST model (1996). A key point in his method is to measure the haze value to be removed. The traditional way to obtain the haze value is to measure the radiance in some deep clear water or shaded areas in image where the radiance in near infrared bands is zero or near to zero. Any over-zero value is considered to be a result of scattering and path radiation. Such haze removal often produces over-correction and is not applicable to the image where dark-object does not exist (Chavez, 1996). A potential approach to acquire this value is by Tasseled Cap transformation. According to Crist *et al.* (1986a), the 4th component of this transformation is a haze indicator, which can be expressed as:

$$H = 0.8832 \times B1 - 0.0819 \times B2 - 0.4580 \times B3 - 0.0032 \times B4 - 0.0563 \times B5 + 0.0130 \times B7 \quad (1)$$

where H is the haze value of pixel.

The equation (1) produces a total haze value for each pixel. On the assumption that whole scene should have the same haze background, the mean haze value derived from this equation was thus used to remove the scattering effect supposing that it was very clear when the images were being sensed (see Wu 2003b).

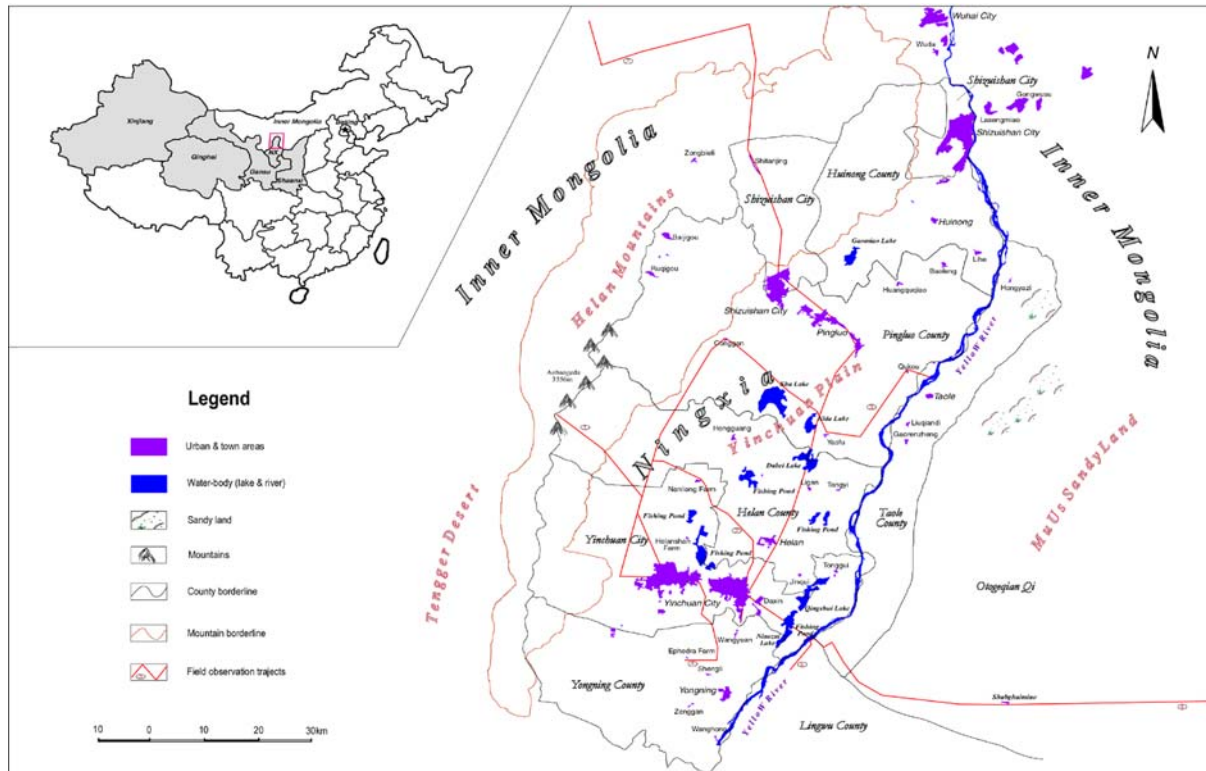


Figure 1: Location, administrative and geomorphologic units of the study area — the region of Yinchuan, Ningxia, China

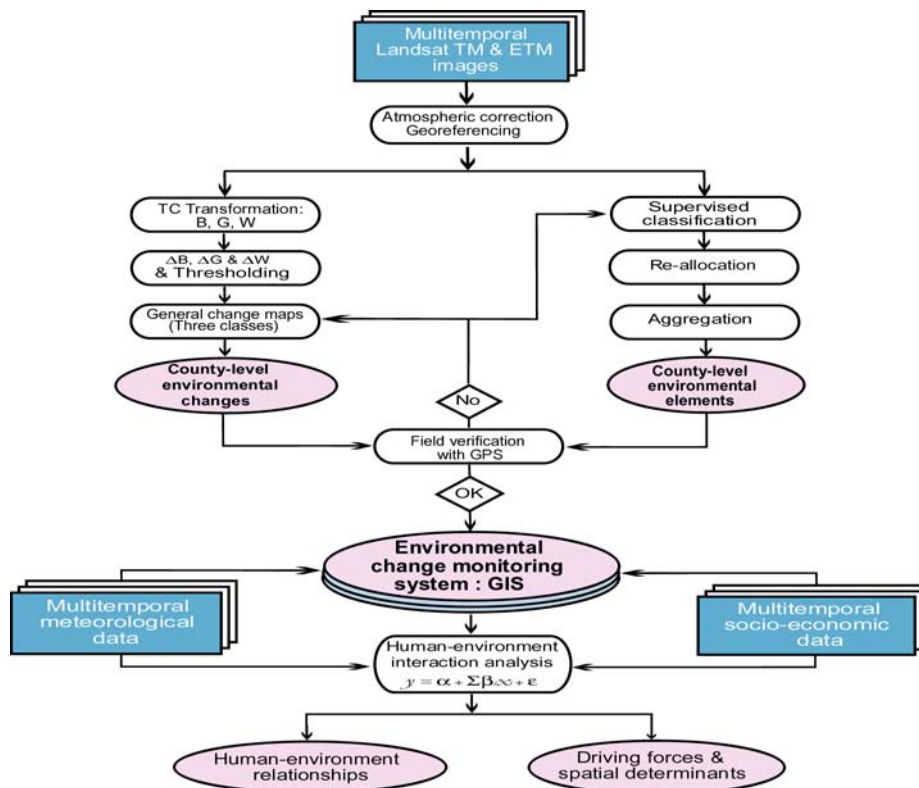


Figure 2: Approaches adopted in the case study

Viewing that the recent and ancient images were acquired respectively on Aug.12, 1999 and Sept.20, 1987/Sept.17, 1989. There are about 32-35 days' difference in Day of Year between the ancient and recent

images. The effect caused by the difference of the sun-earth distance and sun elevation angle should be also corrected. Thus the COST model was used to correct such effect and at the same time transform the at-satellite radiance into the surface feature reflectance according to the following formula:

$$R_s = \frac{\pi (L_{sat} - L_{haze})}{E_o \cos^2 \theta} \quad (2)$$

where R_s — spectral reflectance of the surface;

L_{haze} — haze effect, for example, path radiance ($Wm^{-2} sr^{-1} \mu m^{-1}$);

E_o — solar spectral irradiance on a surface perpendicular to the sun's rays outside the atmosphere ($Wm^{-2} \mu m^{-1}$). E_o contains the Earth-Sun distance term that is in astronomical units (AUs are a function of time of year and range from about 0.983 to 1.017) (see Chander *et al.*, 2003)

θ — solar zenith angle

L_{sat} — at-satellite spectral radiance for the given band ($Wm^{-2} sr^{-1} \mu m^{-1}$). It has the following relationship with the digital counts of pixel (Chavez 1996 and NASA, 2000):

$$L_{sat} = ((Lmax - Lmin)/Maximum DC) * DC + Lmin$$

where $Lmax$ represents the spectral radiance scaled to the maximum digital count (DC), $Lmin$ is the spectral radiance to the minimum DC (see NASA, 2000 and Chander *et al.*, 2003).

(3) Tasseled Cap transformation

A Tasseled Cap transformation (Crist *et al.* 1984a, b and 1986a) was conducted again on the atmospherically corrected ETM and TM images to reduce the data volume and convert the land cover information included in the six bands into three indicators: Brightness (B), Greenness (G) and Wetness (W), which mean respectively land bareness, vegetation vigour and soil moisture.

Reflectance-based Tasseled Cap features (B, G and W) range from -0.5 to 1.4. To facilitate the calculation, they were normalised to the extent from 0 to 255.

(4) Indicator differencing and thresholding

As differencing technique provides lower change detection errors when compared against other approaches (Jensen *et al.*, 1982), it is applied to the change discrimination between the same land cover indicator (e.g., G) of different dates. The differenced values (Δ) vary from -255 to 255. They were normalised to the range of 0 to 255.

(5) Change discrimination

Thresholding produces change maps containing three levels of information: negative change, no change and positive change. Field investigation shows that these "changes" are capable for highlighting where the real modifications have taken places. However, three classes are not enough to illustrate the concrete change types. Based on the field trip, a further identification was carried out. The changes as farmland extension, urban extension, rural built-up increase, land degradation, land to water depression, water-body to land, river narrowing, etc., were discriminated.

Finally, each type of change was quantified to county-level. The results are shown in table 1 and figure 3.

Table 1: Environmental changes in the region of Yinchuan from 1987 to 1999

County	County area	Δ Farmland	Δ Artificial vegetation cover		Δ Urban	Δ Rural built-up	Land degrad.	Land to water body	Water body to land	Δ Water body	Δ River surface
			Grassland in the plain	Forest in the mountains							
Huinong	942.0	14.8	5.0	0.1	0.4	7.1	5.3	7.3	17.0	-9.6	-10.8
Pingluo	2115.8	124.9	48.2	0.5	5.2	21.9	9.7	32.3	23.6	8.6	-22.6
Taole	907.0	33.4	9.8	0	0.1	2.7	7.1	7.8	0.0	7.8	-28.7
Shizuishan	575.7	1.01	0	0.1	9.4	0.0	12.3	0.9	1.1	-0.2	0.0
Helan	1229.5	55.7	10.3	1.7	0.6	15.4	3.5	14.9	3.4	11.5	-5.5
Yinchuan	1321.5	117.9	14.6	0.2	19.1	11.6	13.5	16.7	2.2	14.5	-11.0
Yongning	1028.8	123.8	4.2	0.1	1.1	9.6	4.0	16.6	0.4	16.2	-5.3
Total region	8120.2	471.5	92.1	2.6	35.8	68.3	55.5	96.4	47.6	48.8	-83.8
Proportion in the total territory (%)		5.8	1.1	0	0.4	0.8	0.7	1.2	0.6		1.0
Annual change rate	km ² /yr	39.3	7.7		3.0	5.7	4.6	8.0	4.0	4.1	-7.0
	%	1.5			2.2	4.2				1.0	-6.1

4. HUMAN-NATURE INTERACTION ANALYSIS

Environmental changes, mainly in forms of land use changes, are caused by human activity and mutations in natural conditions (e.g., climate change). The monitoring of such changes would be most relevant and useful

when it is accompanied by the understanding of the forces driving change processes. The question is how to link the changes in environment with the human activity.

As reviewed by Lambin (1994), this task could be calibrated by multivariate regression models, namely either panel analysis or cross-sectional analysis. The former links the changes in dependent variables (e.g., changes in environment) during a certain interval of time with the changes in independent variables (e.g., human activity) in the corresponding period of time and across a large number of localities. The latter associates the dependent variable (e.g., land use pattern) at one point of time with the independent variables (e.g., spatial determinants) at the same point of time across a large number of localities. The panel analysis allows us to understand the driving forces governing change progress and cross-sectional analysis aims at discriminating the spatial determinants for the environmental situation and structure at the observed point of time. These two analyses can be expressed as follows:

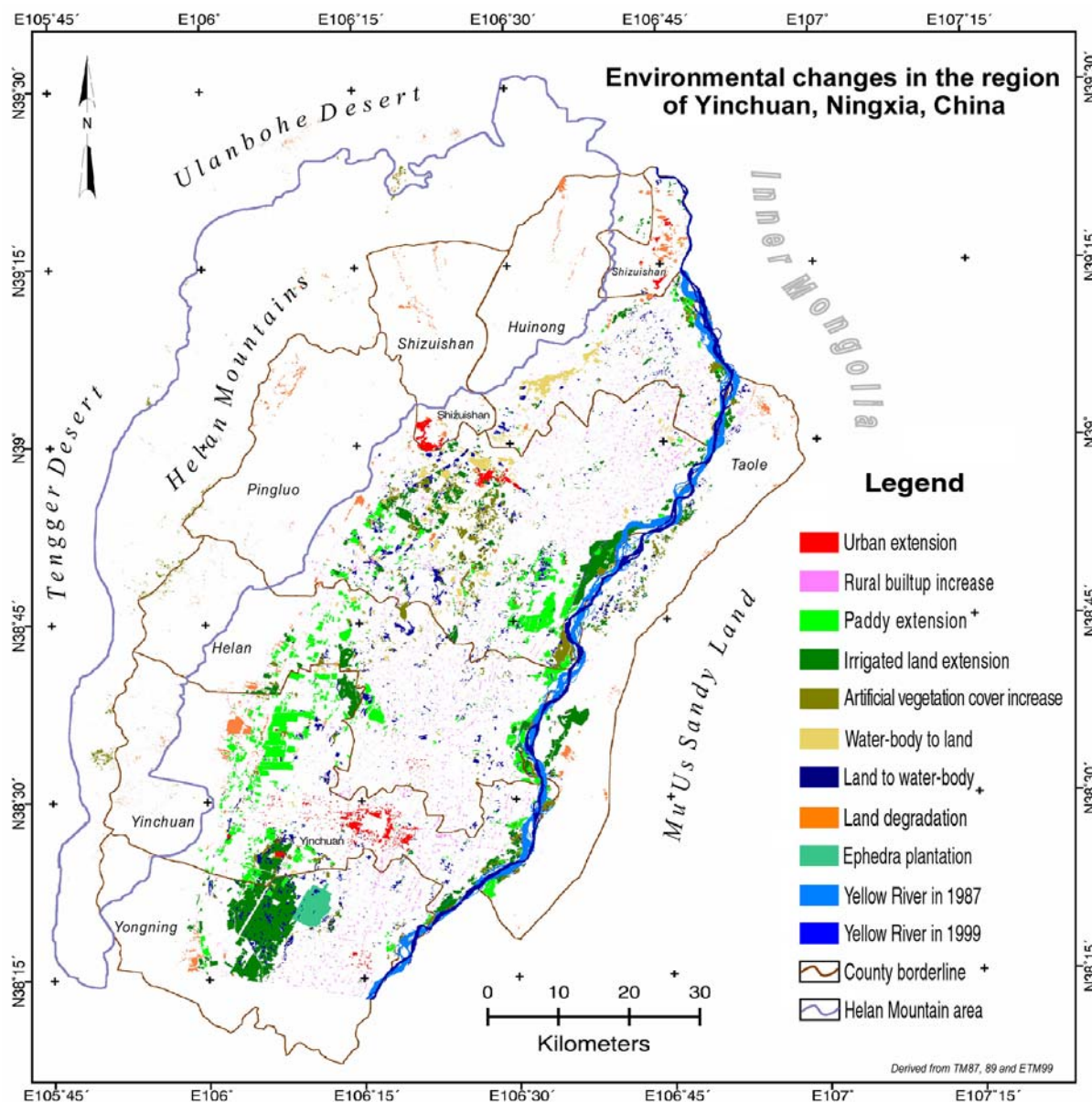


Figure 3: Environmental changes in the region of Yinchuan from 1987 to 1999

Cross-sectional analysis:

$$At\ a\ point\ of\ time\ t: E_j = \beta_0 + \sum \beta_i S_i + \varepsilon_0 \tag{3}$$

where E_j — dependant variable (environmental element j), β_0 — a constant or rather an intercept, β_i — regression coefficients, S_i — interdependent variables (socio-economic indices), ε_0 — error term.

Panel analysis :

$$During\ the\ time\ interval\ \Delta t: \Delta E_j = \beta_0 + \sum \beta_i \Delta S_i + \varepsilon_1 \tag{4}$$

where ΔE_j — change in environmental element j during the time interval Δt , and ΔS_i — changes in socio-economic indices during the corresponding period and ε_1 — error term.

These two kinds of analysis both link the environment elements with the human activity by combining the results acquired by remote sensing processing with the meteorological data and socio-economic data — the best presentation way of human activity.

The environmental changes (table 1) and the corresponding changes in socio-economic data and meteorological data from 1988 to 1999 (tables 2 and 3) were incorporated in SYSTAT. The changes in environment are regarded as dependent variables and the development in socio-economy and evolution in climate as independent variables. The modelling was conducted in a stepwise manner within a confidence level of 0.05 and the results are shown in table 4.

Cross-sectional analysis links the classification results of land use pattern from the ETM images dated 1999 with the socio-economic data of 1999, which has been discussed in another paper of the author (Wu *et al.*, 2003). The modelling results are re-presented in table 5.

Table 2: Evolution in socio-economic indices from 1988 to 1999 in the region of Yinchuan

Counties	ΔTotal population (1000 people)	ΔUrban population (1000 people)	ΔRural population (1000 people)	ΔRural labour force (1000 people)	ΔTotal sown area (1000 ha)	ΔFood crop area (1000 ha)	ΔFood production (1000 ton)
Huinong	-1.10	7.90	-9.00	10.10	8.70	7.00	43.98
Pingluo	19.70	21.50	-1.80	31.00	15.50	15.50	139.98
Taole	9.10	2.30	6.80	2.70	5.00	3.70	17.55
Shizuishan	59.30	68.70	-9.40	0.90	0.10	0.10	2.31
Helan	12.60	14.50	-2.00	26.20	4.20	8.50	112.59
Yinchuan	43.90	146.40	-2.50	10.00	2.30	0.60	34.85
Yongning	18.00	14.50	3.50	19.40	4.90	5.30	67.71
Total region	261.50	275.80	-14.40	100.30	40.70	40.70	418.97

County	ΔVegetable oil product (1000 ton)	ΔTotal meat product (1000 ton)	ΔAgric. output (million yuan)	Annual agric. growth rate (%)	ΔIndustrial output (million yuan)	Annual industrial growth rate (%)	ΔGDP (million yuan)	ΔGDP per capita (yuan)
Huinong	5.84	2.86	250.10	13.96	368.50	31.17	290.16	3895.10
Pingluo	3.88	12.08	508.40	14.21	739.10	15.05	738.05	2792.10
Taole	1.04	1.14	54.30	10.73	17.90	16.93	69.06	2679.90
Shizuishan	-0.05	0.52	26.30	11.36	3024.20	12.89	2020.80	5870.50
Helan	-0.86	4.35	402.30	12.70	583.80	19.01	582.67	3269.20
Yinchuan	-0.44	5.80	446.60	14.04	4421.60	13.20	4973.62	7918.40
Yongning	0.20	2.83	402.00	11.89	693.4	21.73	699.10	3747.00
Total region	9.61	29.58	2090.50	13.17	9844.10	14.95	9373.46	4310.31

Note: Data are from the Statistical Yearbooks of Ningxia, published by China Statistics Press in 1989 and 2000. ΔGDP = GDP1999-GDP1991

Table 3: Climate changes in the region of Yinchuan between 1999 and 1988

Counties	Huinong	Pingluo	Taole	Shizuishan	Helan	Yinchuan	Yongning
Mean Temperature (°C)	1999	10.2	10.4	10.0	11.5	10.5	10.3
	1988	9.1	8.6	8.4	9.6	8.8	8.7
ΔT = T1999 - T1988 (°C)	1.1	1.8	1.6	1.9	1.7	1.5	1.6
Annual Precipitation (mm)	1999	120.0	154.9	133.3	127.0	132.3	165.1
	1988	219.0	211.0	245.0	227.0	158.0	200.9
ΔP = P1999 - P1988 (mm)	-99	-56.1	-111.7	-100	-25.7	-35.8	-19
Annual Evaporation (mm)	1999	2318.0	1897.5	1904.1	2147.2	1814.4	1675.7
	1988	1860.3	1604.8	1645.3	2115.8	1473.4	1491.9
ΔE = E1999 - E1988(mm)	457.7	292.7	258.8	31.4	341	183.8	393.8

Note: The original data are from Ningxia Statistical Yearbook, 1989 and 2000.

5. DISCUSSION

A discussion has been already held on the farmland extension, urban and village development and water-body mobility in the region (Wu *et al.*, 2002a). An insight is particularly given to the change concerning the Yellow River.

The river, with a current surface of 81.3km² (1.0 % of the total territory), has narrowed by 83.8km² at a rate of -7.0km²/a or -6.1 %. The river surfaces shown in the TM and ETM images are an overall expression of the instant hydrological conditions, rainfall and human activity around the dates when images were acquired. This surface

reduction is thus related to several natural and anthropogenic factors. An analysis is hereby focused on the changes in rainfall in the upper reach basin, taking Xining and Yinchuan for example.

Usually, river surface is to some extent associated with the two or three months of rainfall previous to the image acquisition date. Figure 4 shows the monthly rainfall in Xining and Yinchuan from June to Sept. of 1987 and 1999, concerned with the acquisition periods of Landsat images.

Table 4: Relationships between environmental changes and human activity

Dependent	Final entered independent	Const.	Parameter estimate	Std error	Std coef.	Df	F	Pr>F	R ²
ΔFarmland	ΔAgricultural output	- 0.3627	0.0240	0.0060	0.855	1	13.61	0.0140	0.731
ΔArtificial grassland	ΔMeat product	- 3.3314	3.9910	0.5570	0.955	1	51.36	0.0010	0.911
Land degradation	ΔIndustry output	5.0306	0.0020	0.0010	0.841	1	12.11	0.0180	0.708
ΔRural built-up increase	ΔRural labour force	- 1.0098	-1.0305	0.2105	-1.594	1	23.96	0.0160	0.996
	ΔFood product		0.2885	0.0417	1.949	1	47.86	0.0060	
	ΔAgricultural output		0.0281	0.0032	0.721	1	76.02	0.0030	
ΔUrban	ΔUrban population	- 0.1519	0.1340	0.0100	0.986	1	170.07	0.0002	0.971
Water to land	ΔSown area	-2.0059	1.6716	0.3620	0.932	1	22.25	0.0050	0.867
Land to water	ΔAgriculture output	0.3965	0.0448	0.0120	0.862	1	14.46	0.0130	0.743

Table 5: Spatial determinant(s) of the environmental components

Dependent	Final entered independent	Constant	Parameter estimate	Std error	Std coeff.	Df	F	Pr>F	R ²
Farmland	Rural population	1.472	3.9016	0.373	0.9779	1	109.42	0.0001	0.956
Urban	Total industrial output	2.233	0.0101	0.001	0.9815	1	131.57	< 0.0001	0.963
Village	Rural population	3.361	0.2160	0.060	0.8480	1	12.788	0.0160	0.719
Forest	Total agricultural output	-17.366	0.2000	0.072	0.7800	1	7.743	0.039	0.608
Saline-land	Chemical fertiliser Used	3.779	4.015	1.224	0.825	1	10.69	0.022	0.681
Lake & pond	Total sown area	2.318	2.1590	0.582	0.856	1	13.744	0.014	0.733
Marsh	Total sown area	5.492	0.8840	0.274	0.8220	1	10.442	0.023	0.676
Fallow-land	Total sown area	-3.995	2.234	0.613	4.399	1	13.302	0.022	0.894
	Food crop area		-2.035	0.677	-3.623	1	9.026	0.040	

(From Wu *et al.*, 2003b)

From July to Sept. in 1987: 96.4mm in Yinchuan and 149.3mm in Xining (TM images acquired on 20 Sept.);

From June to Aug. in 1999: 78mm in Yinchuan and 278.4mm in Xining (ETM images acquired on 12 Aug.). Between 1999 and 1987, a difference of -18.6mm in Yinchuan and 129.1mm in Xining is observed. Thus the rainfall varies probably from region to region in the upper reaches of the river. It is difficult to say that the river surface narrowing is a result of precipitation reduction in the region of Yinchuan.

Hydraulically, the river has been largely exploited during the last decades: damming in the upstream valley. Currently, five great hydroelectric power stations have been built up: Longyangxia, Lijiaxia, Yanguoxia, Bapanxia and Qingtongxia. This explains partially the impacts of human activity on the flow and surface of the river.

In agriculture, local people have made use of the river water for irrigation and pisciculture in northwestern China, especially in the Yinchuan Plain. With the extension of croplands, fish-ponds and water reserves against the aridity, river water has been increasingly extracted. An increase of 49km² in water surface in the region is a good sign. The use even overuse of water from the river may be also one of the factors influencing the surface narrowing of the river.

Surely, the climate change has made a certain contribution to, however, the human activity should have played a leading part in this narrowing. In the setting of global warming, the running course is likely to be dried after 2010 in the study area if the cropland extension and abusive use of water continue in the upper reaches. The lower reaches in the scope of Henan and Shandong have become from time to time dried. This phenomenon reminds us of the importance to save and control the mother river of China. Under the dryer and warmer background, how

to exploit the river and how to allocate the feasible water quantities to each province in the upper and middle reaches are a challenge for the decision-makers.

6. CONCLUSIONS AND REFLECTIONS

The research uncovers that 11.7% of the total territory in the region of Yinchuan has evolved since 1987, among which the farmland extension — a conversion from the wild sandy land, is the most outstanding environmental change (around 471km²) and associated with the Δ Agricultural output ($R^2 = 0.731$). However, the agricultural output plays an insignificant role in the economy of the region (11.6% of the total GDP growth).

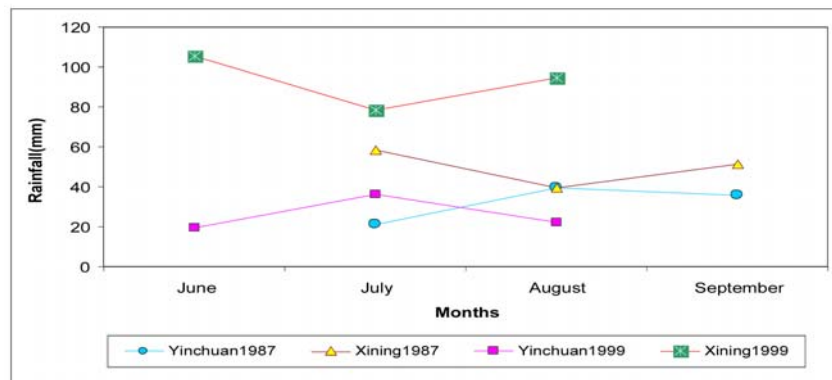


Figure 4 : Precipitation recorded in two major stations in the upper reaches of the Yellow River

The urban extension, driven by the Δ Urban population ($R^2=0.971$), having consumed 36km² of previously cultivated land and enjoying 3.6% of the total environmental change, is related to 88.4% of the GDP growth.

The changes in water surface, narrowing of the river, etc, have been observed. Water resource is surely the first essential for the socio-economic development. However, abuse, or to a certain sense, waste in water, has lead to an increase in water-body surface, formation of marsh, and locally soil salinisation. Probably, the abuse would not only happen in the region of Yinchuan but also in all upstream regions of the river, as local people fight for water for their agricultural and industrial development. In this way, how can the river not be dry in its downstream?

No desertification was observed. However, the signs of environmental degradation marked by vegetation disappearance, soil salinisation, etc, have taken place due to deforestation, overgrazing, exploitation of the natural resources (e.g., coal) and poor environmental management. The coal mining in the mountains (e.g., Shitanjing, Ruqigou), especially, some poorly organised private mining in the valleys and coal industries in Shizuishan, have provoked an environmental degradation, e.g., air pollution, soil erosion, locally destruction of the cultivated land and covering of coal residues and dusts around mines and transport routes. These coal mining related developments have brought about an improvement in the economy of the region but at a cost of environmental degradation. It is necessary to take certain feasibly effective measures to evaluate the potential impacts on the environment before the colliery exploitation.

The aridity can be *a priori* a disadvantage, but the leading cause provoking the impoverishment of soil is the human activity, which is deeply related to the complex socio-economic and political backgrounds. The future confronted with is not too optimistic: no much arable land left for the cropland extension, no much water resource available for the future development, and the Yellow River might become dry... These are worthy of thinking and thinking in the sustainable development planning and environmental management.

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