Environmental Research Journal 2 (5): 232-237, 2008
ISSN: 1994-5396

The Impact of Land Use Change on Karst Groundwater Quantity in Shentou Spring Basin, Shanxi Province, China

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Abstract: Karst aquifers usually form large groundwater reservoirs that play an important role in regional water supply in arid and semi arid regions. Because of their specific physical properties, karst aquifers are vulnerable to pollution, land use and climate changes. In the past 3 decades great changes have taken place in land use patterns in Shanxi province leading to a series of environmental issues and water shortage problems in the region. As a representative of karst springs in the province, the Shentou spring located northwest of the province was selected to study the impact of land use change on groundwater quantity for the period 1976-2000. Linear regression was utilized to analyze the trend in precipitation and spring discharge data series. Land use data were obtained by interpretation of Landsat images of 1976 and 2000, after processing the images using ERDAS IMAGINE and ArcGIS softwares. The relationship between forests, constructed and cultivated land use types and spring discharge was analyzed using regression analysis based on the land use variation data obtained since 1976. The impact of land use change on the basin was a general decrease in the discharge from the spring.

Key words: Land use change, karst aquifer, discharge, impact, shentou springs

INTRODUCTION

Karst is geologically a special type of landscape that is formed by the dissolution of soluble rocks, including limestone and dolomite. Karst regions occupy approximately 10% of the earth's land surface (Zekster *et al*., 2006). They contain aquifers that are capable of providing large supplies of water and thus they are major sources of water supply in these areas. Karst aquifers are generally considered to be very vulnerable to pollution, anthropogenic impacts and climate change. Changes in land use and land cover are among the most significant human modifications affecting the surface of the earth (Lambin *et al*., 2002). Land use represents the most Substantial human alteration of the Earth system in the past 300 years. The Land use of an area reflects the patterns of the natural and human environment including the various anthropogenic activities. As a consequence, hydrological processes on the earth's surface have been severely changed (Kalnay and Cai, 2003).

In China 9.5% of the landmass is karst terrain which is generally concentrated in two regions (Yuan, 1999). Shanxi Province is one of the main karst regions in Northern China and the outcrop area of soluble rocks is 33 000 km^2, occupying 21% of the total provincial area with a lot of large karst springs have formed and they have a discharge of 1-12 m^{-3} sec^{-1} and are in a stable regime (Ma *et al.*, 2004).

The aim of this study is to assess the change in land-use patterns and to assess its impact on the discharge of karst springs in Shanxi province. This study is specifically focused on the impact of land use changes on the discharge from the Shentou springs. It attempts to document land cover changes since, 1976 using two sets of images (Landsat MSS image of 1976 and TM image of 2000) to detect trends in land-use in the late 1970s and 1990s).

MATERIALS AND MEHTODS

Study area: The Shentou springs located in the Shentou town northeast of Shuozhou City, Shanxi Province of China covers an area of 5316 km^2 (Fig. 1). The spring system consists of about 100 spring points distributed along the Yuanzi River beds and banks with an annual average discharge rate of 6.86 m^3 s^{-1} (1958-1999).

The surface river system in the area consists of Shanggan River with Maguan, Qili and Yuanzi Rivers as its tributaries while Huihe River joins it at Mayidong confluence.

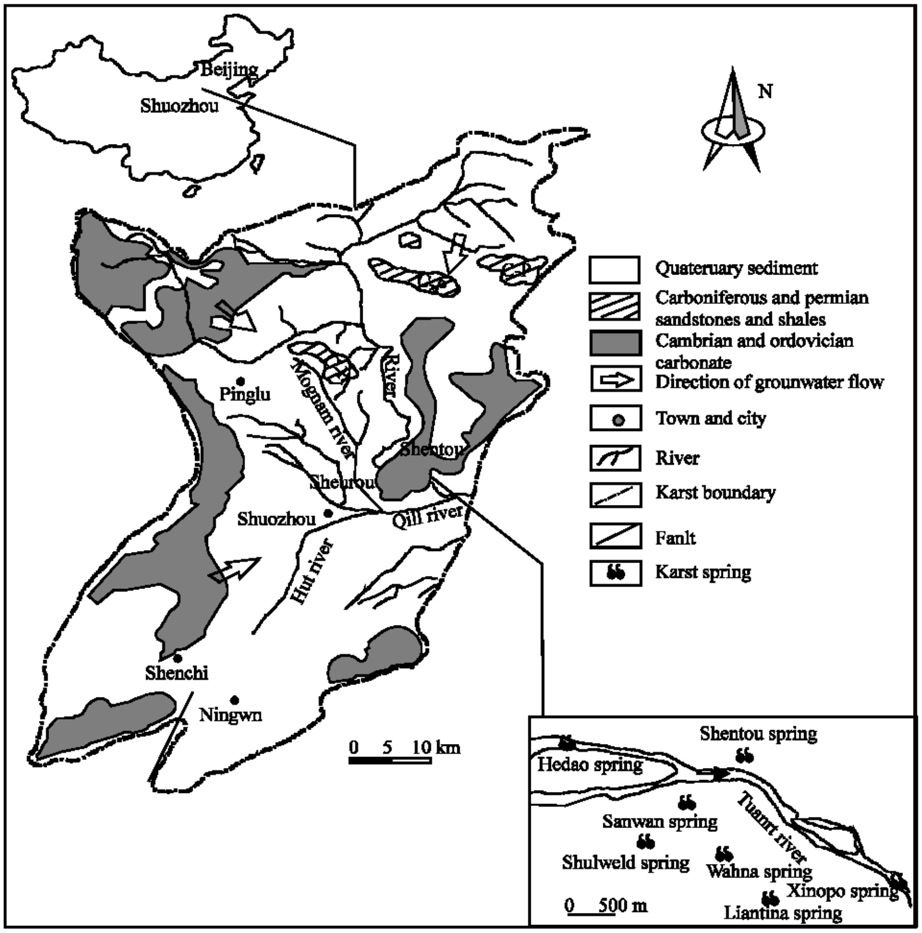

Fig. 1: A simplified hyrdogeological map of Shentou karst water system. Source: Ma *et al*. (2004)

The Shentou springs basin is an independent hyrdogeological unit in which karst water system includes 2 parts, the recharge area and the saturated flow area. The main aquifers of the basin are comprised of karstic Cambrian and Ordovician limestone and porous Quaternary sediments. In addition, the main source of recharge at Shentou is precipitation where groundwater is recharged through surface seepage of precipitation in outcropping limestone areas and via linear leakage of surface runoff.

The main economic activities in the area are coal mining and agriculture.

Hydrological data analysis: The process of data gathering involved a collection of monthly rainfall for a span of over 24 years (1976-2000) including monthly data for spring discharge. The monthly rainfall data were obtained from Nigwu, Pinglu, Shenchi and Shuozhou i.e., at weather stations. The trend in the precipitation data series and spring data series were analyzed using linear regression to reveal the dynamic variation over time. In hydrology, it is often the case that a variable precedes the other variable in time, like peak rainfall intensity preceding the peak runoff discharge. Because of this, correlation analysis was used to examine the relationship between the 2 time series, precipitation and spring discharge.

Table 1: Land use variation amplitudes in the spring basin from 1976 to 2000

Land use type	Forest land	Bare land	Cultivated land	Constructed land
Area in 1976	1168.69	2717.28	944.18	487.35
Area in 1976	21.98	51.10	17.76	9.17
Area in 2000 (%)	1619.03	1316.09	1561.94	820.45
Area in 2000 (%)	30.45	24.75	29.37	15.43
Variation amplitude Pi (%)	38.53	-51.57	65.43	68.35

Land use variation data and analytical methods: Land-use data was obtained by interpreting Landsat MSS and Thematic Mapper (TM) images for 1976 and 2000. Remotely sensed data (1976 and 2000 satellite MSS/TM images) were processed using ERDAS Imagine and ARCGIS softwares. First, land-use categories were obtained using ERDAS IMAGINE software and edited using ArcGIS software.

Table 2: Land-use change matrix in the area from 1976 to 2000 in km^2

Land use category	Cultivated land	Forest land	Constructed land	Bare land	1976 total	(%)
Cultivated land	254.25	162.59	131.00	189.53	737.37	14.8
Forest land	225.85	562.67	92.17	207.78	1088.47	21.8
Constructed land	0.00	0.00	350.93	0.00	350.93	7.0
Bare land	849.29	750.20	467.93	740.61	2808.03	56.3
2000 Total	1329.39	1475.46	1042.03	1137.92		
(%)	26.70	29.60	20.90	22.80		

The land-use patterns in the basin were divided into the following categories (Table 1): forest land, cultivated land, bare land and constructed land. The 2 indices of land-use variation amplitude and land-use transfer rate were used to reveal the basic characteristics and spatial patterns of land-use variations (Liu, 2000; Liu *et al.*, 2003). The corresponding analytical methods are as follows:

- Land use and land cover variation amplitudes: The variation amplitude of a single land type P_i, was calculated using the following mathematical expression:

$$P_i = (LU_{it1} - LU_{it0}) / LU_{it0} \times 100\,\%$$

where, LU_{it0} and LU_{it1} represent, respectively the area of the i type of land use and land cover at the beginning of the study and the area at t time of the study. The variation amplitudes are shown in Table 1.

- The transfer rate of land use and land cover variations:

A transformation matrix of land use types in different periods was established and the matrix corresponding to the elements of a single land type was directly used to analyze the transformation rate of the average land-use type into other land-use types (Table 2).

The land-use distribution of the spring basin during the 2 periods, 1976 and 2000 were Obtained from the analysis of remotely sensed data. Linear interpolation was used to obtain a data series of land-use variations in the 24 years.

RESULTS AND DISCUSSION

Trend in precipitation: Data series with linear trend line of the annual rainfall on the Shentou spring basin for the period 1976-2000 are presented in Fig. 2. It can be seen that precipitation in the basin does not show a definite trend but seems to be fluctuating with time.

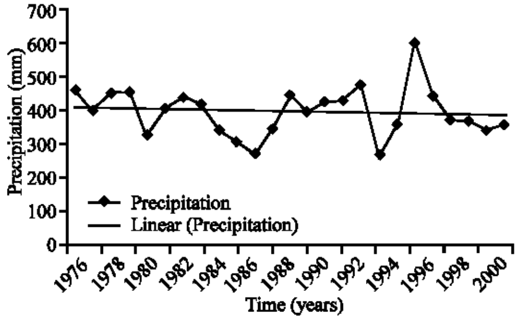

Fig. 2: Time data series of annual rainfall at the Shentou spring basin with trend line for the period 1976-2000

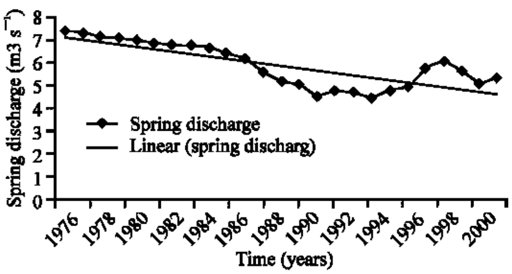

Fig. 3: Time data series of mean annual discharges at the Shentou karst spring basin with trend line for the period 1976-2000

Trend in spring discharge: Data series with linear trend line of the mean annual spring discharges for the period 1976-2000 are presented in Fig. 3. The average annual discharge in the 1976-2000 period was 5.86 m^3 sec^{-1}, while the minimum and maximum observed values were 7.37 m^3 sec^{-1} (1976) and 4.44 m^3 sec^{-1} (1993), respectively. The fluctuating effects in the annual rainfall pattern during the same period could have had an effect on the spring discharge.

Precipitation and spring discharge: A correlation through a linear regression between the annual discharge and the annual rainfall is shown in Fig. 4 with a linear correlation coefficient of only 0.06. This value of the coefficient implies that no obvious linear relation can be deduced between precipitation and spring discharge in the basin.

According to Ma *et al.* (2004), the low correlation coefficient is related to the slow response of the spring to precipitation over such a big area of the Shentou karst

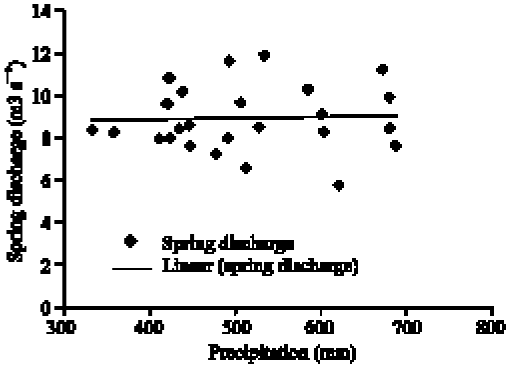

Fig. 4: Linear regression between the spring discharge (Qs) and precipitation

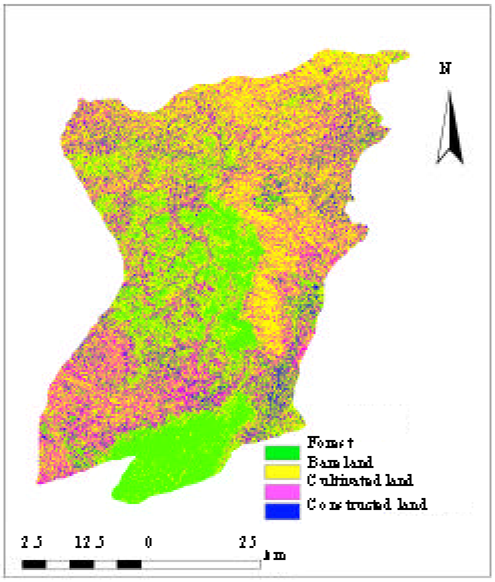

Fig. 5: Land use map of Shentou spring basin in 1976

water system i.e. precipitation is the main source of recharge in this spring basin.

Land use and land cover change patterns: In 1976, the bare land occupied 51.1% of the total spring area, making it the dominant land-use type, followed by forest land with 21.98% and cultivated land with 17.76% (Fig. 5).

In Table 2, the rows show the area of different land-use types in 1976 while the columns show the area of different land-use types in 2000 i.e. forest, cultivated and constructed land areas increased by 38.53, 68.35 and 65.43%, respectively.

The increase in cultivated land was probably caused by the increase in demand for food due to population growth i.e. at 1.25% annually since, 1990, with urban population increasing at 3.15%.

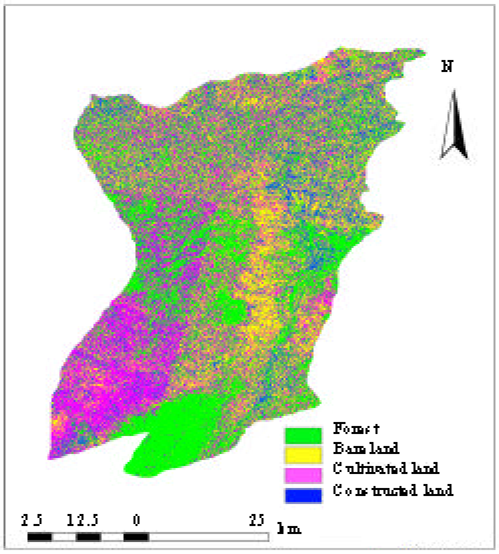

Fig. 6: Land use map of Shentou spring basin in 2000

Similarly, constructed land increased due to urbanization while increased forest was as a result of national afforestation policy where every Chinese citizen except the aged and disabled was obligated to plant 3-5 trees every year.

The main land changes in 24 years were from bare land into cultivated land and forest land and from forest land into cultivated land including constructed land.

It is evident from Fig. 5 and 6 that significant changes in land use and land cover took place between 1976 and 2000 through afforestation, cultivation and construction in the Shentou spring basin.

Impact of reforestation on spring discharge: The main impact of afforestation on water resources, regardless of the type of forest cover (Fig. 7), is a reduction in water yield (i.e. the proportion of total rainfall reaching the ground surface to undergo infiltration or surface runoff) associated with afforestation (Bosch and Hewlett 1982; McCulloch and Robinson, 1993). By contrast, clear felling, i.e., reduction in forest cover, increases water yield (Hibbert, 1967).

Figure 5 illustrates a decrease in spring discharge as the forest area increases. This is an impact of afforestation on groundwater quantity.

Impact of constructed land on spring discharge: The spring discharge seem to decrease as the constructed land area increases (Fig. 8). This is because increased construction (as a result of urbanization) increases the impervious surface cover such as roads and buildings

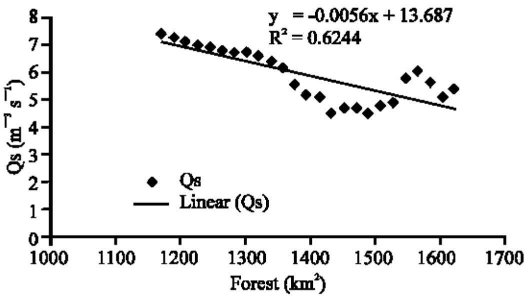

Fig. 7: Linear regression between spring discharge Qs and forest cover

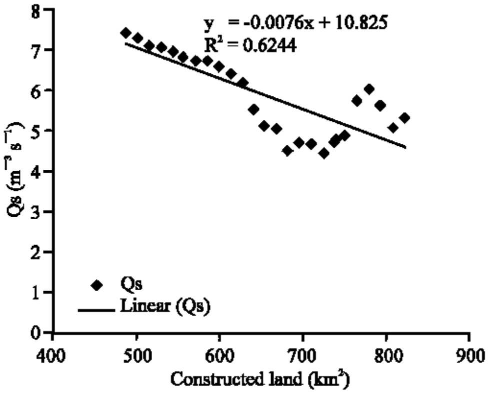

Fig. 8: Linear regression between spring discharge (Qs) and constructed land

which limit direct infiltration of rainfall into the ground creating large amounts of runoff. Runoff will ultimately lead to increased water flow in the streams as opposed to ground recharge. This is a direct impact on spring discharge in this area where precipitation is the only source of recharge.

Impact of cultivated land on spring discharge: The reduction in spring discharge for the area is evident in Fig. 9 and can be attributed to cultivation. This is because in groundwater-fed irrigation systems, increased irrigation pumpage greatly outweighs increased recharge rates, resulting in large groundwater level declines. In addition, cultivation usually involves tilling of the land a process which makes the soil particles loose and may ultimately lead to eventual blockage of permeability channels in the sub-surface and hence reduced recharge in the karst area.

In addition to the above discussed factors, another factor that could have contributed to the decline in the discharge of the spring is coal mining. Surface coal mining operations involve breaking up of the overlying rocks (overburden) to remove the coal. The reclaimed spoil will have higher ground-water storage capacity and higher transmissive properties than in the original rock. These differences will trigger ground-water flow in the reclaimed spoil and may affect neighboring aquifers that are hydraulically connected to the disturbed zone. Also excavation process may cause fracturing of rock strata which in turn can affect the ground-water hydrologic system. This is likely to occur if the confining strata below an aquifer fractures leading to aquifer drainage and subsequent potentiometric surface to drop. This is common in springs fed by ground-water whose discharge could eventually reduce or dry up entirely. It is important to note that there is a cumulative effect on spring discharge by all factors.

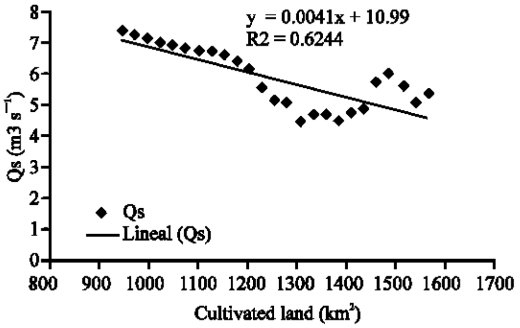

Fig. 9: Linear regression between spring discharge (Qs) and cultivated land

CONCLUSION

The noticeable impact of land use change on karst groundwater quantity in Shentou spring basin is a general decrease in spring discharge. This decrease is a consequence of reduced precipitation recharge due to continuous variations in the spatial patterns of land use and land cover in the basin such as afforestation, cultivation and construction in the area. The regression coefficient R^2 of 0.6244 between different land uses and the spring discharge shows that there is an obvious relationship between land use and spring discharge. Therefore, in order to properly manage karst water systems in this basin, more attention should be paid to the effects of land use on karst spring basins including land-use planning and management in the future.

ACKNOWLEDGEMENT

The author wishes to thank Professor Ma Teng of the School of Environmental Studies, China University of Geosciences (Wuhan) for his supervision, Mr. Hyandye Canute is acknowledged for his assistance in the image processing and everyone who helped in one way or another.

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