

Precipitation change and human impacts on hydrologic variables in Zhengshui River Basin, China

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Abstract Climate change and anthropogenic impacts on hydrologic variables have received significant attention in recent years. We assessed stream flow and water level in the Zhengshui River basin, China, in the period 1960 to 2003 in response to precipitation variation and anthropogenic factors. Analyses of daily discharge and water level records, and derived annual, seasonal and monthly series, showed that Zhengshui River flows had a significant increasing trend, with an abrupt change point in 1990. There was a significant decreasing water level trend with an abrupt change point in 1995. Human activities and precipitation contributed 53 and 47%, respectively, to increase in stream flow during 1991–2003. Anthropogenic activities such as sand dredging, dominated the decrease in water level during 1994–2003. Human-induced land use change, soil erosion and sand excavation driven by rapid economic development have played a more important role than precipitation variation in hydrological changes in the Zhengshui River basin over the past 50 years.

Keywords Human activities · Mann–Kendall test · Precipitation variation · Stream flow · Water level

1 Introduction

It is widely recognized that hydrological cycles are complex processes influenced by both climate change and human intervention (Piao et al. 2007). Climate change resulting in global temperature rises and changes in precipitation amounts, intensities and patterns, could have significant impacts on regional hydrological cycles and subsequently result in changes of flows in streams and large rivers (Burn and Elnur 2002; Labat et al. 2004; Chen et al. 2006; Huo et al. 2008). Apart from climate change, human intervention such as deforestation, wetland filling, irrigation and new dam construction are thought to be major factors which can also lead to significant hydrologic alterations (Sahagian 2000). Stream flow and water level are important hydrologic variables which can be used to monitor possible indications of climatic change and human perturbations. The detection of changes in long-term time series of stream flow and water level and the differentiation between climate change and human impacts is of scientific and practical importance to sustainable water resource management.

There are a number of studies addressing the potential impacts of climate change on hydrologic variables. Labat et al. (2004) provided evidence for global runoff increase related to climate warming, suggesting a 4% increase in global runoff with each 1°C temperature rise. Milly et al. (2002) investigated changes in flooding with discharges exceeding 100-year levels from basins larger than 200,000 km², and found that the frequency of large floods increased substantially during the twentieth century. Kahya and Kalayci (2004) investigated trend characteristics of stream flows obtained from 26 basins in Turkey, and found that basins located in western Turkey exhibited a decreasing trend whereas basins located in eastern Turkey

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showed no change. At the same time, there has been a growing awareness of the role of human interventions in hydrological systems. Vörösmarty et al. (2000) suggested that ‘impending global-scale changes in population and economic development over the next 25 years will dictate the future relation between water supply and demand to a much greater degree than will changes in mean climate’. Brown et al. (2005) reviewed paired catchment studies and found afforestation will lead to reduction in stream flow. Zhang and Schilling (2006) suggested that Mississippi River base flow increase resulted from land use change over the last 60 years due to expansion of soybean cultivation. Other human interventions such as irrigation and sand dredging, which can affect stream flow and water level, have also been investigated (Chen et al. 2007; Hao et al. 2008).

Recently, the impact of climate change and human activities on hydrologic variables in arid regions of China has been conducted. Tao et al. (2003a, b) showed that disastrous droughts on the north and northeast China Plain increased significantly in the last few decades, while runoff increased in the coastal areas of southeast China due to climate change. Human-induced soil degradation could increase the potential for drought and flood disasters (Tao et al. 2005). Huang and Zhang (2004) investigated hydrological responses to conservation practices in the Jialuhe River catchment, a tributary of the Yellow River. They showed that mean annual surface runoff and base flow decreased 32% during the period 1967 to 1989, which was attributed mostly to the establishment of tree plantations. Huo et al. (2008) analyzed changes in annual stream flow in the Shiyang River basin, a typical arid-inland basin in north-west China. They showed that human activities such as irrigation had a significant effect on flow decreases in the 1970s, while climate changes were the main reason for observed flow decreases in the 1980s and 1990s. These previous studies indicated that hydrological systems in arid regions are very sensitive to climate change and human activities, but the situation in relatively humid regions in China remains unclear. Hydroclimatic trends in the humid Yangtze River basin have been investigated by many researchers (e.g. Becker et al. 2006; Zhang et al. 2005, 2006a, b; Gemmer et al. 2008). However, none of them specified the combined effect of climate change and human activities on flows and water levels in the Yangtze River. In this paper, we chose the Zhengshui River basin, a secondary tributary of Yangtze River, to examine sensitivity of stream flow and water level to climate variation (precipitation changes) and human activities (land use change and economic development), and to identify effects of climate change, rapid economic development, and their combination on water resources at the watershed scale.

2 Study area

Zhengshui River is a secondary tributary of Yangtze River (Fig. 1), and is located in south-central Hunan Province in China. The river is 194 km long, with a drainage area of $\sim 3470 \text{ km}^2$. The elevation of the drainage basin ranges from 1098 m at its headwaters to 30 m above sea level. The regional climate is classified as subtropical monsoonal, with annual average precipitation of $\sim 1350 \text{ mm}$ and mean annual temperature 18.1°C . At the basin outlet, hydrological records from 1960 to 2003 demonstrate the annual mean stream flow and water level are $47.1 \text{ m}^3 \text{ s}^{-1}$ and 92.24 m, respectively. The basin is covered dominantly by forest (54%) and arable land (42%), and it covers most of Hengyang County, a traditional agricultural region in Hunan province. This region is an important base of commodity grain production, but significant changes have occurred with rapidly expanding economic development.

3 Data and methodology

3.1 Data collection

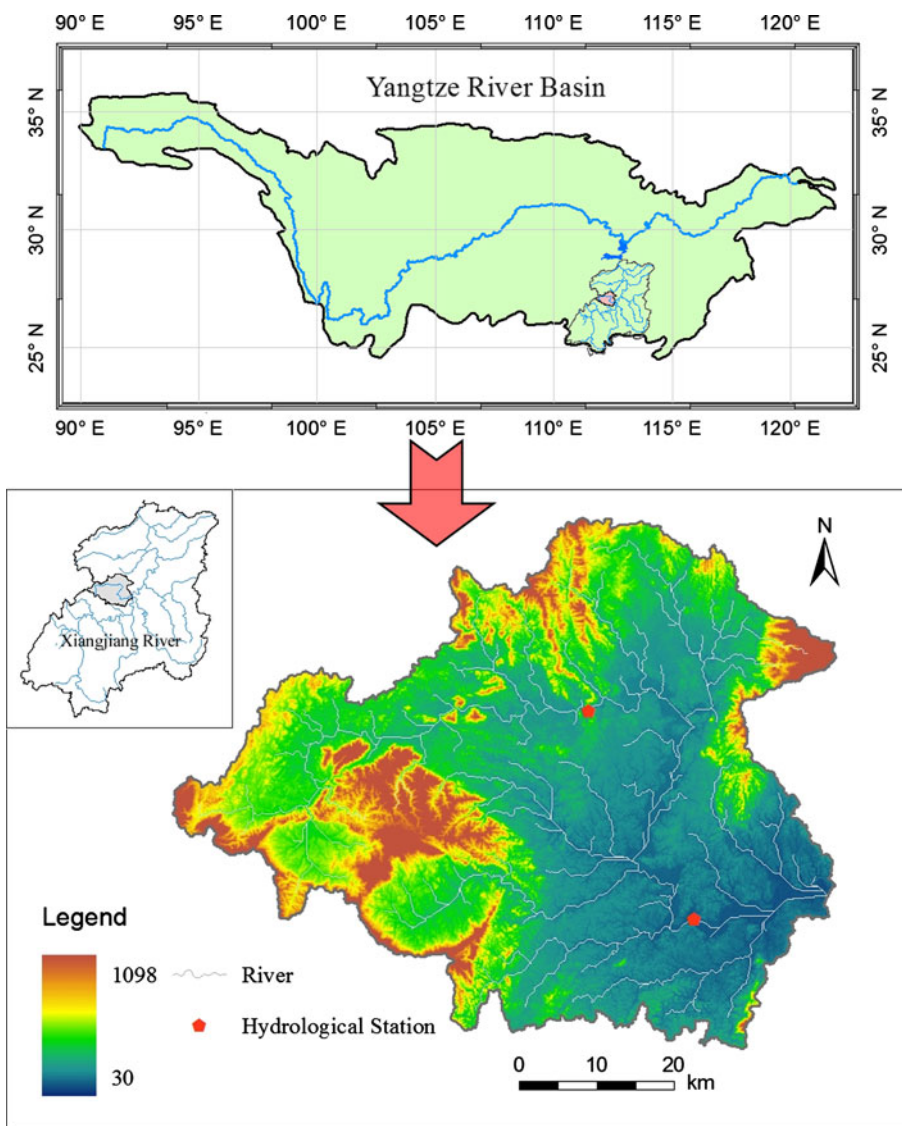
We obtained daily discharge and water level data from the Hunan Hydrographic office. In Zhengshui River basin, there are two stream and water level gauging stations: Shenshantou (SST) station in the lower reach and Shimenkan (SMK) station in the upper reach. The SST records span the period 1960 to 2003, and the SMK station from 1976 to 2003. Based on the daily records, we calculated annual, monthly and seasonal data series to assess responses of river discharge and water level to climate change and human activities. Daily precipitation records for Zhengshui River basin from 1951 to 2005 were provided by the National Climate Centre of China Meteorological Administration (CMA).

3.2 Methods

3.2.1 Mann–Kendall Trend detection

The non-parametric Mann–Kendall (MK) statistical test (Mann 1945; Kendall 1975) is an approach for detecting monotonic trends in a time series. Mann (1945) originally used this test, and Kendall (1975) subsequently derived the test statistic distribution. This test has been used widely to detect trends in hydrology and climatology because it is robust against non-normal distributions and insensitive to missing values. In the MK test, the null hypothesis H_0 is that there is no trend in the population from which the data set X is drawn. The alternative hypothesis H_1 is that a

Fig. 1 Location of the Zhengshui River in Yangtze River Basin



monotonic trend exists in X. The test statistic S is given as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n Sgn(X_j - X_i) \tag{1}$$

where the time-series x_i is ranked from $i = 1, 2, \dots, n-1$, and x_j is ranked from $j = i + 1, \dots, n$, and

$$Sgn(\theta) = \begin{cases} +1 & \theta > 0 \\ 0 & \theta = 0 \\ -1 & \theta < 0 \end{cases} \tag{2}$$

For $n > 10$, the standardized test statistic Z is calculated by

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & S < 0 \end{cases} \tag{3}$$

The Z value is a standard normal variate value which can be related to a significance level of a specific trend. Mann (1945) describes the procedure used to develop Z. The significance level (denoted by α) expresses the probability of obtaining the observed value for the Mann–Kendall statistic when in fact no trend exists. The null hypothesis H_0 should be rejected if $|Z| \geq Z_{1-\alpha/2}$ at the α level of significance. This means an upward or downward trend exists in this time series at significant level α . Another useful parameter derived from the trend test, the magnitude of the slope, β , was determined by Hirsch et al. (1982), and is given by

$$\beta = Median\left(\frac{(X_j - X_i)}{j - i}\right) \quad \forall i < j \tag{4}$$

A positive value of β indicates an upward trend, whereas a negative value represents a downward trend.

3.2.2 Mann–Kendall change-point analysis

To conduct change-point analysis, the non-parametric Mann–Kendall–Sneyers test was employed. The test is a sequential version of the Mann–Kendall rank statistic proposed by Sneyers (Li et al. 2007). The MK rank statistic S_k is defined as:

$$S_k = \sum_{i=1}^k \sum_{j=1}^{i-1} \alpha_{ij} \quad (k = 2, 3, 4, \dots, n) \quad (5)$$

For each element x_i , the numbers n_i of elements x_j preceding it ($j < i$) such that $x_j < x_i$ are computed, namely:

$$\alpha_{ij} = \begin{cases} 1 & x_i > x_j \\ 0 & x_i \leq x_j \end{cases} \quad 1 \leq j \leq i \quad (6)$$

Then, the definition of the statistic index UF_k is calculated as:

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{\text{var}(S_k)}} \quad k = 1, 2, 3, \dots, n \quad (7)$$

UF_k follows the standard normal distribution, which is the forward statistic sequence, and the backward sequence UB_k is calculated using the same equation but with a reversed series of data.

In the two sided test, if the null hypothesis is rejected, an increasing ($UF_k > 0$) or a decreasing ($UF_k < 0$) trend is indicated. The sequential version of the test used here enable detection of the approximate time of occurrence of the trend by locating the intersection of the forward and backward curves of the test statistic. If the intersection occurs within the confidence interval, then it indicates a change point (Moraes et al. 1998; Li et al. 2007).

3.2.3 Double-mass technique

The double-mass technique is used to detect non-homogeneities in time series with a recognized common global pattern (Cluis 1983). The theory of the double-mass curves is based on the fact that a graph of the accumulation of one quantity against the accumulation of another quantity during the same period will plot as a straight line so long as the proportionality between the two remains unchanged, and the slope of the line represents the proportionality (Searay and Hardison 1960). The double mass curves can be defined as:

$$Y(t) = F(X(t)) \quad (8)$$

For the double mass curve between precipitation and stream flow,

$$X(t) = \sum_{i=1}^t x_i, \quad Y(t) = \sum_{i=1}^t y_i \quad (9)$$

where x_i is the annual precipitation for year i , y_i ($10^8 \text{ m}^3 \text{ year}^{-1}$) is the annual stream flow for year i , respectively.

In this research, the double-mass curves of precipitation vs. stream flow and precipitation vs. water level are plotted to determine the time when human activities began to obviously influence river flows and water level in the whole basin.

4 Results

4.1 Trends and change point in stream flow

Statistical analysis results for river discharge series at SST (1960–2003) and SMK (1976–2003) are summarized in Table 1. Annual river discharge showed a significant increasing trend (Table 1). The trend in annual mean discharge was significant at the 0.01 confidence level and the trend in annual maximum discharge was significant at the 0.05 confidence level. Annual mean discharge increased by $0.60 \text{ m}^3 \text{ s}^{-1}$ per year and annual maximum discharge increased by $7.43 \text{ m}^3 \text{ s}^{-1}$ per year.

At a monthly scale, river discharge in most months showed an increasing trend, except in April. Significant increasing trends ($p < 0.05$) were detected in January, February, July, August, September, and October.

We also investigated seasonal trends in river discharge during the study period. We defined spring from March to May, summer from June to August, autumn from September to November, and winter from December to February. There was a significant increasing trend in summer discharge with a slope of $1.24 \text{ m}^3 \text{ s}^{-1}$ per year.

Figures 2 and 3 illustrate the change patterns of annual mean discharge and summer discharge at SST and SMK stations, respectively. Summer discharge at SST station demonstrated a pattern similar to that of annual mean discharge (Fig. 2). Both decreased during 1960–1970, and then increased during 1970–1990, but the trend was not significant. However, after 1990 both the annual mean and the summer discharge showed significant increasing trends. The intersection points of UF and UB curves were ca. 1990 (Fig. 2), which suggests abrupt change points for both annual mean and summer discharge at SST station occurred at this time. The change patterns of annual mean and the summer discharge at SMK station are plotted in Fig. 3. This indicates that there was no significant trend during 1975–1985, but after 1985 SMK station experienced increasing trends in annual mean discharge and summer discharge. The abrupt change points also occurred ca. 1990.

4.2 Trends and change point in water level

The MK trends in water level are shown in Table 2. Water level at SST station showed significantly decreasing trends

Table 1 Mann–Kendall trend test and Sen’s slope results for river discharge at SST station (1960–2003) and SMK station (1976–2003)

Time series ($\text{m}^3 \text{s}^{-1}$)	River discharge (SST station)			River discharge (SMK station)		
	Z statistic	$\beta(\text{m}^3 \text{s}^{-1} \text{yr}^{-1})$	Sig. level	Z statistic	$\beta(\text{m}^3 \text{s}^{-1} \text{yr}^{-1})$	Sig. level
Annual time series						
Mean	2.76	0.60	+**	3.77	0.42	+**
Maximum	1.76	7.43	+*	2.63	10.95	+**
Minimal	-0.16	0	-ns	3.52	0.06	+**
Monthly time series						
January	2.52	0.42	+**	2.35	0.22	+**
February	2.17	0.52	+*	0.06	0.02	+ns
March	1.30	0.47	+ns	1.84	0.54	+*
April	-0.27	-0.12	-ns	0.14	0.02	+ns
May	1.18	0.65	+ns	1.52	0.57	+ns
June	1.08	0.74	+ns	1.36	1.06	+ns
July	3.13	1.22	+**	2.63	1.06	+**
August	2.44	0.79	+**	1.92	0.52	+*
September	2.50	0.39	+**	1.84	0.25	+*
October	1.93	0.52	+*	0.53	0.10	+ns
November	0.15	0.05	+ns	0.22	0.04	+ns
December	0.01	0.01	+ns	1.48	0.11	+ns
Seasonal time series						
Spring	0.68	0.25	+ns	1.96	0.45	+*
Summer	2.74	1.24	+**	3.30	0.81	+**
Autumn	1.37	0.29	+ns	0.60	0.07	+ns
Winter	1.57	0.24	+ns	1.08	0.12	+ns

+ Increasing trend, - decreasing trend

* Significant at $p = 0.05$, ** significant at $p = 0.01$, ns not significant at $p \leq 0.05$

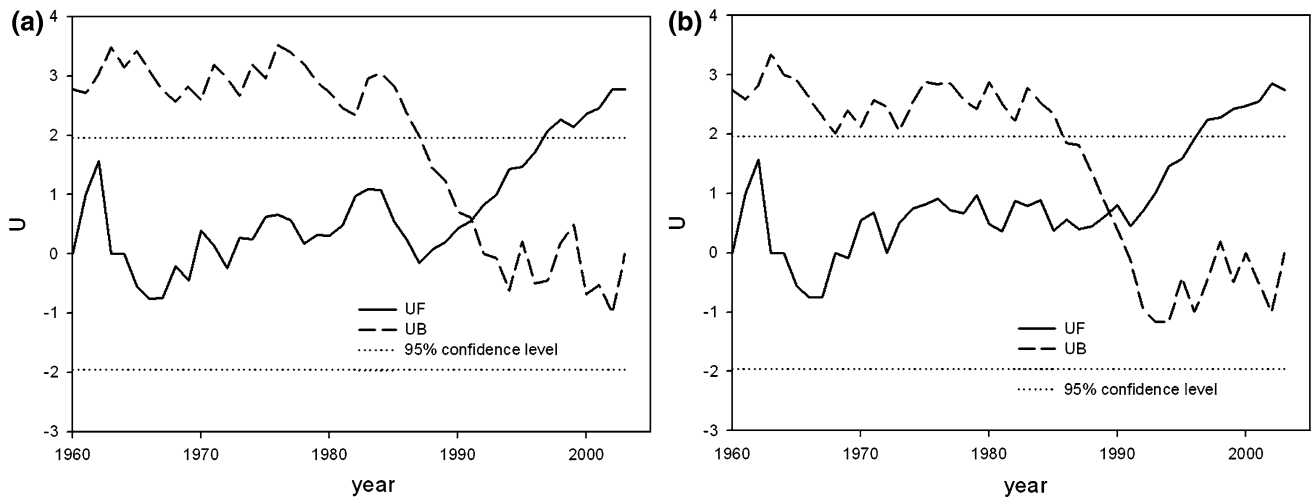


Fig. 2 a Mann–Kendall change-point detection in time series of annual mean discharge (1960–2003) at SST station; (b) Mann–Kendall change-point detection in time series of summer discharge (1960–2003) at SST station

through most of the time period ($p < 0.01$). Compared with SST station in the lower reach, SMK station in the upper reach did not experience significant change in water level except, annual maximum water level.

Figure 4 shows change patterns of annual mean and annual maximum water level at SST station. At SST station there was a relatively stable trend in annual mean water level from the 1960s to 1970s, but after 1985 the annual

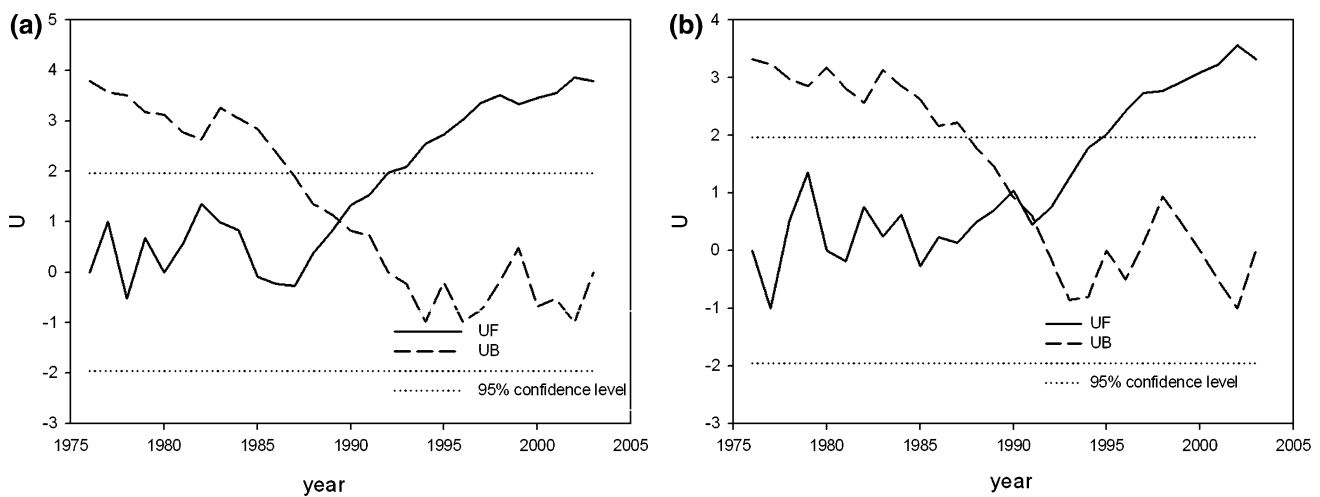


Fig. 3 **a** Mann–Kendall change-point detection in time series of annual mean discharge (1976–2003) at SMK station; **(b)** Mann–Kendall change-point detection in time series of summer discharge (1976–2003) at SMK station

Table 2 Mann–Kendall trend test and Sen’s slope results for water level at SST station (1960–2003) and SMK station (1976–2003)

Time series (m)	Water level (SST station)			Water level (SMK station)		
	Z statistic	$\beta(\text{m yr}^{-1})$	Sig. level	Z statistic	$\beta(\text{m yr}^{-1})$	Sig. level
Annual time series						
Mean	−4.84	−0.017	−**	0.29	0.001	+ns
Maximum	−0.32	−0.004	−ns	1.89	0.075	+*
Minimal	−5.45	−0.018	−**	−0.27	0	−ns
Monthly time series						
January	−2.98	−0.012	−**	−0.12	−0.001	−ns
February	−2.92	−0.014	−**	−0.12	−0.002	−ns
March	−3.54	−0.017	−**	−0.62	−0.008	−ns
April	−4.84	−0.033	−**	−0.04	0	−ns
May	−4.69	−0.027	−**	1.07	0.012	+ns
June	−3.99	−0.025	−**	0.70	0.008	+ns
July	−1.15	−0.007	−ns	−0.29	−0.003	−ns
August	−2.80	−0.014	−**	0.45	0.009	+ns
September	−3.45	−0.016	−**	−0.21	−0.002	−ns
October	−3.23	−0.016	−**	−0.87	−0.010	−ns
November	−5.02	−0.025	−**	−0.95	−0.016	−ns
December	−5.47	−0.020	−**	−0.12	0	−ns
Seasonal time series						
Spring	−4.80	−0.025	−**	0	0.001	
Summer	−3.49	−0.017	−**	0.62	0.008	+ns
Autumn	−4.34	−0.020	−**	−1.63	−0.018	−ns
Winter	−4.33	−0.015	−**	−0.50	−0.004	−ns

+ Increasing trend; − decreasing trend

* Significant at $p = 0.05$, ** significant at $p = 0.01$, ns not significant at $p \leq 0.05$

mean water level showed a sharply negative trend. The intersection point of UF and UB curves in Fig. 4a was in 1995, which means the abrupt change point of annual mean water level at SST station occurred at this time. The

summer water level at SST station also showed a downward trend. The change pattern was very similar to the annual mean water level (Fig. 4b). The abrupt change point of summer water level at SST station was ca. 1996.

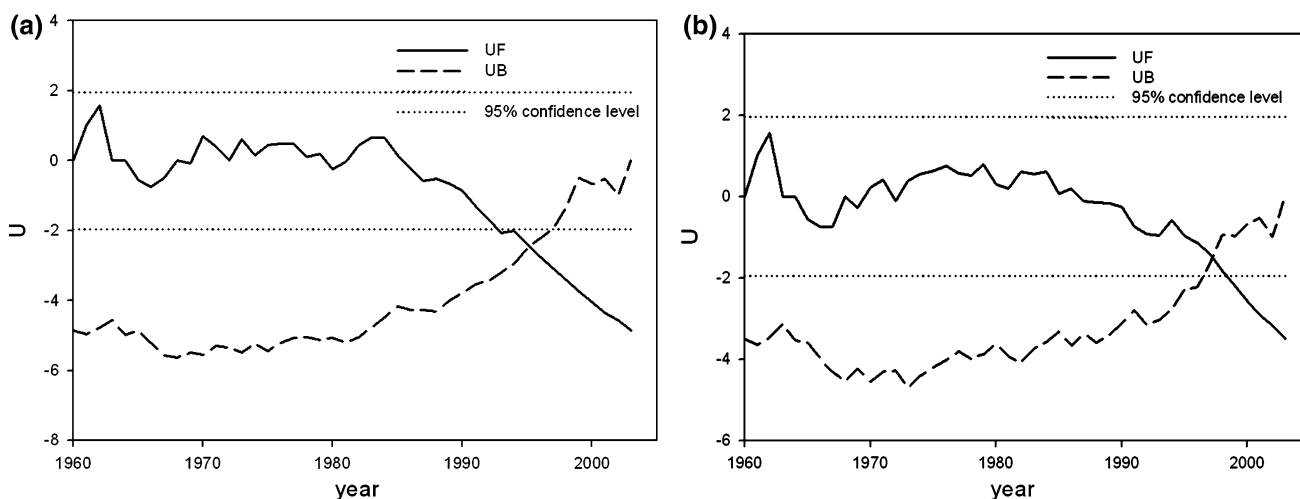


Fig. 4 **a** Mann–Kendall change-point detection in time series of annual mean water level (1960–2003) at SST station; **(b)** Mann–Kendall change-point detection in time series of summer water level (1960–2003) at SST station

4.3 Trends and change point in precipitation series

Precipitation is the main cause of variability in water balance over space and time on the Earth’s surface. Changes in precipitation have important implications for hydrology and water resources (IPCC 2001a, b; Novotny and Stefan 2007). Precipitation can be used as an index to reflect the impact of climate change on hydrologic variables. In this study, we investigated precipitation trends and their association with hydrologic variables.

Results of MK analysis for precipitation series are summarized in Table 3. Annual precipitation, including annual total, annual maximum 1-, 3-, 7- and 10-day precipitation, had increasing trends, but the trends were not significant ($p > 0.05$). The MK test for monthly precipitation in Zhengshui River basin showed significant increasing trends in January ($p < 0.01$), July and September ($p < 0.05$), while decreasing trends occurred in April and November ($p < 0.05$). But there was no discernible change-point of precipitation detected.

5 Discussion

5.1 Different stages of stream flow and water level

To determine the time when human activities began to notably affect river flows and water level, we investigated the double mass curves of annual precipitation-stream flow and summer precipitation-water level. If there were no influences of human activities on hydrological processes, the double mass curve would be a straight line (Zhang and Lu 2009). The distribution of cumulative points of the

Table 3 Mann–Kendall trend test and Sen’s slope results for precipitation time series during the period 1960 to 2003

Time series (mm)	Precipitation		
	Z statistic	$\beta(\text{mm yr}^{-1})$	Sig. level
Annual time series			
Total	0.80	2.59	+ns
Maximum 1-day	0.38	0.13	+ns
Maximum 3-day	1.39	0.5	+ns
Maximum 7-day	0.90	0.4	+ns
Maximum 10-day	0.29	0.17	+ns
Monthly time series			
January	2.78	1.32	+**
February	0.46	0.18	+ns
March	0.64	0.47	+ns
April	-1.72	-1.43	-*
May	1.37	1.25	+ns
June	0.32	0.37	+ns
July	1.65	1.36	+*
August	0.12	0.16	+ns
September	2.24	0.97	+*
October	0	0.03	
November	-1.77	-1.25	-*
December	-1.12	-0.47	-ns
Seasonal time series			
Spring	0.58	1.11	+ns
Summer	0.40	1.00	+ns
Autumn	-1.19	-1.51	-ns
Winter	1.23	1.06	+ns

+ Increasing trend; - decreasing trend

* Significant at $p = 0.05$, ** significant at $p = 0.01$, ns not significant at $p \leq 0.05$

annual precipitation-stream flow curve began to increase during the period 1970 to 1990, and became obvious after 1990 (Fig. 5a). The turning point in 1990 was the same as the change point for annual mean and summer discharge shown by MK. Similarly, the double cumulative points of summer precipitation-water level began to show downward deviation from the regression line from 1993, and this 1993 turning point was very close to the change point for annual mean water level in 1995 and the change point for summer water level in 1996, shown by MK (Fig. 5b).

Based on analysis of abrupt change points and characteristics of double mass curves, the evolution of river flows can be divided approximately into three stages: 1960–1969, 1970–1990 and 1991–2003. The evolution of water level can be divided into two stages: 1960–1993 and 1994–2003.

5.2 Impact of precipitation *versus* human activities

To describe quantitatively the impact of precipitation and human activities on hydrologic variables at different stages, we need to distinguish the “reference period” from “affected periods”. “Reference period” means no human impacts or relatively fewer human impacts on the river system during the study period, while “affected period” means human activities impose a drastic influence on river system. It is important to note that observed stream flow and water level records at the watershed outlet reflect basin integration of both natural variation and changes induced by human impact, so we use SST station records to analyze the impacts of precipitation and human activities on stream flow and water level.

During the 1960–1969 stage, there were relatively fewer anthropogenic activities in Zhengshui River basin. This period is assumed to represent hydrologic variables under natural conditions, and is taken as the “reference period”

to establish the relationship between the precipitation and hydrologic variables. Simple linear relationships between annual precipitation (AP) and annual stream flow (ASF), and summer precipitation (SP) and summer water level (SWL) at SST station during this period were as follows:

$$ASF = 0.0181AP + 92.9747 \quad (r^2 = 0.66; p < 0.0001) \quad (10)$$

$$SWL = 0.0017SP + 92.7887 \quad (r^2 = 0.81; p = 0.0004) \quad (11)$$

The coefficient of determination r^2 and significant level p for the linear equations show that they can generate reasonable results, so we used these equations to estimate stream flow and water level under the impacts of precipitation variation in the “affected period”. We further obtained changes in stream flow and water level caused by human activities in the affected period by subtracting the measured values of hydrologic variables from the estimated values (Table 4).

During the 1970–1990 stage, changes in stream flow were dominated by changes in precipitation, and human activities played a weak role (Table 4). During the 1991–2003 stage, human activities and precipitation had equal contribution in stream flow changes. Approximately 47% of the stream flow increase was explained by changes in precipitation, and 53% of stream flow increase was due to human activities. The linear regression relationship between annual stream flows and annual precipitation for the reference and affected periods are plotted in Fig. 6a. The fitted line in the reference period 1960 to 1969 is above that in the affected period 1970 to 2003, suggesting the annual stream flow had increased with precipitation.

For summer water level, both changes by human activities and precipitation during the 1979–1993 stage

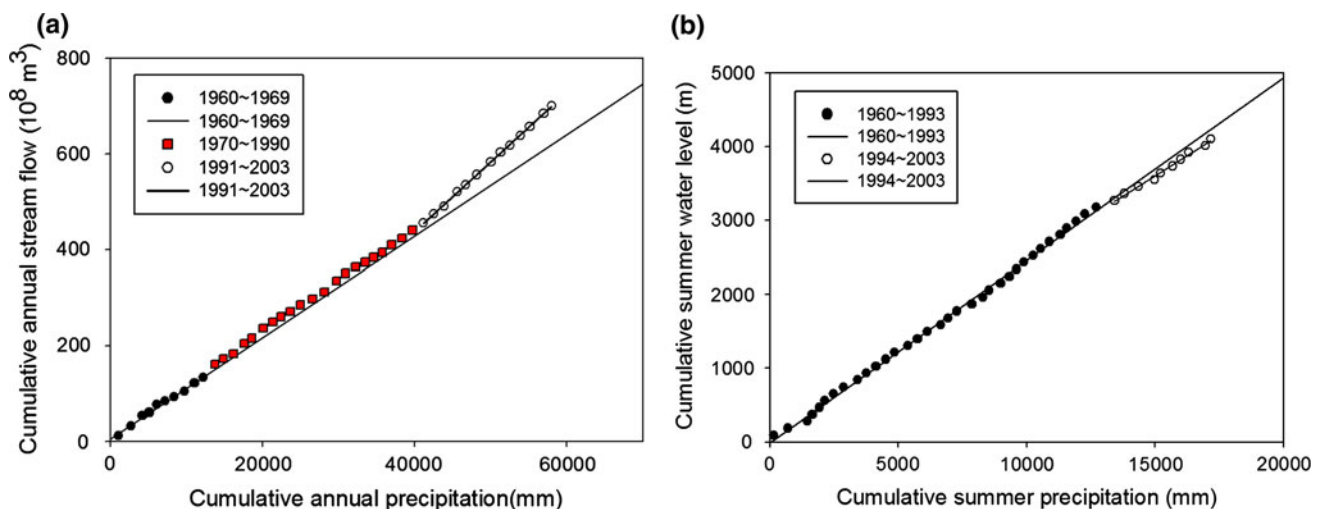


Fig. 5 Double mass curves of (a) annual stream flow and annual precipitation; (b) summer water level and summer precipitation

Table 4 Estimated impacts of human activities and precipitation changes on annual stream flow and mean summer water level in Zhengshui River basin

Period	Estimated value by precipitation only	Observed value	Changed value by human activities		Changed value by precipitation only	
			Value	Percentage (%)	Value	Percentage (%)
Annual stream flow ($10^8 \text{ m}^3 \text{ a}^{-1}$)						
1970–1990	14.903	14.631	-0.272	-20.5	1.6	120.5
1991–2003	16.440	20.019	3.579	53.3	3.137	46.7
Mean summer water level (m a^{-1})						
1970–1993	93.423	93.444	0.021	0	-0.017	0
1994–2003	93.546	92.890	-0.656	-119.3	0.106	19.3

Mean stream flow in the reference period is $13.303 \times 10^8 \text{ m}^3$, and the mean summer water level in the reference period is 93.44 m

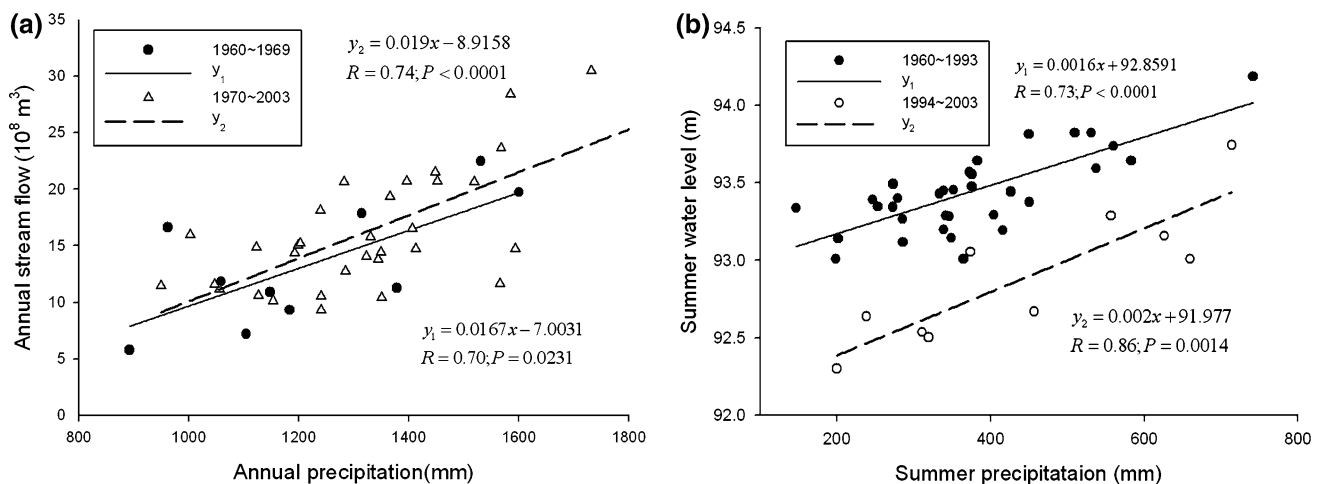


Fig. 6 Linear regression of (a) annual stream flow and annual precipitation; (b) summer water level and summer precipitation

were so small as to be negligible. However, during the affected period 1994 to 2003, human activities may have caused a water level decrease of 0.656 m per year. Precipitation increased water level by 0.106 m per year, but could not offset the effect of human activities. The linear regression relationship between summer water level and summer precipitation for periods 1960 to 1993 and 1994 to 2003 support this finding (Fig. 6b). The fitted line during the period 1994 to 2003 is below that during the period 1970 to 2003, suggesting the summer water level has decreased after 1993 due to the impact of human activities.

5.3 Potential human influences on the increasing stream flow and the decreasing water level

Although the increase in natural precipitation is the main and direct cause of the increasing in stream flow, the effects of human activities, especially water-related human activities on hydrology have been intensified in recent years with economic development and growing population.

In the Zhengshui River basin, the potential human influences can be summarized as follows:

(a) *Land use change.* Over the last 30 years, the land use has significantly changed due to increased anthropogenic pressure in the Zhengshui River basin. Based on the land use/land cover data (1:100,000-scale) for 1986, 1995 and 2005 obtained from the Data Center for Resources and Environmental Sciences Chinese Academy of Sciences (RESDC), we found that forest and arable land were the dominant land use types, accounting for more than 90% of the basin. Urban sprawl and increase in rural housing areas were obvious, especially the latter which increased from 30.16 km² in 1986, to 48.92 km² in 2005, an increase of 60%. Changes in main land use types in Zhengshui River basin are presented in Fig. 7. In these agricultural areas, water-related activities mainly refer to water extraction to satisfy irrigation needs. The increase in urban area and rural housing land at the expense of arable land and forest means less water is used for irrigation which leaves more water in the rivers, and also leads to less infiltration due to surface sealing, and consequently discharge is higher.

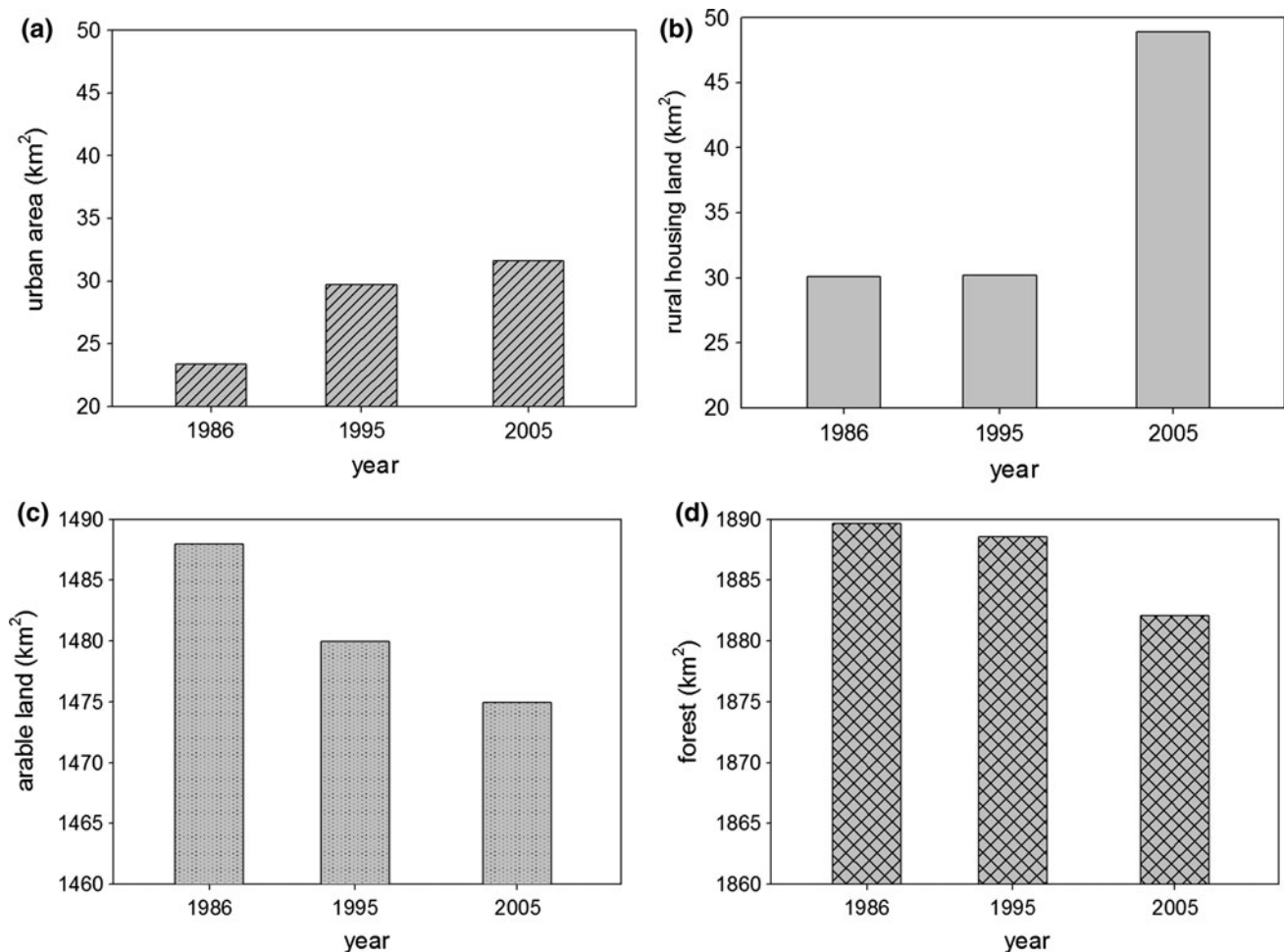


Fig. 7 Land use change in Zhengshui River basin in 1986, 1995 and 2005 (a) urban area (b) rural housing land (c) arable land (d) forest

(b) *Soil erosion.* The dominant soil type of the Zhengshui River basin is red soil with smaller areas of purple soil, and both of them account for 57.9 and 14.03% respectively (Liu 2002). These kinds of soils have poor water retention capacity. Once the vegetation cover was destroyed, the soil erosion would become more serious, especially in the rainy season. However, since the 1950s, the vegetation of the Zhengshui river basin has experienced three times serious damages due to some historical reason. The first time was during “the Great Leap Forward” period (1958–1960), only the destroyed tea area was up to 6,666 hm². The vegetation coverage in 1957 was 31.72%, but decreased to 23% by the year 1961. The second time was during the “Cultural Revolution” period (1966–1976), the large area of forest had been cut down, almost 89% primeval forest had been damaged. The third time was at the beginning of 1980s, a lot of short-sighted farmers only focused on grain production, which resulted in over reclamation and serious erosion of soil and water. Due to the destruction of forest, soil erosion area has been increased, which leads huge quantity of silt sediments to deposit in

rivers and reservoirs and promotes increased surface runoff and discharge.

(c) *Sand excavation.* To determine the causes of water level decrease, we conducted field surveys in the summer of 2008/2009. Through discussion with local representatives of government agencies and communities, we determined that highly in-channel sand dredging was the main reason for the decline of water level in Zhengshui River. Sand excavation activities emerged in the mid-1980s, and became widespread in the early 1990s. This was caused by rapid economic development in this region. Traditionally, in Zhengshui River basin there were three or four family generations living in the same house (so called “Si Shi Tong Tang”). With the introduction of a market-based economy, many farmers become affluent and began to prefer multi-functional, more comfortable and spacious houses (Long et al. 2007), which give rise to a construction boom for a number of years. In Hengyang County, the administrative unit of the Zhengshui River basin, the output of the construction sector has shown exponential growth in the last 10 years (Fig. 8). Sands excavated locally are the

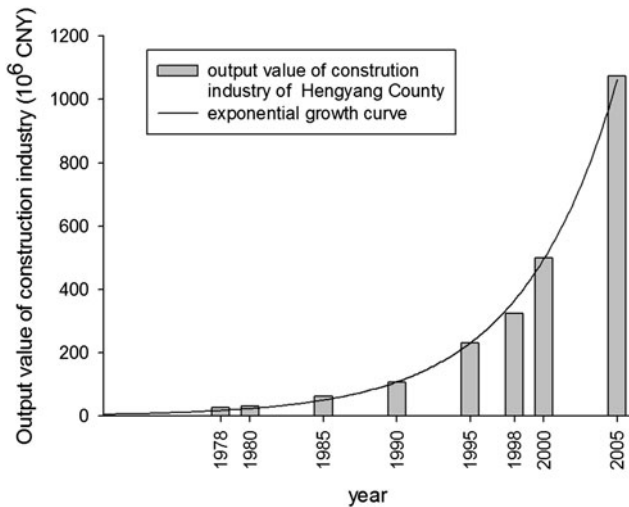


Fig. 8 Construction industry output value in the study area from 1978 to 2005

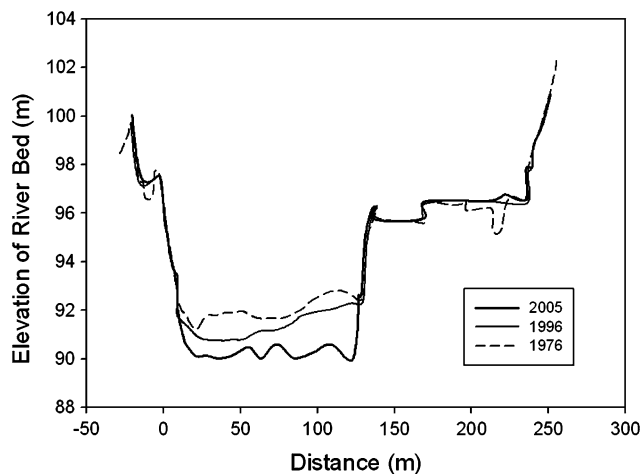


Fig. 9 Temporal changes in the river cross section at SST station most easily available and cheap materials for building houses. This market demand led to the creation of several small private enterprises which undertook illegal sand

excavation. During the second half of the 1990 s, sand dredging was so intense that almost all river channels in Zhengshui River basin were impacted. Sand dredging has caused many problems. For example, it has caused an unacceptable amount of bed degradation that has lowered the river bed. Fig. 9 shows that the river bed has lowered more than 2 m from 1976 to 2005. Figure 10a shows several large gravel mounds in the river channel formed by gravel dumping in the process of sand dredging, which block passage of the river channel. Moreover, local mining activities are polluting the Zhengshui River and putting in danger the health of thousands of people who depend on the river for their drinking water. The negative environmental influences have finally been recognised by governmental agencies, and authorities have issued successive policies to prohibit such activities within the Zhengshui River channel since 2002. Because of tightened control, the situation has changed significantly, but it is still difficult to eliminate such activities in the short term (Fig. 10b).

6 Conclusions

Several significant conclusions can be drawn from the analyses of the Zhengshui River basin. Stream flow increased significantly, including annual mean and maximum discharge, and several monthly and summer discharges, with an abrupt change point in 1990. Water level showed the most significant decreasing trends at most time scales, with an abrupt downward change point in 1995. Precipitation also had an increasing trend. However, the weak increasing precipitation trend was not sufficient to explain the observed change in discharge. This inconsistency identified in basin water discharge and water level suggests anthropogenic factors are the main reasons for the negative trend in water level.

Based on analysis of abrupt change points and the characteristics of double mass curves, the study period

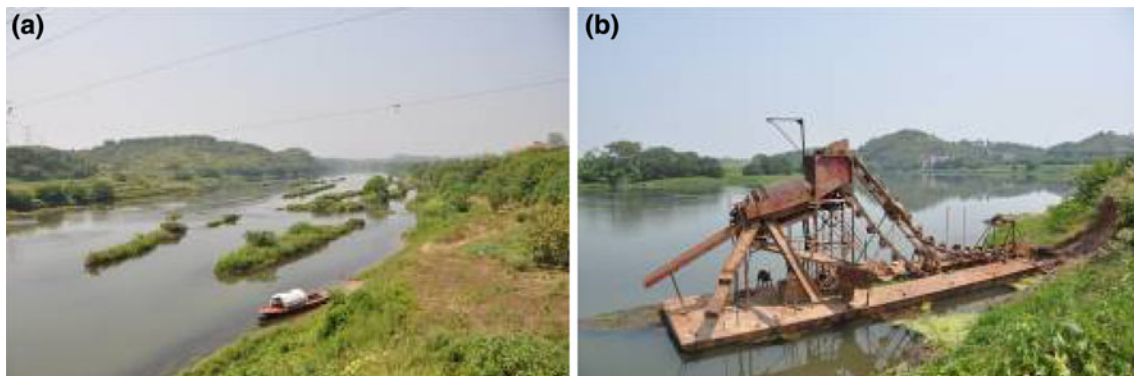


Fig. 10 Photographs of (a) large gravel mounds in Zhengshui River channel (b) sand dredging boat at Zhengshui River bank (photos taken by Fei He on 20th, August 2009)

1960–2003 can be divided into three stages. Taking the period 1960–1969 as the reference period, quantitative contributions of precipitation variation and human activities on stream flow and water level in affected periods were estimated using linear regression. During the period 1991–2003, contributions of increasing precipitation and land use change to the increasing discharge were 57 and 43%, respectively. During the period 1994–2003, human activities played a dominant role in decreasing water level. We consider sand dredging to be the main reason. This research indicated that hydrologic variables are more vulnerable to human activities than to climate change, due mainly to rapid economic development and population increase. For sustainable development of the entire Zhengshui River basin, reduction of human intervention, and balancing economic development and environmental protection, are of critical concern.

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References

- Becker S, Gemmer M, Jiang T (2006) Spatiotemporal analysis of precipitation trends in the Yangtze River catchment. *Stoch Environ Res Risk Assess* 20(6):435–444
- Brown AE, Zhang L, McMahon TA, Western AW, Vertessy RA (2005) A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *J Hydrol* 310(1–4):28–61
- Burn DH, Elnur MAH (2002) Detection of hydrologic trends and variability. *J Hydrol* 255:107–122
- Chen YL, Takeuchi K, Xu CC, Chen YP, Xu ZX (2006) Regional climate change and its effects on river runoff in the Tarim Basin, China. *Hydrol Precess* 20:2207–2216
- Chen YD, Zhang Q, Yang T, Xu C, Chen X, Jiang T (2007) Behaviors of extreme water level in the Pearl River delta and possible impacts from human activities. *Hydrol Earth Syst Sci Discuss* 4:4361–4378
- Cluis DA (1983) Visual techniques for the detection of water quality trends: Double-Mass Curves and Cusum Functions. *Environ Monit Assess* 3:173–184
- Gemmer M, Jiang T, Su BD, Kundzewicz ZW (2008) Seasonal precipitation changes in the wet season and their influence on flood/drought hazards in the Yangtze River Basin, China. *Quat Int* 186:12–21
- Hao XM, Chen YN, Xu CC, Li WH (2008) Impacts of climate change and human activities on the surface runoff in the Tarim River basin over the last fifty years. *Water Resour Manag* 22: 1158–1171
- Hirsch RM, Slack JR, Smith RA (1982) Techniques of trend analysis of monthly water quality data. *Water Resour Res* 18(1):107–121
- Huang MB, Zhang L (2004) Hydrological responses to conservation practices in a catchment of the Loess Plateau, China. *Hydrol Process* 18(10):1885–1898
- Huo ZL, Feng SY, Kang SZ, Li WC, Chen SJ (2008) Effect of climate changes and water-related human activities on annual stream flows of the Shiyang river basin in arid north-west China. *Hydrol Process* 22:3155–3167
- IPCC (2001a) Climate Change 2001: Impacts, adaptations, and vulnerability, contribution of working group to the third assessment report of the Intergovernmental Panel on Climate Change. IPCC, UNEP WMO, Arendal, Norway, Cambridge University Press
- IPCC (2001b) Climate change 2001b: Working Group I: the scientific basis, contribution of working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. IPCC, UNEP WMO, Arendal, Norway, Cambridge University Press, Cambridge, UK
- Kahya E, Kalayci S (2004) Trend analysis of streamflow in Turkey. *J Hydrol* 289(1–4):128–144
- Kendall MG (1975) Rank correlation methods. Griffin, London
- Labat D, Godd eris Y, Probst JL, Guyot JL (2004) Evidence for global runoff increase related to climate warming. *Adv Water Resour* 27:631–642
- Li LJ, Zhang L, Wang H, Wang J, Yang JW, Jiang DJ, Li JY, Qin DY (2007) Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China. *Hydrol Process* 21:3485–3491
- Liu LF (2002) A study on the vulnerability of agriculture drought disaster in Hengyang basin. *Trop Geogr (in Chinese)* 22(1): 19–23
- Long HL, Heilig GK, Li XB, Zhang M (2007) Socio-economic development and land-use change: analysis of rural housing land transition in the Transect of the Yangtze River, China. *Land Use Policy* 24:141–153
- Mann HB (1945) Nonparametric tests against trend. *Econometrica* 13:245–259
- Milly PCD, Wetherald RT, Dunne KA, Delworth TL (2002) Increasing risk of great floods in a changing climate. *Nature* 415:514–517
- Moraes JM, Pellegrino HQ, Ballester MV, Martinelli LA, Victoria R, Krusche AV (1998) Trends in hydrological parameters of a southern Brazilian watershed and its relation to human induced changes. *Water Resour Manag* 12:295–311
- Novotny EV, Stefan HG (2007) Stream flow in Minnesota: Indicator of climate change. *J Hydrol* 334:319–333
- Piao SL, Friedlingstein P, Ciais P, de Noblet-Ducoudr e N, Labat D, Zaehle S (2007) Changes in the climate and land use have a larger direct impact than rising CO₂ on global river flows. *Proc Natl Acad Sci* 104(39):15242–15247
- Sahagian D (2000) Global physical effects of anthropogenic hydrological alterations: sea level and water redistribution. *Glob Planet Change* 25:39–48
- Searay JK, Hardison CH (1960) ‘Double-mass curves’. U.S.G.S. Water supply paper 1541-B, 66 pp
- Tao FL, Yokozawa M, Hayashi Y, Lin ED (2003a) Changes in agricultural water demands and soil moisture in China over the last half-century and their effects on agricultural production. *Agric For Meteorol* 118:251–261
- Tao FL, Yokozawa M, Hayashi Y, Lin ED (2003b) Future climate change, the agricultural water resources, and agricultural production in China. *Agric Ecosyst Environ* 95:203–215
- Tao FL, Yokozawa M, Hayashi Y, Lin ED (2005) A perspective on water resources in China: interactions between climate change and soil degradation. *Clim Change* 68:169–197

- Vörösmarty CJ, Green P, Salisbury J, Lammers RB (2000) Global water resources: vulnerability from climate change and population growth. *Science* 289:284–288
- Zhang SR, Lu XX (2009) Hydrological responses to precipitation variation and diverse human activities in a mountainous tributary of the lower Xijiang, China. *Catena* 77:130–142
- Zhang YK, Schilling KE (2006) Increasing streamflow and baseflow in Mississippi river since the 1940s: effect of land use change. *J Hydrol* 324:412–422
- Zhang Q, Jiang T, Gemmer M, Becker S (2005) Precipitation, temperature and runoff analysis from 1950 to 2002 in the Yangtze basin, China. *J Hydrol Sci* 50(1):65–80
- Zhang Q, Liu CL, Xu CY, Xu YP, Jiang T (2006a) Observed trends of annual maximum water level and streamflow during past 130 years in the Yangtze River basin, China. *J Hydrol* 324:255–265
- Zhang Q, Xu CY, Becker S, Jiang T (2006b) Sediment and runoff changes in the Yangtze River basin during past 50 years. *J Hydrol* 331:511–523