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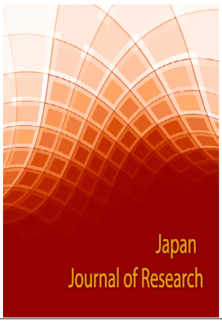

River Flood Characteristics Along the Canal Area Effected By Hanzhuang Canal Jacking

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Keywords
Hanzhuang Canal; jacking; flood risk; water level; discharge; flood control and scheduling.

Abstract

In this paper, flood characteristics along the canal area effected by Hanzhuang Canal jacking are studied. By coupling the rainfall runoff (NAM) model with the hydrodynamic (HD) model, a 1-D hydrologic-hydrodynamic coupling model was built. On the basis of parameter calibration and model validation, different flood simulation schemes are drawn up, and the influence range of Hanzhuang Canal jacking and the flood characteristics of tributaries affected by Hanzhuang Canal jacking are analyzed respectively. The results show that with the increasing discharge of Hanzhuang Canal, the water level of Hanzhuang canal rises gradually, the main stream flood flows upstream along the tributaries, the water level of the tributaries rises gradually, and the risk of flood disasters increases. Among the tributaries, Taogou River is most affected by Hanzhuang Canal jacking and has the highest risk of flood disaster, followed by Dasha River, Dasha River Floodway and Sizhi Ditch. The results also show that the backwater of Hanzhuang Canal on the tributaries is mainly reflected in the influence on the upstream flood water level process, but has little or no influence on the flood discharge process, which can provide a reference for regional flood control and scheduling department.

Introduction

In recent years, under the influence of various factors such as extreme climate and natural environment, the frequency of flood disasters is increasing [1]. River is the main channel of flood discharge and plays a very important role in resisting flood disaster. According to the topographic and geomorphic conditions, the river can be divided into hill region river, plain region river and hill-plain mixed region river. Among them, the upstream of the river in the mixed hill-plain area is mostly hilly land with steep slope, short source and rapid flow, and the middle and lower reaches enter the plain or depression area with slow slope, which is susceptible to the dual influence of the inflow from the upstream basin and the top support of the downstream water level, and the risk level of flood disaster is high. Lots of scholars have carried out a large number of studies on flood disasters, but most of the studies mainly focus on flood disasters caused by incoming water in the upstream basin [2-7], and there are relatively few studies on flood disasters affected by downstream water jacking. Hu Guojian et al. [8] used a two-dimensional numerical model to analyze the influence of the lower reaches of Puyang River on the crest of Qiantang River. Wu Yin et al. [9] used the measured data system to analyze the variation of water level of Xiangjiaba Hydrology Station under the influence of separate flooding of Hengjiang River and Minjiang River. Sun Yanbing et al. [10] studied the variation law of water level of Nenjiang River under the influence of the upper support of the Second Songhua River by using hydrologic method and two-dimensional hydrodynamic model method successively. Hanzhuang Canal is the southernmost section of the Beijing-Hangzhou Grand Canal in Shandong Province, which is an important part of the east route of the South-to-North Water Diversion project, plays an important role in drainage, flood control, water diversion and comprehensive utilization of shipping. Based on the main stream of Hanzhuang Canal, Sizhi Ditch, Dasha River, Dasha River Floodway and Taogou River, this paper built a one-dimensional hydrologic and hydrodynamic mathematical model to simulate the flood evolution process of rivers along the canal area influenced by different water levels of Hanzhuang Canal, which can provide reference for regional flood control and disaster alleviation.

Overview of the study area

Hanzhuang Canal is an important flood discharge channel for Nansi Lake [11], with a total length of 42.5 km and a watershed area of 1,828 km^2. The main tributaries include Yizhi Ditch, Erzhi Ditch, Yinpingsha River,

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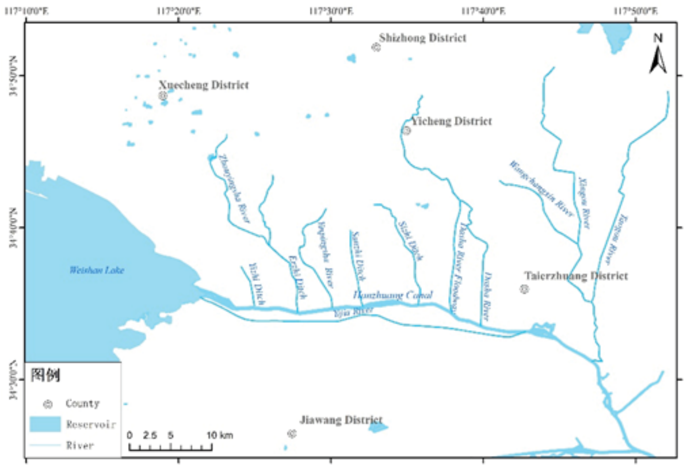


Figure 1. *Scope of study area*

Sanzhi Ditch, Sizhi Ditch, Dasha River, Dasha River Floodway and Taogou River, joined by Yijia River on the right bank. Hanzhuang Canal has been treated according to the 50-year flood control standard [12], and the main tributaries along the canal have been treated according to the 20-year flood control standard. The banks of Hanzhuang Canal are low-lying, and the water level in the flood movement exceeded the ground outside the bank. Influenced by the inflow from the upper river basin and the top support of the lower canal, various tributaries of Hanzhuang Canal, especially Dasha River, Dasha River Floodway and Taogou River, had a high number of flood disasters in the history. The research focused on the influence of Hanzhuang Canal jacking on Sizhi Ditch, Dasha River, Dasha River Floodway and Taogou River in Shandong Province, and the scope of this study area is determined as the plain waterlogging depression area north of Hanzhuang Canal, east of Sizhi Ditch and west of Taogou River. The scope of the study area is shown in Figure 1.

Coupling model of rainfall runoff model (NAM) and hydrodynamic model (HD)

Rainfall runoff model

Watershed information

For the convenience of the study, according to the characteristics of Hanzhuang Canal and its tributaries in the study area, the study area is divided into five basins, and the information of each basin is shown in Table 1.

Table 1. *Catchment area of tributaries and drains*

Serial number	Basin	Confluence area (km^2)
1	Dasha River	525
2	Taogou River	187
3	Xingou River	350
4	Sizhi Ditch	64.7
5	Beiluo Catchwater Drain	10.42

NAM model attribute

The NAM model is mainly used to simulate the rainfall runoff process in natural watersheds [13]. NAM model parameters mainly include surface-root zone parameters, groundwater parameters, snowmelt parameters, irrigation parameters, initial condition parameters and automatic calibration parameters. Refer to Literature [1] for the main parameter range to be set in each parameter page.

Time series

In the basin where the research area is located, four rainfall stations in Eshan, Nigou, Shuiguo and Yinping were collected, and three hydrological stations in Yicheng, Taierzhuang Gate and Taogou Bridge, but no evaporation data was collected. Therefore, the rainfall data required for model calibration and verification in this paper are measured data from rainfall stations, and evaporation data are drawn up with reference to relevant references in the region. The flow data with hydrological stations are measured data from hydrological stations, and the flow data without hydrological stations are compared with measured data from neighboring basins, and are comprehensively determined according to field survey data.

Hydrodynamic model

River network

The scope of HD model is the area of the plain waterlogging depression area north of Hanzhuang Canal, east of Sizhi Ditch and west of Taogou River. The river systems in the research area mainly include Hanzhuang Canal, Sizhigou, Dasha River, Dasha River Floodway, Xingou River, Taogou River and Beiluo Catchwater Drain, which is seen in Figure 2. Among them, the Hanzhuang Canal is the main river, Sizhigou, Dasha River, Dasha River Floodway, Xingou River, Taogou River are the main tributaries, and Beiluo Catchwater Drain is a ditch in the research plain that lists waterlogging areas as vulnerable to danger.

BIGEMAP software was used to obtain the image map of the study area. DEM elevation data was the 30m precision data of NASA data source. BIGEMAP software is a 3D digital earth software, providing multiple image data sources, the downloaded image is the earth map data. By comparing several groups of sectional measurement data with downloaded DEM data, it is found that the fit degree is high, the accuracy of downloaded data meets the model requirements. The river network map of the study area was obtained by combining the image map and DEM map of the study area with the basin extraction function of ArcGIS. After testing, the river channel extraction was basically consistent with the actual situation.

Cross sections

The cross section data of Hanzhuang Canal and its tributaries/drains are obtained from the measured data of the management projects in recent years. In order to meet the requirements of model accuracy and operational stability, 128 cross sections are set up in the study area, among which 45 cross sections are set up in Hanzhuang Canal mainstream and 76 cross sections in major tributaries and drainage ditches, including 14 cross sections in Sizhi Ditch, 27 cross sections in Dashan River, 16 cross sections in Dasha River Floodway, 10 cross sections in Taogou River, 9 cross sections in Xingou River and 7 cross sections in Beiluo Catchwater Drain.

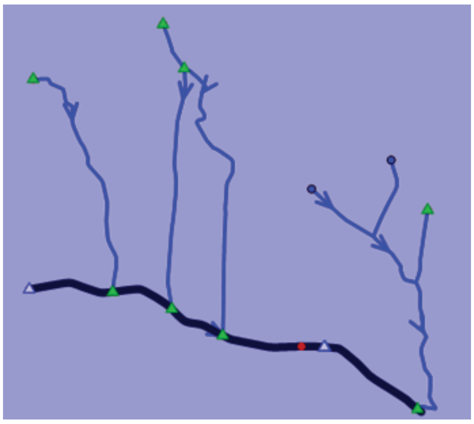


Figure 2. *Schematic diagram of generalized model of river network in the study area*

Boundary conditions

The Inflow of Hanzhuang Canal main flow was set as the inflow boundary. The measured or designed flood flow data of Hanzhuang Gate Hydrological Station was adopted according to the actual simulated working condition, and the outflow was set as the stage-discharge relation boundary (Q-h), which was obtained from the water level and discharge data of downstream Taierzhuang Gate at the provincial section. The inlet of each tributary of Hanzhuang Canal was set as the flow boundary, and the measured flood data of hydrographic station or NAM model was used to calculate the generated flow data according to the actual simulation conditions.

Parameter file

The initial flow in this study was set as 0, and the initial water depth was the average water depth in flood season in the river channel. Roughness can reflect the comprehensive influence of river boundary roughness, terrain and other factors on flow resistance [14]. The roughness value refers to the natural river roughness table compiled by Holden in the United States, and the initial roughness value is determined according to the field investigation.

Hydrologic-hydrodynamic model coupling

Mike11 can realize the coupling solution of rainfall runoff (NAM) model and hydrodynamic (HD) model. Specifically, the runoff generated by rainfall runoff (NAM) model enters into the river network of Mike11 hydrodynamic model as a side inflow, and the HD model treats the inflow runoff as a boundary condition for calculating the water level and discharge along the river.

Model Calibration and Verification

Model Calibration

The rainstorm process from August 10, 2019 to August 12, 2019 was used to calibrate the model. In fact, the process of parameter calibration is to constantly adjust the value of each parameter of the model until the calculated value of the model is in good agreement with the measured data [15]. Specifically, the automatic calibration function of the NAM model combined with manual fine-tuning was firstly used to calibrate the parameters of the NAM model. On the basis of the parameter calibration of the NAM model, the riverbed roughness in the HD model and the parameters of the NAM model were further checked by the hydrology-hydrodynamic coupling model. Using the above parameter calibration method, the values of each parameter are finally determined after calibration, as shown in Table 2 and Table 3.

Model Verification

On the basis of model calibration, the process of rainstorm from July 27 to July 30, 2021 was adopted for model verification. The measured rainstorm and flood process can be seen in Figures 3-5. It can be seen from the verification results that the simulated values and measured values in each basin are in good agreement with each other, which is similar to the change rule of model calibration. The calibrated parameters basically meet the accuracy requirements, indicating that the hydrodynamic model can basically reflect the hydrodynamic characteristics of the study area, and the overall simulation results of the model are credible.

Table 2. *NAM parameter values of each basin*

S. No	Parameter	Dashahe River Basin	Taogou River (including the new river) basin	Sizhi Ditch basin	Beiluo Catch-water Drain
1	U_{max}(mm)	15.23	11.543	15.23	10
2	L_{max}(mm)	112.92	100.38	112.92	100
3	C_{QOF}	0.95493	0.99757	0.95493	0.5
4	C_{KIF}	774.29	273.31	774.29	1000
5	CK12(h)	16.391	38.079	16.391	10
6	TOF	0.01668	0.016581	0.01668	0
7	TIF	0.37634	0.11883	0.37634	0
8	TG	0.62424	0.94584	0.62424	0
9	CK_{BF}(h)	2498.4	2020.1	2498.4	2000

***Table 4**. Characteristics and roughness value of each reach*

S No.	Basin	Riverbed Characteristics	Representative Photograph	Roughness Factor
1	Hanzhuang Canal	Riverbed by pebbles, stone, bed surface is relatively flat, there are weeds in the beach		0.035
2	Sizhi Ditch	River bed by pebbles, block stone composition, bed surface is relatively smooth		0.032
3	Dasha River	River bed by pebbles, block stone composition, bed surface is relatively smooth		0.032
4	Dasha River floodway	River bed by pebbles, block stone composition, bed surface is relatively smooth		0.032
5	Taogou River	River bed by pebbles, stone, bed surface is relatively flat, there are weeds at the bottom of the river		0.038
6	Xingou River	River bed by pebbles, stone, bed surface is relatively flat, there are weeds at the bottom of the river		0.038
7	Beiluo Catchwater Drain	River bed by pebbles, stone, bed surface is relatively flat, there are weeds at the bottom of the river		0.038

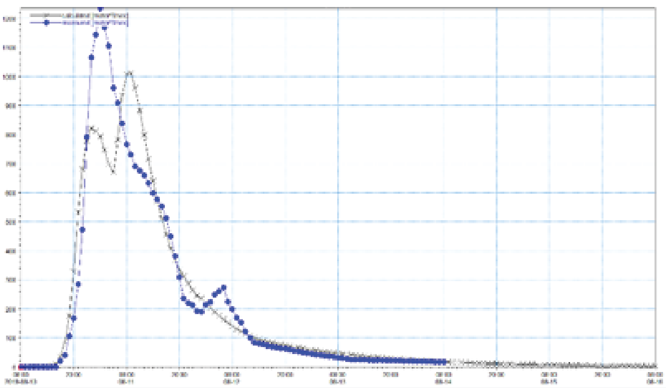


***Figure 3.** NAM simulation results of Dasha River Basin flooding from July 27 to August 5, 2021*

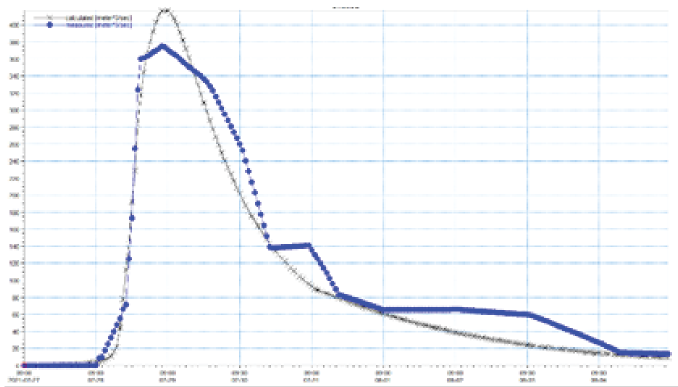


***Figure 4.** Simulation results of Hanzhuang Canal flooding from July 27 to August 5, 2021*

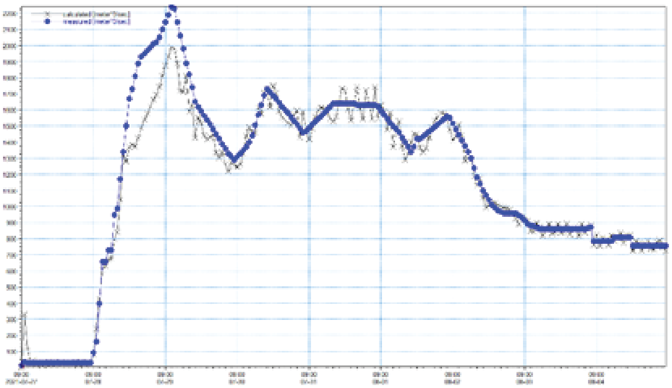
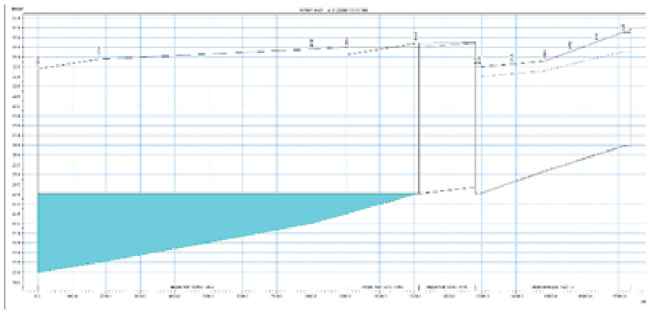


Figure 5. *Simulation results of Hanzhuang Canal flooding from July 27 to August 5, 2021*

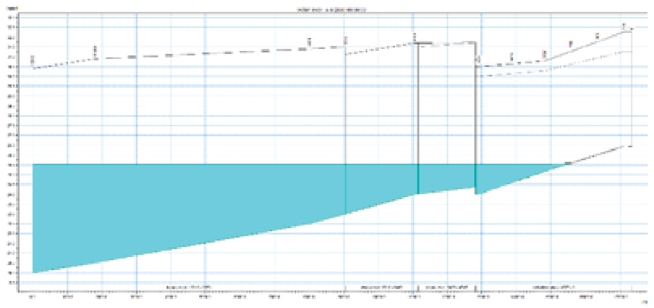
Influence Range of Hanzhuang Canal Jacking

The rainfall of each tributary is set as 0, and the influence range of Hanzhuang Canal Jacking on each tributary (Sizhi Ditch, Dasha River, Dasha River Floodway and Taogou River) under the discharge conditions of 500m³/s, 1000m³/s and 2000m³/s of the main stream of Hanzhuang Canal is simulated respectively.

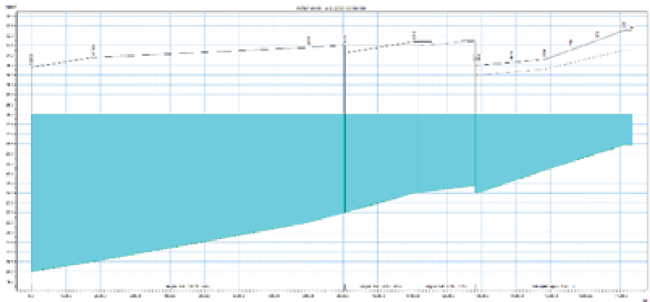
Figure 6 shows the simulated water surface of Taogou River on different flow conditions of Hanzhuang Canal. It shows that when the discharge of Hanzhuang Canal is 500m³/s, the water level of Taogou River entering Hanzhuang Canal is 24.0 m, and the upstream distance of Hanzhuang Canal flood along the Taogou River is about 11.1 km. When the discharge of Hanzhuang Canal is 1000m³/s, the water level of Taogou River entering Hanzhuang Canal is 25.6 m, and the upstream distance of Hanzhuang Canal flood along the Taogou River is about 15.6km, reaching up to Xingou River. When the discharge of Hanzhuang Canal is 2000m³/s, the water level of Taogou River entering Hanzhuang Canal is 28.0 m, and the upstream distance of Hanzhuang Canal flood along the Taogou River is about 17.2 km, reaching up to the starting point of Beiluo Catchwater Drain, passing by Xingou River.The result shows that with the increase of Hanzhuang Canal discharge, the influence of Hanzhuang Canal water level jacking on Taogou River increases gradually. In the simulated flow range, the maximum upstream distance of Hanzhuang Canal is more than 17.2 km, and the maximum jacking water level is 28.0 m.



(a) Hanzhuang canal discharge 500m³/s



(b) Hanzhuang canal discharge 1000m³/s



(c) Hanzhuang canal discharge 2000m³/s

Figure 6. *Simulated water surface of Taogou River - Xingou River - Beiluo Catchwater Drain under different flow conditions in Hanzhuang Canal*

Table 5. *The influence range of Hanzhuang Canal jacking on its tributaries under different flow conditions in Hanzhuang Canal*

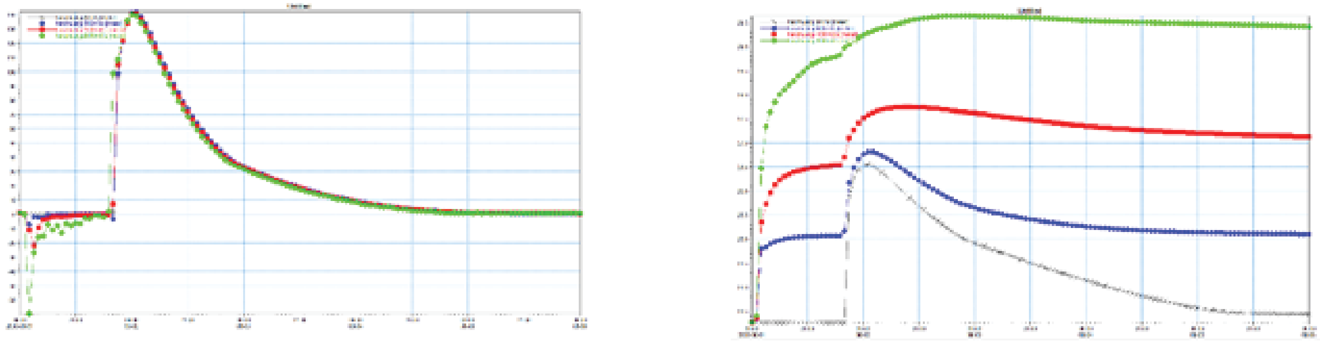
Sernario	Sizhi Ditch		Dasha River floodway		Dasha River		Taogou River	
	Water level at canal entry (m)	Upstream distance (km)	Water level at canal entry (m)	Upstream distance (km)	Water level at canal entry (m)	Upstream distance (km)	Water level at canal entry (m)	Upstream distance (km)
Hanzhuang Canal 500m³/s	25.8	2	25.6	4.7	25	6.5	24	11.1
Hanzhuang Canal 1000m³/s	27.7	6.5	27.2	5	26.6	10.5	25.6	15.6
Hanzhuang Canal 2000m³/s	30	12.5	29.6	8.5	29	12.5	28	More than 17.2

Table 5 shows the influence range of Hanzhuang Canal jacking on its tributaries under different flow conditions. As can be seen from the table, on the whole, with the continuous increase of Hanzhuang Canal discharge, the influence of Hanzhuang Canal water level jacking on its tributaries gradually increases, and the risk of flood disaster is greater. By comparing the data of water level, upstream distance and water depth of various tributaries in the study area, combining with the cross section data and historical flood disaster records, it can be seen that Taogou River was the most influenced by Hanzhuang Canal jacking, with the longest upward tracing distance of the flood, the biggest water level change and the highest risk of the flood disaster, followed by Dasha River and Dasha River Floodway. The influence on Sizhi Ditch is minimal.

Flood characteristics of tributaries affected by Hanzhuang Canal backwater

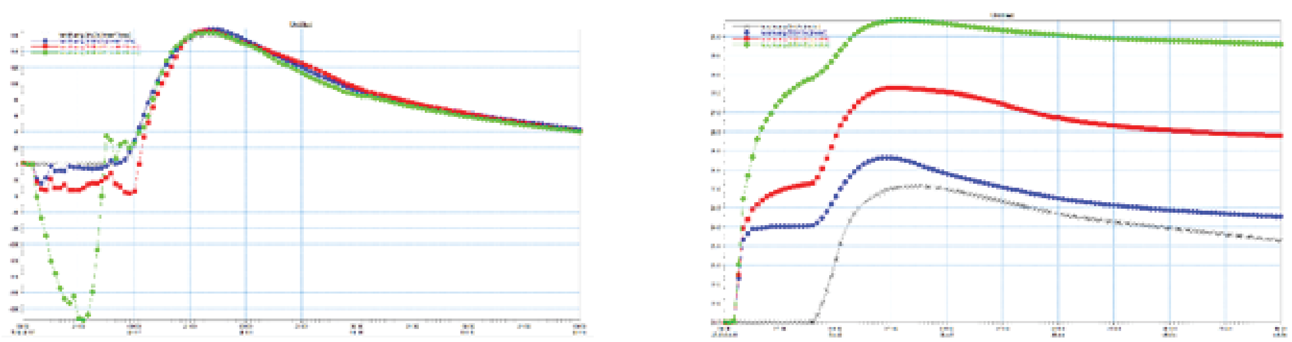
According to the research needs, the mainstream discharge of Hanzhuang Canal is set in four situations: 0m³/s (not considering the canal jaking), 500m³/s, 1000m³/s and 2000m³/s, and the tributary of Hanzhuang Canal is set in three situations: 5-year, 10-year and 20-year design rainstorm. Hydrodynamic processes under different dispatching combination conditions are simulated respectively and the risk of flood disaster is analyzed.

Figures 7-9 shows the variation of discharge and water level with time at 8877.5m of Taogou River under 5-year, 10-year and 20-year design rainstorm of each tributary. As can be seen from the figure, under the 5-year design rainstorm condition and when the discharge of Hanzhuang Canal is 0m³/s, 500m³/s, 1000m³/s and 2000m³/s, the maximum peak discharge at 8877.5 m of Taogou River is 106.1m³/s, 108.0m³/s, 108.7m³/s and 102.7m³/s respectively, and the highest water level is 24.5 m, 25.1 m, 27.0 m and 29.1 m respectively. Under the 10-year design rainstorm condition and when the discharge of Hanzhuang Canal is 0m³/s, 500m³/s, 1000m³/s and 2000m³/s, the maximum peak discharge at 8877.5 m of Taogou River is 160.8m³/s, 167.2m³/s, 165.5m³/s and 163.3m³/s, respectively, and the highest water level is 25.1 m, 25.8 m, 27.6 m and 29.4 m respectively. Under the 20-year design rainstorm condition and when the discharge of Hanzhuang Canal is 303.2m³/s, 301.7m³/s, 309.1m³/s and 296.2m³/s, the maximum peak discharge at 8877.5m of Taogou River is 160.8m³/s, 167.2m³/s, 165.5m³/s and 163.3m³/s, respectively, and the highest water level is 26.0 m, 27.2 m, 28.1m and 30.0 m respectively. It can be seen that when the rainfall is constant, with the increase of the discharge of Hanzhuang Canal, the



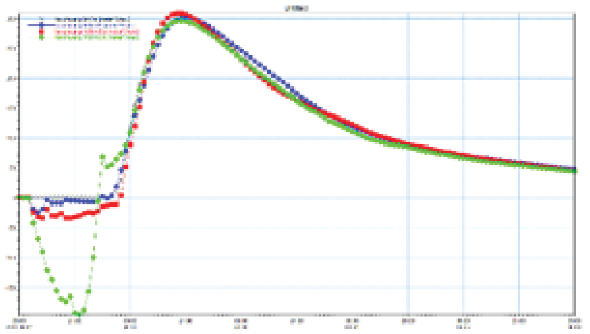
(a) Discharge variation process over time (b) Water level variation process over time

Figure 7. *Time variation of discharge and water level at 8877.5m in Taogou River under 5-year design rainstorm*

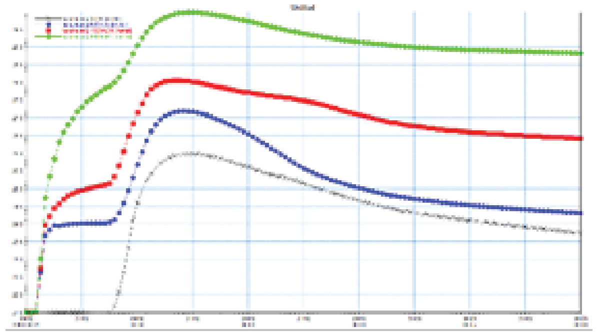


(a) Discharge variation process over time (b) Water level variation process over time

Figure 8. *Time variation of discharge and water level at 8877.5m in Taogou River under 10-year design rainstorm*



(a) Discharge variation process over time



(b) Water level variation process over time

Figure 9. *Time variation of discharge and water level at 8877.5m in Taogou River under 20-year design rainstorm*

Table 6. *Peak discharge and water level of typical sections in Hanzhuang Canal under different discharge conditions*

Conditions	**Condition setting**	**Sizhi Ditch 10295.5m**		**Dasha River Flood-way 11100.0m**		**Dasha River 16023.6m**		**Taogou River 8877.5m**	
		peak discharge (m³/s)	**maxi-mum water level (m)**	**peak discharge (m³/s)**	**maxi-mum water level (m)**	**peak discharge (m³/s)**	**maxi-mum water level (m)**	**peak discharge (m³/s)**	**maximum water level (m)**
Condition 1	The tributaries in 5 years design rainstorm, Hanzhuang canal dis-charge 0m³/s	38.3	28.3	170.6	23.8	142.3	26.6	106.1	24.5
Condition 2	The tributaries in 5 years design rainstorm, Hanzhuang canal dis-charge 500m³/s	38.3	28.3	166.9	26.4	141.8	26.8	108	25.1
Condition 3	The tributaries in 5 years design rainstorm, Hanzhuang canal dis-charge 1000m³/s	38.3	28.6	167	28.1	140.5	27.7	108.7	27
Condition 4	The tributaries in 5 years design rainstorm, Hanzhuang canal dis-charge 2000m³/s	37.7	30.2	169	30	140	29.6	102.7	29.1
Condition 5	The tributaries in 10 years design rainstorm, Hanzhuang canal dis-charge 0m³/s	68.6	28.9	301.5	24.8	253.8	27.6	160.8	25.1
Condition 6	The tributaries in 10 years design rainstorm, Hanzhuang canal dis-charge 500m³/s	68.6	28.9	303.1	27.1	253	27.8	167.2	25.8
Condition 7	The tributaries in 10 years design rainstorm, Hanzhuang canal dis-charge 1000m³/s	68.6	29.1	303.1	28.5	251.7	28.4	165.5	27.6
Condition 8	The tributaries in 10 years design rainstorm, Hanzhuang canal dis-charge 2000m³/s	67.5	30.6	302.5	30.2	251.2	29.9	163.3	29.4

Conditions	Condition setting	Sizhi Ditch 10295.5m		Dasha River Floodway 11100.0m		Dasha River 16023.6m		Taogou River 8877.5m	
		peak discharge (m^3/s)	maximum water level (m)	peak discharge (m^3/s)	maximum water level (m)	peak discharge (m^3/s)	maximum water level (m)	peak discharge (m^3/s)	maximum water level (m)
Condition 9	The tributaries in 20 years design rainstorm, Hanzhuang canal discharge $0m^3/s$	105.2	29.4	449.9	25.6	384.8	28.5	303.2	26
Condition 10	The tributaries in 20 years design rainstorm, Hanzhuang canal discharge $500m^3/s$	105.2	29.4	442.7	27.9	383.6	28.7	301.7	27.2
Condition 11	The tributaries in 20 years design rainstorm, Hanzhuang canal discharge $1000m^3/s$	105.1	29.6	450.9	28.9	382.2	29.1	309.1	28.1
Condition 12	The tributaries in 20 years design rainstorm, Hanzhuang canal discharge $2000m^3/s$	103.6	30.9	450.3	30.6	380.2	30.3	296.2	30

water level of Taogou River shows a rising trend, while the discharge changes little or stays basically unchanged, indicating that the influence of Hanzhuang Canal jacking on Taogou River is mainly on the upstream water level process, but has little or no influence on the discharge process.

Table 6 shows the statistical table of peak discharge and water level of typical sections in Hanzhuang Canal under different discharge conditions. It can be seen from the table that, on the whole, with the continuous increase of the discharge of Hanzhuang Canal, the water level of the main stream of Hanzhuang Canal gradually rises. Affected by the water level of the main stream, the water level of each tributary gradually rises, and the risk of flood disaster is greater. In addition, it can be seen that with the continuous increase of the discharge of Hanzhuang Canal, the peak discharge process of each tributary has almost no change on the whole except for the fluctuation of the discharge affected by the jacking in the initial stage, which indicates that the influence of Hanzhuang Canal jacking on each tributary is mainly on the upstream water level process, while the influence on the discharge process is small or almost none. This achievement received little attention among previous achievements [16-17], which can provide reference for regional water situation forecast and flood control and dispatching command departments.

Conclusion

In this paper, a one-dimensional hydrologic-hydrodynamic coupling model is adopted to investigate river flood characteristics along the canal area effected by Hanzhuang Canal jacking. The main conclusions are as follows:

1. By coupling rainfall runoff (NAM) model with hydrodynamic (NAM) model, a one-dimensional hydrologic-hydrodynamic coupling model was built. The main parameters of the model are determined by parameter calibration. It can be seen from the calibration and verification results that the calibration parameters basically meet the accuracy requirements, the model can basically reflect the hydrologic and hydrodynamic characteristics of the study area, and the simulation results are credible.
2. With the continuous increase of Hanzhuang Canal discharge, the influence of Hanzhuang Canal jacking on its tributaries gradually increases, and the risk of flood disaster is greater.
3. The influence of Hanzhuang Canal jacking on each tributary is mainly on the upstream water level process, while the influence on the discharge process is small or almost none, which can provide reference for regional flood control and dispatching departments.
4. Among the main tributary in the research area, Taogou River was the most influenced by Hanzhuang Canal jacking, with the longest upward tracing distance of the flood, the biggest water level change and the highest risk of the flood disaster, followed by Dasha River and Dasha River Floodway. The influence on Sizhi Ditch is minimal.

Declarations

Ethical approval

Not applicable

Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

Li Chengguang and Li Junfeng wrote the main manuscript text, Chen Xuequn provided the guidence of the article, and Zhu Riqing processed the data.

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Data availability

The calculated and measured data can be accessed through the corresponding author.

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