Sediment and runoff changes in the Yangtze River basin during past 50 years

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Summary Annual runoff and annual suspended sediment loads of hydrological gauging stations along the mainstream of the Yangtze River basin (Pingshan station, Yichang station, Hankou station and Datong station) and main tributaries (Beipei station in Jialingjiang River, Wulong station in Wujiang River and Huangzhuang station in Hanjiang River) were analyzed with the help of Mann–Kendall trend analysis and linear regression analysis. Research results indicate that (1) changing patterns of runoff and sediment loads are different in different parts of the Yangtze River basin. No significant trend is detected for annual runoff at all stations at >95% confidence level. Changes of sediment loads, however, demonstrate different pictures in the Yangtze River basin. The sediment loads are in increasing trend in Pingshan station- the most upstream station on the Yangtze River basin (this increasing trend is significant at >95% confidence level after about 1990), but are in decreasing trend at other stations (including stations in the tributaries studied in this paper). This decreasing trend becomes more obvious from Yichang station to Datong station. (2) Water reservoirs exerted more influences on changes of sediment loads than on runoff, which is the main reason for the decreasing trend of sediment loads found in most stations. (3) Influences of water reservoirs on sediment loads are more obvious in the tributaries than in the mainstream of the Yangtze River basin, while in the mainstream the variation patterns of sediment loads are determined by multiple factors.

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KEYWORDS
Sediment load;
Runoff;
Mann–Kendall trend test;
Yangtze river basin

Introduction
Fluvial geomorphology is sensitive to climatic changes and human disturbance, and these changes alter the dynamic processes of the erosion and deposition of the fluvial system.
of the river channel (Xu and Sun, 2003; Brandt, 2000). Understanding of the sediment load and runoff changes will be greatly helpful for flood mitigation, river channel training and fluvial management.

More and more scholars draw increasing concerns on geomorphological response of river channels to the changes of sediment load and runoff. In the Rhone Valley (France), most channel changes have been characterized by channel in-filling which took place when sediment supply exceeded the river transport capacity (e.g. Bravard et al., 1997; Provansal et al., 2002; Arnaud-Fassetta, 2003). Goswami et al. (1999) suggested that modification of river channel appears to be initiated by the increase or decrease of either water or sediment load. Kondolf et al. (2002) contrasted changes in land use, bedload sediment load and channel response of the Pine Creek catchment of Idaho, USA (200 km²) and the Drôme catchment, France (1640 km²). They showed that, as for the Pine Creek catchment, hard-rock mining near the end of the 19th century, road construction, etc. resulted in increased bedload, leading to channel instability; as for the Drôme River catchment, reforestation, construction of dams reduced the erosion and led to reduction of the bedload sediment supply, which further decreased channel width and braided reaches.

Runoff and sediment load analyses of the Yangtze River basin have drawn considerable concerns from scientific community (Xu, 1996; Lu et al., 2003). Chen et al. (2001) analyzed annual mean discharge from Yichang, Wuhan and Datong stations with special focus on human influences on the discharge from the drainage basin to the sea during the dry season. They examined discharge variability and sediment flux of the Yangtze River basin based on hydrological data from three stations. Zhang and Wen (2004) analyzed sediment flux and annual runoff of the upper Yangtze River basin, showing that the sediment load has no visible trend, which may be due to the offsetting consequences of the sediment load changes in the two biggest tributaries (e.g. Jinsha River and Jialing River). Yang et al. (2002) analyzed sediment discharge and suspended sediment concentration (SSC) of two hydrological stations (Datong and Yichang stations) from 1951 to 2000 to show the variations in river sediment supply to the delta; possible human influences on sediment variations were also discussed in the study.

Previous studies analyzed sediment load and discharge variations of different parts of the Yangtze River basin and discussed the possible influences of human activities on variations of discharge and sediment load. However, they analyzed hydrological data from a small number of hydrological stations of the Yangtze River (e.g. Yang et al., 2002), or part of the Yangtze River basin (e.g. Lu et al., 2003; Zhang and Wen, 2004). Few studies were performed jointly on the sediment load and discharge flux of the whole Yangtze River basin. Furthermore, river dynamics have been significantly affected by human activities such as land use changes, urbanization, dam construction, gravel and sand mining. Since these disturbances cause substantial changes to the runoff and sediment regimes, at present few rivers are in a natural or semi-natural condition in China. At the same time, sediment load and runoff variations of the Yangtze River will exert direct influences on accretion/recession of the Yangtze Delta (Yang et al., 2003), which will be of profound significance for the social and economic development of the Yangtze Delta region. It is therefore desirable to study the variations of sediment load and runoff as well as their correlations at all major stations along the main stream and the major tributaries of the Yangtze River, and explore the possible causes of the variations.

In this paper, annual suspended sediment load (SY) and runoff from four stations along the main channel of the Yangtze River, i.e. Pingshan, Yichang, Hankou and Datong, and three stations from the main tributaries of the Yangtze River, i.e. Beipei, Wulong and Huangzhuan (Fig. 1) were used to perform the study. Four stations along the mainstream of the Yangtze River basin are the main hydrological measurement stations. Almost all the water reservoirs in the Yangtze basin are located in the tributaries. Up to the end of 1980s, 11931 water reservoirs were constructed in the upper Yangtze River basin, with a total storage of $2.05 \times 10^{10}$ m³, of which 1880 water reservoirs in the Jinhaijiang River with a total storage of $2.813 \times 10^9$ m³, 4542 water reservoirs in the Jialingjiang River with a total storage of $3.61 \times 10^9$ m³, and 1630 water reservoirs in the Wujiang River with a total storage of $4.406 \times 10^9$ m³ (Xu, 2005). Only the Three Gorges Dam (the construction was started in 1993 and will be completed in 2009 with a total storage of $3.93 \times 10^{10}$ m³) and Gezhoubia dam (the construction of Gezhoubia Dam started in 1970 and the operation started in earlier 1980s with a total storage of $1.58 \times 10^9$ m³) are located in the mainstream. Therefore, three stations along the tributaries are studied for possible human impacts on sediment load and runoff changes.

The objectives of this paper are (1) to detect the trend and the correlations of runoff and sediment flux of the Yangtze River basin; (2) to explore and discuss the possible influences of human activities and climatic variability on runoff and sediment load of the Yangtze River basin.

**Data and methods**

**Data preparation**

Hydrological data of annual runoff and suspended sediment load of Pingshan, Yichang, Hankou and Datong stations along the mainstream of the Yangtze River, and annual runoff and suspended sediment load from Beipei, Wulong and Huangzhuan stations in the main tributaries of the Yangtze River basin were taken from the Changjiang Water Resources Commission, China (CWRC, 2000a,b). The sediment load data used in this paper refer to the suspended sediments. Sediment concentrations were collected on a monthly basis using equal width increment sampling and yields were determined using the relationship between runoff and sediment concentration. The locations, the drainage areas and the data periods of the stations are presented in Fig. 1 and Table 1. The homogeneity and reliability of the data have been checked and firmly controlled by CWRC before the data were released. The data series used in this study are in good consistency and with no missing data. The data are not published, but they are printed and issued for internal use in relevant institutions such as research institutes and universities (e.g. Zhang and Wen, 2004; Chen et al. (2001)). Serial correlation analysis was performed in
this study on all the data series for modified Mann–Kendall trend test.

**Methodology**

Two methods, namely, simple linear regression and Mann–Kendall trend test are used in the current study to detect trend and test its significance for the annual runoff and sediment loads of the Yangtze River basin. Each method has its own strength and weakness, the results of these two methods can complement each other as will be shown in the following section. The simple linear regression method, the parametric \( t \)-test is powerful in testing the significance of the long-term linear trend, while the Mann–Kendall test can show detailed changing trends of different periods in the analyzed time series and does not require the data to be normally distributed. The simple regression method consists of two steps, fitting a linear simple regression equation

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**Table 1** Detailed hydrological record of stations along the tributaries and mainstream of the Yangtze River basin

<table>
<thead>
<tr>
<th>Station name</th>
<th>Drainage area (km²)</th>
<th>Time Interval Runoff</th>
<th>Time Interval SL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stations along the tributaries of the Yangtze River</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Stations along the mainstream of the Yangtze River</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Datong station</td>
<td>1,705,383</td>
<td>1953–2000</td>
<td>1953–2000</td>
</tr>
</tbody>
</table>
with the time \( t \) as independent variable and the hydrological variable, \( Y \) as dependent variable, and testing the statistical significance of the slope of the regression equation. The parametric \( t \)-test requires the data to be tested is normally distributed. The normality of the data series is first tested in the study by applying the Kolmogorov–Smirnov test (Xu, 2001). The method first compares the specified theoretical cumulative distribution function with the sample cumulative density function based on observations, then calculates the maximum deviation, \( D \), of the two. If, for the chosen significance level, the observed value of \( D \) is greater than or equal to the critical tabulated value of the Kolmogorov–Smirnov statistic, the hypothesis of normal distribution is rejected.

The rank-based Mann–Kendall method (MK) (Mann, 1945; Kendall, 1975) is a nonparametric and commonly used method to assess the significance of monotonic trends in hydro-meteorological time series (e.g. Yue and Pilon, 2004). This test has the advantage of not assuming any distribution form for the data and has the similar power as its parametric competitors (Serrano et al., 1999). Therefore, it is highly recommended for general use by the World Meteorological Organization (Mitchell et al., 1966). In this study, the Mann–Kendall test procedure follows Gerstengarbe and Werner (1999) who used the method to test an assumption about the beginning of the development of trend within a sample. The Mann–Kendall test procedure as shown in Eqs. (1)–(5), the statistic variables, \( dk \), \( E(dk) \), \( \text{Var}(dk) \), and \( Z_k \) will be calculated for the retrograde sample. The \( Z \) values calculated with progressive and retrograde series are named \( Z_1 \) and \( Z_2 \), respectively, in this paper. The intersection point of the two lines, \( Z_1 \) and \( Z_2 \) (\( k = 1, 2, \ldots, n \)) gives the point in time of the beginning of a developing trend within the time series. The null hypothesis (the sample is not affected by a trend) must be rejected if the intersection point is significant at 5% significant level (i.e. outside the 95% confidence interval).

The influence of serial correlation in the time series on the results of MK test has been discussed in the literature (e.g. von Storch, 1995; Yue et al., 2002). In this study, before the MK test was applied, the runoff and sediment load series were tested for persistence by the serial correlation analysis method presented in Haan (2002) by using the following equation:

\[
\rho_m = \frac{\text{cov}(X_t, X_{t+m})}{\sqrt{\text{Var}(X_t)} \sqrt{\text{Var}(X_{t+m})}}
\]

where \( X_t \) \((t = 1, 2, \ldots)\) is the tested time series; \( X_{t+m} \) is the same time series with a time lag of \( m \); \( \overline{X} \) is the mean of the time series. The equation shows that \(-1 < \rho < 1\). If \( m = 0 \) then \( \rho = 1 \). For a purely random (stochastic) series, \( \rho_m \approx 0 \) for all \( m \neq 0 \). If the series of \( \rho_m \) (for \( m \neq 0 \)) falls between the 95% confidence level calculated by \( \frac{\sigma}{\overline{z}} = (-1 \pm z_{1-\frac{1}{2}} \sqrt{n - 1})/(n - 1) \) \((n \) is the length of the tested time series, \( 1 \) and \( u \) are the lower and upper limits, \( z \) is the significance level, 5% in this case, \( z \) is the critical value of the standard normal distribution for a given \( z \)), the tested series is an independent series at 95% confidence level. The serial correlation analysis was performed on all annual sediment and runoff series of the stations in this paper. The results (not shown) indicated that almost all series of runoff and sediment load of the stations used in this study are statistically independent processes. Only the data sets of sediment load of Hankou and Datong stations have significant serial correlation at lag 1. Therefore, we limit the effect of serial correlation on MK test based on the methods of Yue and Wang (2004) by modifying the variance \( V(S) \) to \( V'(S) \). The modified variance \( V'(S) \) is given as \( Yue \) and \( Wang \) (2004): \( V'(S) = V(S) \times \phi^{-\frac{1}{2}} \), where \( V(S) \) is the original MK variance and \( n \) is the actual size of sample, \( n^* \) is given as:

\[
n^* = \frac{n}{1 + 2 \sum_{m=1}^{n/2} (1 - \frac{1}{z})^{m}}
\]

where \( \rho_m \) is the lag-\( m \) serial correlation coefficient of the actual time series with linear trend eliminated and can be calculated using Eq. (6).

Results

The results are first presented for individual stations in tributaries and then for individual stations in the mainstream of the Yangtze River basin. The common and unique features are discussed thereafter.
Stations along the tributaries

Beipei station
The results of MK trends of sediment load and runoff changes of Beipei station in Jialingjiang River are shown in Fig. 2. It can be seen that during 1960–1970 the sediment load of Beipei station is in increasing trend (but not significant at >95% confidence level); after 1970 the sediment load is in decreasing trend and after 1990 this decreasing trend is significant at >95% confidence level. Deforestation as a result of large-scale social and economic development and exploitation began in about 1958 led to the increase of sediment load in the Jialingjiang and Minjiang River catchments, after about 1968, construction and operation of the water reservoirs exerted tremendous influences on sediments transportation (Xu, 2000). Different influences from human activities during different periods were reflected by the changes of the sediment load as can be seen from Fig. 2. Up to 1980s, 4542 water reservoirs were constructed in the Jialingjiang River catchment with a total storage of about $3.61 \times 10^9$ m$^3$ (Xu, 2005), large amounts of sediments were stored in these water reservoirs. The deforestation in the Jialingjiang River catchment was serious before 1958, leading to increasing sediment loads, after the end of 1960s, water reservoirs (e.g. Bikou water reservoir in Jialingjiang River) started their operation (Xu, 2000), hindering large amount of sediments. The decreasing runoff of Beipei station is mainly the result of decreasing precipitation after about 1970 (Zhang et al., 2005). The annual runoff at the station is mainly following the variations of the precipitation in the catchment. Upper reaches of the Jialingjiang River basin is dominated by decreasing precipitation trend during 1970–1975 (Su et al., 2005; Zhang et al., 2005), leading to the decrease of runoff, which, to some extent, also contributed to the decreasing trend in sediment load in the period. The correlation between runoff and

Figure 2  The results of MK trend test, linear regression analysis and correlation of sediment load (SL) and annual runoff of Beipei station.
sediment load is good for Beipei station, partly due to both series have a decreasing trend although with different significance level.

**Wulong station**

In the case of Wulong station (Fig. 3), the sediment loads and runoff demonstrate different changing patterns if compared to those of Beipei station. The sediment load is in decreasing trend during 1960–1970 and 1990–2000; but is in increasing trend during 1970–1990 (not significant at 95% confidence level), showing complex changing characteristics. The runoff of Wulong station is in increasing trend (not significant at >95% confidence level) because of an increasing precipitation trend (Zhang et al., 2005), while the sediment load is decreasing as a result of operation of water reservoirs, leading to a less good correlation between runoff and sediment load \( (r = 0.67) \) as compared with that of Beipei station. It should be noted that the sediment load at Wulong is 2 orders of magnitude lower than in other stations (see the following sections), which is due to its much smaller catchment area as compared with other river catchments studied in this paper (Table 1). Up to 1980s, there were about 1630 water reservoirs constructed along the Wulong River with a total storage of \( 4.406 \times 10^9 \text{ m}^3 \) (Xu, 2005). Smaller catchment area and large amounts of water reservoirs combined to lead to less sediment loads than other tributaries mentioned in this paper. Furthermore, the runoff increase compensated to some extent the sediment load decrease caused by operation of water reservoirs, which led to a mild decreasing trend in sediment loads as compared with that of Beipei station.

**Huangzhuang station**

The changes of sediment load and runoff of Huangzhuang station, Hanjiang River are shown in Fig. 4. Hanjiang River

![Figure 3](image-url) "The results of MK trend test, linear regression analysis and correlation of sediment load (SL) and runoff of Wulong station."
was used as a good exemplification showing the human impacts on sediment load and runoff changes of the river system (Xu, 2000). The construction of the Danjiangkou water reservoir (the total storage is $2.097 \times 10^{10}$ m$^3$) was completed in 1959 and started its operation thereafter. It can be seen from Fig. 4 that the sediment load was much reduced immediately after the construction was completed and the operation of the Danjiangkou water reservoir, and after 1970 when the reservoir was in full operation this decreasing trend is significant at >95% confidence level. In the case of runoff changes of Huangzhuang station, the runoff is in a mild decreasing trend (not significant at 95% confidence level) because of the decreasing precipitation in the upper Hanjiang River basin (Su et al., 2005; Zhang et al., 2005). Correlation between sediment load and runoff is not good in comparison with that of Beipei and Wulong stations, showing the prominent influences of water reservoir on sediment load, which, to a large degree, decreased the discharge of sediment load to the downstream of Hanjiang River. Furthermore, decreasing precipitation is another less important reason for decreasing production of sediment load in the Hanjiang River catchment (Zhang et al., 2005).

**Stations along the mainstream**

**Pingshan station**

Fig. 5 shows that before 1985 the sediment load of Pingshan station has no obvious changes, and after 1985, however, the sediment load is in increasing trend. After 1995 this increasing trend reaches 95% confidence level. Linear regression indicates that the long-term linear increasing trend is not significant at >95% confidence level ($p = 0.11 > 0.05$). Furthermore, sediment load variations in the Pingshan station follow quite well the changes of annual runoff and do not show an obvious influence of water reservoir on changes of sediment loads as compared with other stations studied in this paper. Runoff changes of Pingshan station show a mild increasing trend (not significant at
>95% confidence level and \( p = 0.29 > 0.05 \) for linear trend). Pan (1999) indicated that the mean sediment loads during the flooding season (June–October) account for about 95.4% of the annual sediment load and that during July to September account for about 76.8% of the annual sediment load. Serious soil erosion will be responsible for obvious increasing sediment load in the Jinshajiang River (Pingshan station). The summer precipitation of parts of the area in the upstream of Pingshan station is increasing but not significant at >95% confidence level. The rainstorm in the southwest of Yangtze River basin is in increasing trend at >90% confidence level (Su et al., 2005), which is also one of the factors responsible for increasing sediment load. Furthermore, the riverbed slope of the upper reaches of the Yangtze River basin, especially Jinshajiang River is large. This region is densely populated with a heavy economic exploitation, like mineral mining and deforestation, leading to serious soil erosion (Pan, 1999). This is one of the reasons that the changing trend of sediment load is more significant than runoff in Pingshan station. Good correlation occurred between runoff and sediment load of Pingshan station, showing the important role of water discharge in sediment transportation in this region.

**Yichang station**

Fig. 6 shows that the sediment load of Yichang station is in increasing trend (not significant at >95% confidence level) before about 1975, and after 1975 the sediment load is in decreasing trend (not significant at >95% confidence level); the linear regression analysis shows that the sediment load is in decreasing trend (not significant at >95% confidence level as \( p = 0.09 > 0.05 \)), showing different changing patterns of sediment load in comparison with Pingshan station. The MK analysis of sediment changes of Yichang station shows that the jump time (intersect point of \( Z_1 \) and \( Z_2 \) line) lies during 1986–1988. The Gezhouba Dam (the total storage is \( 1.58 \times 10^9 \text{ m}^3 \)) started its operation at 1981–1986, corresponding well to the jump time of sediment load changes. Sediment changes of Yichang station also show that after about 1981–1986 the sediment load has a continuous decreasing trend (but not significant at >95% confidence level) except in 1998 which is a very wet year causing serious

**Figure 5** The results of MK trend test, linear regression analysis and correlation of sediment load (SL) and runoff of Pingshan station.

\[ y = 0.02x - 28.12 \quad n = 45 \quad p = 0.11 \]

\[ y = 2.83x - 4178.78 \quad n = 45 \quad p = 0.29 \]

\[ y = 0.003x - 1.51 \quad n = 45 \quad r = 0.79 \]
floods in several areas in the Yangtze River basin. Both the MK analysis and the linear regression analysis show the annual runoff has no obvious trends ($p = 0.53$ in linear regression analysis). Previous research results (Su et al., 2005; Zhang et al., 2005) indicated that the upper reaches of Minjiang, Jialingjiang and Hanjiang River catchments were dominated by a decreasing precipitation trend and upper Wujiang River was dominated by an increasing precipitation trend; the offset of precipitation led to no obvious trend of runoff changes of Yichang station. The Gezhouba Dam has no influence on annual runoff changes but exerted tremendous impacts on sediment loads, by holding large amounts of sediments in the water reservoir. Earlier research results (Chen and Huang, 1991) indicated that the annual sediment loads before the operation of Gezhouba Dam (1973–1978) of Yichang station is 8,780,000 tons/year and this number reduced to 1,440,000 tons/year after the operation of Gezhouba Dam in 1984, leading to a serious down-cutting of the river channel downstream of Yichang station. The correlation between annual runoff and sediment load is less good ($r = 0.69$) in comparison with that of Pingshan station ($r = 0.79$), which is an indication of the Gezhouba Dam has largely decreased the transportation of sediment loads and has no influence on runoff changes.

**Hankou station**

Fig. 7 shows that the sediment load of Hankou station is in increasing trend during 1955 and 1985 (not significant at >95% confidence level), during 1985 and 2000, however, the sediment load is in decreasing trend, which, after 1998, is significant at >95% confidence level. The changing patterns of the sediment load in Hankou station are determined by the combined effect of the following factors. (1) The operation of Gezhouba Dam started in middle 1980s reduced the sediment in the mainstream of the Yangtze River basin, (2) the decreasing sediment loads in Hanjiang River due to the operation of Danjiangkou reservoir also reduced the sediment at Hankou station, (3) the river reach between Yichang and Hankou is the transitional zone from mountainous area to plain area, and the riverbed slope is decreased greatly, which is largely beneficial for sediment deposition in the river channel, and (4) Dongting lake has also adopted a certain amount of sediments. In the case of annual runoff of Han-
kou station, it is in decreasing trend during 1955–1960, and after 1960 the annual runoff of Hankou station is in slightly increasing trend (not significant at >95% confidence level). Linear regression analysis shows the annual runoff has no trend ($p = 0.86$) of. Fig. 7 shows a poor correlation between runoff and sediment load of Hankou station ($r = 0.08$). The reason is that the sediment load is in significantly decreasing trend ($p = 0.001$) due to the factors discussed above and the annual runoff has no trend.

Datong station

Fig. 8 shows that, after 1970, the change of the sediment load of Datong station is dominated by a decreasing trend, and after about 1990 this decreasing trend is significant at >95% confidence level. The linear regression analysis result of the sediment load also indicates the significant decreasing trend ($p < 0.0001$). No large tributaries are available between Hankou and Datong stations (Fig. 1). The changing patterns of sediment and annual runoff show a similar picture as in Hankou station. Poyang Lake adopted a certain amount of sediments, together with the storage effect of the river channel on sediments, made the decreasing trend in sediment loads stronger than in the Hankou station. The annual runoff of the Datong station is in decreasing trend during 1955–1965, but is in increasing trend during 1990–2000 (not significant at >95% confidence level) which is quite similar as in Hankou station. Fig. 8 shows a poor correlation between runoff and sediment load ($r = 0.19$) which is also similar to that of Hankou station as expected.

Discussions and conclusions

Human activities exerted increasing impacts on natural process of input and output of the sediments over time and along the flow directions in the Yangtze River basin as a fluvial system. Research results of this paper have demonstrated that human activities (deforestation, dam construction and operation, etc.) exert more influences on sediment loads than on annual runoff. The variation of the annual runoff is mainly controlled by climate variability
(i.e. precipitation variations). Up to the end of 1980s, 11,931 water reservoirs were constructed (all kinds of water reservoirs without considering their size, storage and functions) in the upper Yangtze River basin with a total storage of $2.05 \times 10^{10}$ m$^3$ (Xu, 2005), and most of them are located in the tributaries. Water reservoirs in the tributaries stored large amounts of sediments, reducing very much the downstream discharge of sediments (e.g. Huangzhuang station). The reduced rainfall/runoff may, to a less degree, have been responsible for reduced sediment load at Beipei and Huangzhang stations. In the mainstream however, influences from climatic changes (precipitation), sedimentary-deposition–transportation process of sediments along the river channel, different changing patterns of sediment loads and water discharge from different tributaries combined to make sediment load and runoff changes more complicated in comparison with those in the tributaries of the Yangtze River basin. As presented in the result section, the changing pattern of sediment in mainstream station is determined by several factors, including the operation of Gezhouba Dam in the mainstream, operation of reservoirs in the tributaries, changing slope of the river bed, and the effect of large lakes, etc.

Earlier study suggested that the river suspended sediments are mainly from the upper Yangtze River basin (Pan, 1999), the sediments from Jinshajiang River alone accounts for about 39.4% of that in Yichang station (Xu, 2005). Over-exploitation in the upper Yangtze basin led to an increasing trend of sediment load in the Pingshan station (Pan, 1999). Though the sediment load in Pingshan station is in increasing trend, greatly reduced sediment load from the tributaries because of construction of water reservoirs, and also impacts from Gezhouba dam on sediment loads led to a reduced sediment load in the Yichang station.

The annual runoff of Hankou station is in slightly increasing trend (not significant at >95% confidence level), while the sediment load is in an even stronger decreasing trend in comparison with that of Yichang station. As discussed in the result section, there are multiple factors to determine the changing pattern of sediment load at Hankou station. The impacts from Dongting water system is one of the important factors in this reach of the river. Research (Wang et al., 2000) indicated that during 1949 to present, the accumulative sediment deposition in the Dongting Lake region will exceed 40 hundred billion tons, reducing the volume of Dongting Lake from 293 hundred billion cubic

Figure 8  The results of MK trend test, linear regression analysis and correlation of sediment load (SL) and runoff of Datong.
influences on flood mitigation in the middle and lower Yangtze and filling of the river channel, which will exert direct changes of the sediment load will directly impact the scour-Delta (Yang et al., 2003). Furthermore, spatial and temporal the geomorphological evolution of the river channel of the discharge of the sediment load, which will further impact of water reservoirs or dam greatly reduced the downstream changes are drawing more and more concerns from aca-
dam construction, sand mining, deforestation/forestation. Therefore, land use and land coverage changes are drawing more and more concerns from academic circles as one of the important factors influencing flood hazards and river channel evolution (e.g. Kondolf et al., 2002; Crooks and Davies, 2001). The under constructed Three Gorges Dam (the construction was started in 1993, and will be completed in 2009, the total storage is $3.93 \times 10^{10}$ m$^3$) will further alter the spatial and temporal changes of sediment loads and runoff changes. Construction of water reservoirs or dams greatly reduced the downstream discharge of the sediment load, which will further impact the geomorphological evolution of the river channel of the middle and lower Yangtze River basin, and will also exert tremendous influences on the development of the Yangtze Delta (Yang et al., 2003). Furthermore, spatial and temporal changes of the sediment load will directly impact the scouring and filling of the river channel, which will exert direct influences on flood mitigation in the middle and lower Yangtze River basin.

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