Impacts of Human Activities in the Hanjiang River Basin, China

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ABSTRACT


The eastern part of China has a large number of rivers. Humans have a long history of development of rivers, and human activities have a strong impact on rivers. The major impacts are the construction of reservoir dams and river sand excavation. In this study, the Hanjiang River located in the southeast of China's Guangdong Province was chosen as a representative site to study the effects of dams and sand mining on rivers. For dams, the main research is on the impact of dams on the river flow and sediment processes. A comparative analysis of long-term sequence hydrological data before and after the dam construction at the Chaoan Hydrometric Station indicates that dams have a significant effect on sediment reduction. Based on the analysis of the annual average water level data of the long-term sequence at the Lihuang hydrological station, the multi-year average water level in the middle river decreased by 1.91 m mainly because of the sand mining. The results of the studies on river sand mining have shown that excessive sand mining caused serious downcuts and water level drop in the middle and lower Hanjiang River, especially in the lower river. Dams and river sand mining will change the water and sand balance of the river, affecting the stability of the river course and river regime. These results can be used as a reference for scientific and rational water conservancy project construction, ecological restoration and protection, rational development, and management decisions for rivers in eastern China.

ADDITIONAL INDEX WORDS: Dams, sand mining, annual precipitation, annual sediment load, multi-year average water leve, double mass curve, the Hanjiang river.

INTRODUCTION

The eastern part of China is densely populated and has a lot of rivers with various sizes. Humans have a long history of river development and utilization in the area, especially since China reform and opening up, people have greatly intensified their river development activities. The main human activities include construction of reservoir dams from upstream to downstream, river sand mining, and river channelization, but major impacts are the construction of reservoir dams and river sand mining.

In river ecosystems, hydrological runoff is the main driving force. In water conservancy planning, flood prevention and mitigation, water resource utilization, and ecological and environmental protection, the changes in the river water and sand are the main factors that must be considered (Hu et al., 2008). Dams will inevitably affect the runoff and sediment transport processes in rivers. The impacts of dams have been investigated in detail, especially the impacts of dams on the water and sediment process (Mohammad, Zahra, and Mohammad, 2014; Gao et al., 2015; Khan, Daitiari, and Chakrpani, 2016; H.F. et al., 2018; Li et al., 2018; Fakira and Equeenuddin, 2016; Guo, Yu, and Gao, 2018). The variations in water discharge and sediment load are mainly affected by climate change and human activities (Zhao, Zou, and Liu, 2017). Anthropogenic effect on water discharge and sediment load mainly include land use and constructions of dams. In China, research in this aspect was mainly directed to large rivers such as the Yellow River and the Yangtze River, and there are a few studies on small and medium-sized rivers due to incomplete hydrological data or other reasons. Water and sand discharge in the Hanjiang River Basin have also been studied (Guo et al., 2018; Zhao et al., 2015; Yang et al., 2018; Gao et al., 2015).

River sand is an important part of the riverbed and is the material basis for river stability, water and sand balance, and it is also a natural resource with great economic value. It is widely used as building sand and stone material, and land filling. Through the erosion, transport, and accumulation of flowing water, sediments erode in the upper reach of river basin and accumulate in the middle and lower reaches of the river and some of them enter the ocean. After a long period of natural evolution, the river itself can maintain dynamic sediment balance and river regime stability. The rivers in the middle and lower reaches, especially the lower reaches of the river, have a lot of stagnating conditions in a year. The gravel that has been deposited in the river for many years can be moderately mined, and there will be no negative impact on river safety. However, with the development of the economy, the demand for sand is increasing rapidly, and the price of river sand continues to rise, leading to a serious disorder in sand mining. There has been frequent chaos of indiscriminate sand mining in China.

A lot of research has been also carried out on river sand mining (Chen, Zhang, and Mu, 2005; Ramachandra, Vinay, and...
Chandran, 2017). Out-of-order sand mining can change the river flow path, disproportionate flow and water distribution, and lower the average riverbed elevation and water level (Brendan, Yuill, and Mead, 2016).

Both dams and sand mining may significantly decrease the sediment discharge from upstream. Under the new hydrodynamic conditions, the riverbed topography will be readjusted so that some sediment from the upstream will be deposited on the riverbed, decreasing the sediment discharge to the estuary. In the Yangtze River, sand mining is likely a minor factor in the decline of suspended sediment discharge to the sea compared to dam construction and soil conservation (Du, Yang, and Feng, 2016). Dams and excessive sand excavation will destroy the natural riverbed structure (Mingist, and Gebremedhin, 2016), change the normal material transport process, erosion and deposition regularity of the river course, interfere with the natural evolution of the river, and not only affect the stability of the river regime, flood and navigation safety, but also affect wading buildings and river ecosystems security (Tang et al., 2011; Sreedharan et al., 2011; Jia et al., 2007).

The Hanjiang River Basin is located in the east of Guangdong Province and southwest of Fujian Province and is densely populated. It has a total length of 470 km and a drainage area of 30112 km². People have carried out various transformations and developments of rivers, including a large number of reservoirs in the upstream area, tide-block dams on the downstream tributaries, and several large-scale water conservancy projects in the middle and lower mainstream of the river. In addition, river sand mining is very common in the entire basin. The humans have intervened in various ways in the Hanjiang River, but main impacts are the construction of dams and river sand mining similar to other rivers in the southeastern part of China. Since the situation of the Hanjiang River is very common in the southeastern part of China, the Hanjiang River was selected as the representative of rivers in the eastern region to investigate the impacts of dams and sand mining. The research results can be used as a reference for scientific and rational water conservancy project construction, ecological restoration and protection, rational development and management decisions for the rivers in the eastern part of China.

STUDY AREA

The Hanjiang river is made up of the Mei River (or Meijiang river) and the Tingjiang river, with the Mei river as the mainstream. The Mei River originates in the Zijin County, Guangdong Province, passes from southwest to northeast, and converges with the Tingjiang River at Sanheba in the Dapu County. Afterwards, it is called the Hanjiang river, then it turns to south and enters the South China Sea at Shantou City (Figure 1). The downstream of the Hanjiang River from Chaohou Station is a river network delta and divided into the Dongxi, Xixi, and Beixi Rivers to the South China Sea. The Xixi River is also divided into the Meixi, Xinjin, and Waisha Rivers at Danjiayuan. The catchment area of the Hanjiang river basin is 30112 km². Among them, there is 11802 km² in the Tingjiang river basin, 13929 km² in the Mei river basin, 3,346 km² in the catchment area between Sanheba to Chaohou hydrological stations, and 1,035 km² in the downstream from Chaohou hydrological station (Hanjiang river delta).

The Hanjiang River basin is located between longitudes 115°13'-117°09'E and latitude 23°17'-26°05'N. The topography of the basin is tilted from the northwest and northeast to the southeast, with an elevation of 20 to 1 500 m. The basin is characterized by hills and mountains. The mountains account for 70% of the total drainage area with a general elevation above 500 m, mostly in the northern and central parts of the basin. The hills account for 25% and are mostly distributed in the Mei River basin and other main and tributary valleys. The hills in the basin generally have an elevation of less than 200 m above sea level; the plains account for 5% with elevation generally below 20 m, mainly in the Hanjiang River delta.

The rainfall in the river basin is abundant. According to the statistical data from various stations within the river basin, the average annual rainfall is between 1450 to 2000 mm, and the average annual rainfall at Chaohou station is 1610 mm, but the distribution is not uniform during a year, and flood season is from April to September, accounting for about 80% of the annual rainfall. Precipitation is affected by the topography, and its distribution increases from the coast to the north, but it gradually decreases toward the northwest after crossing the Lotus Mountain.

There are a lot of small or middle size reservoirs, which had been built in the upper reaches of the river and tidal gate built on all tributaries to the sea in the lower reaches before 1990. In recent years, large dams began to built, and three large dams have been built on the 107 km main stream of the Hanjiang River. Dongshan Water Control Project is a large water control dam, built on the mainstream of the Hanjiang River and located in the upstream in Fengshun County, Guangdong province (Figure 1). The project invested 980 million yuan, with a total installed capacity of 75 MW. The project was officially started on September 1, 2006 and completed and put into operation in December 2010. Chaozhou Water Control Project is another large-scale water conservancy project built and put into operation almost simultaneously with the Dongshan Water Control Project. It is located on the main stream downstream of the Chaohou Station, with much larger scale. The third large-scale dam located on the main stream upstream of the Dongshan Water Conservancy Project is the Gaopi Water Conservancy Project finished in 2018.
Since China reform and opening up, urban construction has developed rapidly, and the amount of sand used for infrastructure construction has rapidly increased, which in turn has intensified sand mining activities in the Hanjiang River. The dredging of sand started from the Meixi, Xinjinhe, and Xixi River in the downstream in Shantou city to the Xiangziqiao river section in Chaozhou city. The statistics in 1996 showed that about $150 \times 10^4$ m$^3$ of river sand was excavated from the Hanjiang River in the Chaozhou area and an average of $200 \times 10^4$ m$^3$ in the river network delta every year.

At present, sand mining in the lower reaches of the Hanjiang River has restricted, but that in the middle and upper reaches is still very common, and the middle is particularly rampant (Figure 2a).

**Figure 1.** Location of the study area and related gauging stations and dams.

**Figure 2a.** A scene of a large number of sand transporters gathered together in the upper stream of the dam of Dongshan Water Control Project in the middle Hanjiang River to wait for going through the lock.

**Figure 2b.** A scene of greatly reduced river water in the downstream of dams in the upper Hanjiang River.

**Figure 2c.** A scene of exotic species water hyacinth growing wildly in the upper Hanjiang River.

**Figure 2d.** A large amount of garbage accumulated in the upper reservoir area of the dam of Dongshan Water Control Project in the middle Hanjiang River, and some of the garbage surface even has growth of vegetation (at the left top of the image).

Chaoan, Liuhuang, and Sanheba hydrological stations were selected as the study stations; the Chaoan station is the unique station with complete hydrological data in the basin, and the Liuhuang and Sanheba stations are the only water level stations. The upstream of the Sanheba station is the upper reaches of the Hanjiang River and Sanheba to the Zhugan Mountain near the Chaoan Hydrological Station are the middle reaches, and below are the lower reaches. The length of the middle reach is 107 km, and the Liuhuang water level station is 71 km from its upstream Sanheba Station and 36 km from its downstream Chaoan Station (Figure 1).

**DATA AND METHODS**

**Data Collection**

The main considerations of this study are the effects of reservoir dams in the middle and upper reaches on the sediment and water processes. The Chaoan Hydrometric Station located at the mid-downstream junction was selected as the research site, and its hydrological data were used for this study. The data used...
include annual runoff ($10^6$ m$^3$), annual sediment transport ($10^7$ t), and basin annual precipitation (mm). All the data in this study are taken from the "Hydrological Yearbook of the People’s Republic of China."

A total of 44-year observation data were collected from the Chaoan Hydrometric Station from 1954–1987 and 2006–2015. The 1988–2005 data were missing or could not be observed. In the 1980s, although a number of small and medium-sized reservoirs were built in the upper reaches of the Hanjiang River, their impacts on the runoff of the Hanjiang River was relatively slight, and many large and medium-sized reservoirs did not start operating until after 2005. Therefore, the difference in the intensity of the construction of dams between the years 1988–2005 and years before 1988 was not significant. After 2005, a total of 10 years of hydrological data from 2006 to 2015 were obtained. Although there were only 10 years of hydrological data, the calculation results showed that the 10-year average annual runoff and sediment load at the Chaoan station and 10-year average annual precipitation sample in the upper reaches as the upper limit of the estimation error of the multi-year average are 9.8%, 33.6%, and 5.1% ($p = 0.68$) respectively. Therefore, the 10 years from 2006 to 2015 was considered true representative for the multi-year average. The period before 1987 is longer, and the comparison between the two periods can be understood as a comparison between the recent observations and background values. Therefore, the relevant hydrological data obtained in this study can meet the research needs.

At present, intense sand excavation activities are carried out in the entire middle reaches of the Hanjiang River; therefore, the hydrological data at the Liuhuang station are very representative, and the Liuhuang water level station was selected as the research site. In addition, the hydrological data of the adjacent Sanheba and Chaoan stations are used for comparative study. Due to the short length and a few hydrological stations in the middle reaches, the historical hydrological data at some hydrological stations are incomplete, and multiple hydrological stations data cannot be used for cross-validation studies. The annual average water level data of the Liuhuang, Sanheba, and Chaoan Hydrology Stations were collected from 1955 to 2015. Although hydrological data between 1988 and 2005 of the three stations were all missing, the data collected still met this study needs, because massive sand excavation in the middle Hanjiang River occurred in the past 10 years, and the data before 1988 can represent the situation before sand extraction, and the data after 2006 can represent the situation after sand extraction. The annual precipitation and runoff data in the study area are only relatively complete in the Chaoan station; therefore, the relevant hydrological data at the Chaoan station can serve as a reference for the missing data at the other two stations.

Methods for Impacts of Dams Study

The upstream control catchment area of Chaoan Station is 29 077 km$^2$ has many rainfall stations. Since 1954, except for the records of only 20 stations in the first two years, there are 150 to 200 rainfall stations in other years. Therefore, the arithmetic average method was used to calculate the regional precipitation in each year of the upper reaches of the Chaoan station.

In this study, t-test was used to compare the hydrological data between the two periods before 1987 and after 2006, and the significance of the difference between pre-1987 and post-2006 periods was compared. If the test results were significant (i.e., $p < 0.05$), we consider that changes occurred.

Then, the double mass curve method was used to examine the turning points of annual precipitation and annual runoff cumulative change, as well as the turning points of the annual precipitation and cumulative change of the annual sediment discharge. The turning points on the double mass curve indicates the change in the relationship between the rainfall runoff and sediment discharge, and this change can be attributed to human activities.

Methods for Impacts of Sand Mining Study

By comparing the changes in the annual average water level before and after sand mining, the effect of the sand mining on the river channel was roughly judged. First, analyze the multi-year average water level and annual runoff during the two periods before and after the sand extraction at the Liuhuang station. Second, compare multi-year average water level and annual runoff at the upstream Sanheba station and downstream Chaoan station in the same periods. Then, refer to the annual runoff of Chaoan Station and the annual precipitation in the upstream area during the entire study period to comprehensively analyze the effect of sand mining on the river course in the middle Hanjiang River.

In addition, the Liuhuang and Sanheba Stations are the water level stations with no runoff data. Since the area of the Hanjiang River Basin is not large, the geographical and environmental differences in the entire basin are small; the annual runoff data of the two stations were calculated according to the annual runoff at the Chaoan station by using the ratio of the drainage area actually controlled by each station.

RESULTS AND DISCUSSION

Results

(1) Changes of each hydrological parameter in the two periods

The change in the average annual precipitation and average annual runoff in the Chaoan station in post-2006 period is not significant compared to pre-1987 (Table 1), and the relative rate of change is about 10%. However, the average annual sediment load changes significantly and is less than 1/3rd of the pre-1987 period (Table 1). The t-test results did not show any statistically significant change in the annual precipitation ($p = 0.46$) and annual runoff ($p = 0.85$) in the two periods, and it was also confirmed by their multi-year change trend (Figure 3). Since 1954, both of them increased, but the annual runoff trend line is slightly less upward than the annual precipitation trend line. However, statistically significant changes were observed in the amount of annual sediment transport ($p = 0.001$) during the two periods, and the latter period showed comparatively less significant change, as observed from the annual sediment transport change figure (Figure 4).

Table 1. Average hydrological data of the Chaoan hydrology station in the study periods.

<table>
<thead>
<tr>
<th>Study periods</th>
<th>Average annual</th>
<th>Average annual runoff ($10^6$ m$^3$)</th>
<th>Average annual sediment load ($10^4$ t)</th>
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<td></td>
<td></td>
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</tbody>
</table>
The curve clearly showed the cumulative deviation from the straight line before and after the turning point and can be calculated by the linear regression equation. With the turning point in 2006 as the boundary, two cumulative linear regression equations for the two periods were established (Figure 5). The cumulative sand volume difference at the end of the previous and subsequent periods is the accumulated sediment reduction in the later period caused by human activities. The linear fitting equations for the accumulation during the two periods are as follows:

\[ y_{2006-2015} = 0.0913x + 21056, \quad (R^2 = 0.9502) \quad (2) \]

To calculate the cumulative amount of sediment reduction since 2006 by the straight line fitting equations for the above two periods, a sediment value (\( y_1 \)) can be represented by the following equation \( y_1 = 32542.61 \times 10^4 \) t, where \( y_1 \) is the accumulation of Chaoan Station in 2015 assuming that it had not been affected by human activities during the period 2006–2015. Then, substituting the accumulated precipitation of 72514.3 mm into Formula (2) leads to \( y_2 = 27676.56 \times 10^4 \) t, where \( y_2 \) is the accumulated sediment transport at the Chaoan Station during the period 2006–2015 due to human activities. The amount of total sand reduction from 2006 to 2015 is \( y_1 - y_2 = 4866.05 \times 10^4 \) t, and the annual average amount of sand reduction is 486.61 × 10^4 t.

The following are the quantitative estimates of the impact of human activities on the sediment discharge since 2006 based on the double mass curve of precipitation-sand transport. To estimate the change in the cumulative sediment load after the occurrence of a significant turning point since 2006 to 2015, the amount of sand load reduction since 2006 was obtained. This amount of change is actually the cumulative deviation from the straight line before and after the turning point and can be calculated by the linear regression equation. The turning point in 2006 as the boundary, two cumulative linear regression equations for the two periods were established (Figure 5). The cumulative sand volume difference at the end of the previous and subsequent periods is the accumulated sediment reduction in the later period caused by human activities. The linear fitting equations for the accumulation during the two periods are as follows:

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(4) Changes in the multi-year average water level in the Lihuang station

From 1955 to 1987, the multi-year average water level at the Lihuang Station is 17.19 m, while that from 2006 to 2015 15.28 m decreased by 1.91 m (Table 2), indicating an obvious drop in the water level. However, the water level of the Sanheba Station increased slightly by 0.19 m and that at the Chaoan Station was also higher after 2009 (Table 2), because of the
control of the downstream Chaozhou Water Control Project; therefore, it cannot be used as a reference.

Table 2. Multi-year average water level and average annual runoff of the three gauging stations during 1955–2015.

<table>
<thead>
<tr>
<th>Study periods</th>
<th>Liuhuang station</th>
<th>Sanheba station</th>
<th>Chaoan station</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multi-year average water level (m)</td>
<td>Multi-year average runoff ($\times 10^8$ m$^3$)</td>
<td>Multi-year average water level (m)</td>
</tr>
<tr>
<td>2006–2015</td>
<td>15.28</td>
<td>231.0</td>
<td>35.78</td>
</tr>
</tbody>
</table>

The average annual runoff data were combined to analyze the reason of water level drop at the Liuhuang station (Table 2), indicating that the average annual runoff at the Liuhuang station is 234.8×$10^8$ m$^3$ from 1955 to 1987, while from 2006 to 2015 is 231.0×$10^8$ m$^3$ decreased by 3.8×$10^8$ m$^3$; at the same time, the average annual runoff at the Sanheba and Chaoan stations decreased by 3.5×$10^8$ m$^3$ and 3.9×$10^8$ m$^3$, respectively, reflecting the consistency of the changes in the hydrological conditions of the entire river. In the period from 1954 to 2015, the annual runoff at the Chaoan Hydrological Station is also consistent with the fluctuation of the annual precipitation in the upstream area (Figure 3). However, the reduction in the 3.8×$10^8$ m$^3$ annual runoff at the Liuhuang Station cannot drop the annual average water level by 1.91 m in the middle Hanjiang River, because the water runoff only reduced by 1.62% and the water level reduced by 5.37%. This phenomenon does not even occur in the upper part of the cross section in the river. Therefore, the decline in the multi-year average water level at the Liuhuang station was related to the sand excavation in the river.

But upstream and downstream reservoirs and hydropower stations can also change the water levels. The upstream reservoir dam will cause the water level to drop, while the downstream reservoir dam will raise the water level. Hydroelectric dams were constructed before or after 2009 on the upstream and downstream of the Liuhuang station. Because the dam of the hydropower station is located more than 30 km far away from the station, it has little effect on the water level and has less impact on the multi-year average water level. Therefore, considering these factors comprehensively and comparing with the average annual water level at the Sanheba station showed that the water level decline in the middle river is mainly due to excessive sand mining.

(5) Sand mining in the lower Hanjiang river

As a result of excessive sand mining, the water and sand balance of the lower Hanjiang River was severely damaged. Before 1979, the river course in the lower Hanjiang River was characterized by the sedimentation or interphase distribution of erosion and siltation, and riverbed changes were mainly siltation. Since late 1970s to 1990s, except for the interphase distribution of erosion and siltation in the middle river, the erosion in the lower river decreased to different degrees, and that in the Xixi River is most obvious, followed by the Xinjin River, Meixi, and Nanxi rivers, and that of the Hanjiang and Beixi rivers are relatively slight. Moreover, sand mining caused the water level decline obviously in the lower reaches. Compared to 1979, the average water level dropped 2.91 m, and the maximum was 4.38 m in the Xixi River in 1998. Through the comparison of the topography of the river channel, the channel water capacity of the low water level in Xixi in 1998 was 2.24 times that of 1979 and 1.59 times that of high water level. From 1979 to 1998, the total amount of the river scouring reached 5.880 × $10^4$ m$^3$, an average of 309.5 × $10^4$ m$^3$ per year. All lines downcut, and the water level drop in the Xixi River drastically changed the Dongxi and Xixi river flow diversion ratios and even caused an inversion. Before the end of the 1980s, the ratio of diversion in the dry season of the Dongxi and Xixi Rivers was approximately 8:2, but it changed to 2:8 at the end of the 1990s.

The H–Q curves of the three hydrological stations, Chaoan, Shuitoudong, and Shuitouxi, in 2000 and 2001 indicate that the riverbed is still undercutting. According to calculations, if sand dredging stopped from 2006, the lower reaches of the Hanjiang River will begin to silt after 2010, but it will take a long time to recover to the mid-1970s or early 1980s.

Discussion

(1) Water and sediment discharge change

Variations in the water discharge and sediment load are mainly affected by climate change and human activities. In this study, the annual runoff at the Chaoan Hydrological Station was found to be consistent with the annual precipitation in the upstream area and they all have no unusual fluctuation (Figure 3); therefore, we can consider that climate change has little effect on the water and sediment discharge in this basin (Figure 4). Anthropogenic influences on the water discharge and sediment load mainly include land use and dams construction. In the middle and upper Hanjiang River basin, natural vegetation is always good, only vegetation in the Wuhua River basin in the upper reaches of the Meihe River was destroyed in the 1960s. Therefore, the cumulative annual runoff and sediment discharge at the Chaoan Station from 1961 to 1962 increased slightly (Figure 5). The Wuhua River Basin has been rehabilitated for nearly 10 years, and soil erosion has basically been controlled before 1990. In addition, a large number of reservoir power stations have been built on the tributaries in the upper reaches of the river since 1980s, but sediment discharge at the Chaoan Station reduced significantly since 2006 and the runoff changed slightly in the entire study period (Figure 5). Therefore, we considered that the construction of both the dams in the upper reaches in 1980s and vegetation restoration in the Wuhua River Basin had only a slight effect on the water and sediment discharge in the Hanjiang River basin.

This investigation revealed that the main reason for significant reduction of sediment discharge since 2006 is the construction of Dongshan Water Control Project. The project cofferdams were closed in 2006, when the amount of sediment transported at the Chaoan Station began to decrease significantly, indicating that big dams on the mainstream of the Hanjiang River played major roles in the reduction of sediment discharge. Because of the significant reduction in the sediment content and clear water leakage, it will undercut the riverbed downstream of...
the project and affect the stability of the river bed and river regime.

In addition, dams break the vertical continuity of the river. In the Hanjiang River basin, the downstream of dams, river water greatly reduced, especially in the upper Hanjiang River, and river bed even became dry often during the dry seasons (Figure 2b), which not only undermined the vertical continuity of the river, but also directly affected the health of the river ecosystems. The growth of exotic species water hyacinth in many river sections in the downstream of dams may be related to this (Figure 2c). In contrast, garbage accumulated in the upper reservoir area of the dam. A large amount of garbage accumulated in the reservoir area upstream of the dams on the Hanjiang River (Figure 2d), affecting not only water quality but also navigation.

The terrain of the eastern part of China is dominated by plains and hills. However, driven by interests, most of the rivers here have also built multi-level dams to generate electricity. The following questions are worth thinking: Should large-scale hydraulic projects and hydropower stations be built on the rivers in the plains? Compared to the long-term stability riverbeds and river regime, long-term ecological safety of rivers and other long-term benefits, short-term benefits such as power generation of water conservancy projects, which is more important?

(2) About sand mining impacts

No bank collapses were observed in the middle Hanjiang River. The analysis indicates that the water level drop in the middle river is mainly related to sand mining. Sand mining caused riverbed elevation drop, and the water level decline correspondingly. Water level dropped obviously in the middle river in recent years and dropped more in the Xixi River in the lower Hanjiang River from 1980s to 1990s, which even drastically changed the Dongxi and Xixi river flow diversion ratios from 8:2 to 2:8. In fact, the water level drop in the Xixi river is also mainly caused by sand mining.

Unregulated sand mining has many disastrous effects on the river stability and the safety of the wading structures. Excessive sand mining in recent years has changed the river structure in the middle Hanjiang River. Sand mining easily forms sand pits. Once sand pit is formed, erosion will be traced on the upstream side, and the sand mining pit will be expanded. If the sand pit is close to bridges and other wading structures, it will threaten the safety of wading structures. Due to sand mining in the river, the Lihuahu River Bridge has become a dangerous bridge and has been suspended.

Excessive sand mining has more negative impacts on the spawning grounds of migratory fishes and riverine environment. Anguilla marmorata and Anguilla japonica are migratory fish resources in the Hanjiang River. Sand mining activities interfere with fish migration and affect the spawning populations and their early life stages by polluting the water, destroying the spawning grounds and removing vegetation. In recent years, the Hanjiang river fish resources have plummeted. In addition to overfishing, river sand mining and various water conservancy projects have also had a significant negative impacts on them.

CONCLUSIONS

The impacts of human activities on the Hanjiang River from the dams construction and sand extraction were investigated, and the following conclusions were obtained:

1) The impacts of dams on the movement process of water and sediment in the Hanjiang River were investigated. The Chaoan Hydrometric Station located at the mid-downstream junction was selected as the research site. The amount of sediment discharge at the Chaoan station significantly decreased since 2006 and confirmed that the main reason is the construction of the Dongshan Water Control Project on the main stream of the Hanjiang River upstream of the station. The large dams on the mainstream of the Hanjiang River trapped sediment discharge seriously.

2) Sand mining is another major human disturbance activity in the Hanjiang River. Sand mining has caused serious undercutting and the water level drop in the lower reaches, especially in the Xixi River and in the middle Hanjiang River. The multi-year average water level at the Lihuahu station dropped by 1.91 m in recent years. The analysis indicates that the water level decline is mainly due to excessive sand mining. Excessive sand extraction, coupled with dams blocking sand flow reduced the amount of sediments coming from upstream, seriously damaging the balance of water and sediment in natural rivers to impact the geomorphological evolution of the river channel of the middle and lower Hanjiang River basin. More importantly, it will exert a positive effect on the conservation of ecological environment and flood mitigation in the Hanjiang River basin (Guo, Yu, and Gao, 2018).

3) An integrated environmental assessment, management and monitoring program should be conducted on the reservoir dams and sand mining, and awareness campaign should be launched at various levels about river sand mining (Padmala, Maya, and Sreebh, 2008). Furthermore, the environmental state of rivers and immediate control measures should be presented in the entire Hanjiang River basin.

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