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Research Article

STUDY ON THE ECOLOGICAL WATER DEMAND OF DULIUJIAN RIVER IN TIANJIN

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ABSTRACT

The Duliujian River is an important ecological river channel in the southern of Tianjin City. However, the Duliujian river has been facing the problems such as water quantity reduction, complicated water source and deterioration of water quality in recent years. In order to restore its ecological function, it is therefore necessary to study its ecological water demand. This study defined the water demand (W) of the rivers as the sum of water cycle consumption water demand (Wa) and the biological habitat water demand (Wb). The ecological water demand of the Duliujian River was then calculated monthly. The research results showed that the ecological water demand gap of the Duliujian River is relatively large, and it needs to be supplemented by external water sources. The findings of this study may provide data support for the joint dispatch of multiple water resources in the Duliujian River.

INTRODUCTION

Ecological water demand refers to the river flow that needs to be maintained to ensure the health of the river ecosystem and its water and sediment balance, water and salt balance, as well as the ecological environment balance in the estuary (Xia *et al*., 2006; Ye *et al*., 2010). For longer rivers, there are differences in geological conditions, water volume, and functions along the way, so there are also differences in the ecological water requirements required for different river sections (Liu *et al*., 2002; Yan *et al*., 2007). The determination of river ecological water demand is of great significance for maintaining the ecological function of the river (Richter *et al*., 2003).

The ecological water demand is a quantity that varies with the temporal and regional changes, and is closely related to the goal of ecological protection (Liu *et al*., 2002; Cai and Rosegrant, 2004). Under different target requirements, the ecological water demand is fairly different (Xu, *et al*., 2018; Yu *et al*., 2018). If there is anobvious lack of ecological water demand, ecological water supplement with external water resources will become to be essential (Ling *et al*., 2014; Feike *et al*. 2015).

Combining the characteristics of predecessors and the characteristics of the river, the ecological environment water requirement (W) of the river is defined as the sum of water consumption (Wa) and the water requirement of biological habitat (Wb) (Wang *et al*. 2014; Wei, 2017;Liu *et al*., 2018). The water demand for water circulation is the consumable water, the water requirement for biological habitat is non-consumptive water (Ye *et al*., 2014; Mao *et al*., 2016), and the water content for salinity is compatible with the water demand for sediment transport. Therefore, the water demand for biological habitat is calculated to be the largest (Wei, 2017; Zhang and Sun, 2016).

In this study, the water demand for the water circulation and the water demand for the biological habitat were firstly calculated month by month. Secondly, based on the principle of numeric value, the ecological water requirement for the Duliujian River was found to be reduced in this study, and the water replenishment plan for the river was therefore determined. In addition, the ecological water demand of the Duliujian River was calculated separately month by month.

STUDY AREA AND METHOD

The Duliujian River is the end of the Daqing River system in the Haihe River Basin, located in the southern of Tianjin (see Fig. 1). The excavation of the river was carried out in 1952–1953 and the river was expanded in 1968-1969. Then, the total length of the river channel increased to 70km. After the completion of the Duliujian River, two large reservoirs, namely Beidagang and Tuanbowa, and three medium-sized reservoirs were built successively. It is the main channel for flood diversion into the sea from Daqing River, Ziya River,

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South Canal, Machang River and other rivers (see Fig. 2). In the past 50 years, it has experienced five major floods, with a total flood discharge of 33.9 billion m^3, and has therefore played a huge role in safeguarding the safety of people's lives and property in the urban areas of Tianjin. In addition, the use of the Duliujian River and these five reservoirs to intercept runoff and store water has played an irreplaceable role in the urban life and economic development of Tianjin.

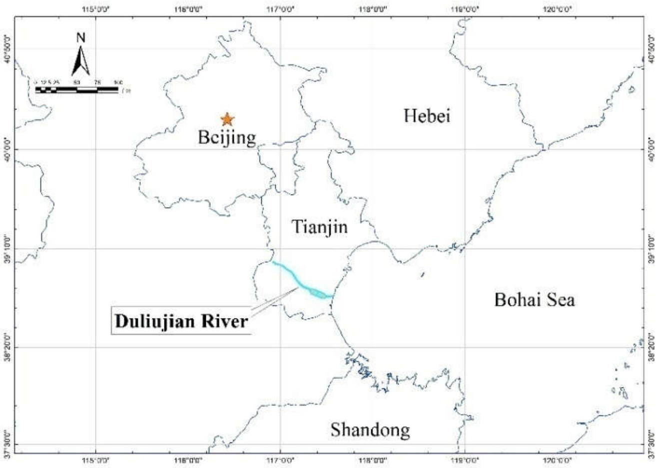

Fig 1 The geographical location of the Duliujian River in Beijing-Tianjin-Hebei Region

Along with the economic and social development, the Gongnongbing Gate, which is an ebb gate preventing the seawater intrusion, has gradually lost its function of preventing seawater intrusion. Due to the serious leakage of the two control gates of Dagang Power Station, the chloride content in the deep trough of the Duliujian River has far exceeded the surface water V standard. At the same time, the river alone also took over the petrochemical pollution wastewater in the sewage river in southern Tianjin, which seriously polluted the water quality of the river. The above problem has caused great damage to the regional water ecology, and the surrounding land was therefore seriously polluted. In order to deal with the serious pollution problems, a Kuanhecao Wetland was constructed in the downstream area of Duliujian River (see Fig. 2).

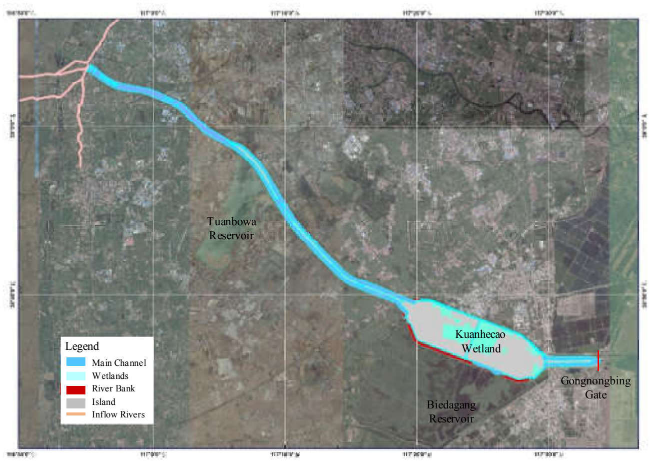

Fig 2 The geographical distribution and trend of the Duliujian River

The water demand for the water circulation

The evaporation of the openwater

Based on the data service provided by the Chinese National Meteorological Information Center, the meteorological data in 1980-2010 of the weather stations within Jinghai District and Jinnan District was collected. And the evaporation of the open water within the study area could be calculated with Eq. (1) month by month.

$$Q_E = E \cdot A \qquad \text{Eq. (1)},$$

where Q_E is the monthly evaporation of the open water within the study area, E is the monthly evaporation per unit area and A is the area of the open water in the study area. The monthly calculated minimum, appropriate and maximum evaporations of the open water in the study area and the Kuanhecao Wetland alone were listed in Table 1.

Table 1 The monthly minimum, appropriate and maximum evaporations of the open water in the study area and the Kuanhecao Wetland

Month	Evaporation of the open water in the study area ($\times10^8 m^3$)			Evaporation of the open waterwithin the Kuanhecao Wetland($\times10^8 m^3$)		
	Min.	Appr.	Max.	Min.	Appr.	Max.
Jan.	0.014	0.027	0.041	0.004	0.008	0.012
Feb.	0.014	0.029	0.043	0.004	0.008	0.012
Mar.	0.026	0.052	0.077	0.007	0.015	0.022
Apr.	0.056	0.113	0.169	0.016	0.032	0.049
May	0.060	0.120	0.180	0.017	0.035	0.052
Jun.	0.060	0.120	0.180	0.017	0.034	0.052
Jul.	0.045	0.089	0.134	0.013	0.026	0.039
Aug.	0.044	0.089	0.133	0.013	0.026	0.038
Sep.	0.039	0.078	0.116	0.011	0.022	0.033
Oct.	0.035	0.071	0.106	0.010	0.020	0.030
Nov.	0.020	0.041	0.061	0.006	0.012	0.018
Dec.	0.013	0.026	0.040	0.004	0.008	0.011

The water demand of wetland soil

The calculating formula for the water demand of wetland soil was

$$Q_t = a\gamma H_t A_t \qquad \text{Eq. (2)},$$

where Q_t is the water demand of wetland soil, a is the percentage of field capacity or saturated water capacity which relies on the soil type in the study area, γ is the soil density, H_t is the soil thickness and $A_t$is the soil area in the wetland.

The wetland soil around the coastal area in Tianjin belongs to Clay and Sub-clay with a saturated percentage of water at about 60%. Then, 60% of saturated water capacity was determined as the appropriate water demand of wetland soil, while 30% and 90% of saturated water capacity as the minimum and maximum ones respectively. The soil density and thickness of the study area were selected at 1.39 g/cm^3 and 120cm respectively since that the soil in the study area is mainly cinnamon soil, meadow soil, marsh soil and fluvo aquic soil. As can be seen in Table 2, the minimum, appropriate and maximum water demands of wetland soil in the study area and the Kuanhecao Wetland alone were calculated monthly.

Table 2 The monthly minimum, appropriate and maximum water demands of wetland soil in the study area and the Kuanhecao Wetland

Month	Water demand of wetland soil in the study area ($\times 10^8$ m^3)			Water demand of wetland soilwithin the Kuanhecao Wetland($\times 10^8$ m^3)		
	Min.	Appr.	Max.	Min.	Appr.	Max.
Jan.	0.052	0.103	0.155	0.046	0.092	0.138
Feb.	0.052	0.103	0.155	0.046	0.092	0.138
Mar.	0.052	0.103	0.155	0.046	0.092	0.138
Apr.	0.052	0.103	0.155	0.046	0.092	0.138
May	0.052	0.103	0.155	0.046	0.092	0.138
Jun.	0.052	0.103	0.155	0.046	0.092	0.138
Jul.	0.052	0.103	0.155	0.046	0.092	0.138
Aug.	0.052	0.103	0.155	0.046	0.092	0.138
Sep.	0.052	0.103	0.155	0.046	0.092	0.138
Oct.	0.052	0.103	0.155	0.046	0.092	0.138
Nov.	0.052	0.103	0.155	0.046	0.092	0.138
Dec.	0.052	0.103	0.155	0.046	0.092	0.138

The vegetation evapotranspiration

Based on the analyses of literature and meteorological data, the potential average value of vegetation evapotranspiration was determined. Then, the monthly minimum, appropriate and maximum vegetation evapotranspiration in the study area and the Kuanhecao Wetland could be generated by multiplyingthe potential evapotranspiration with the ratios of 0.8, 1.0 and 1.2, respectively. The calculated results were listed in Table 3

Table 3 The monthly minimum, appropriate and maximum vegetation evapotranspiration in the study area and the Kuanhecao Wetland

Month	Vegetation evapotranspiration in the study area ($\times 10^8$ m^3)			Vegetation evapotranspiration within the Kuanhecao Wetland($\times 10^8$ m^3)		
	Min.	Appr.	Max.	Min.	Appr.	Max.
Jan.	0.000	0.000	0.000	0.000	0.000	0.000
Feb.	0.000	0.000	0.000	0.000	0.000	0.000
Mar.	0.034	0.042	0.051	0.028	0.035	0.042
Apr.	0.080	0.100	0.120	0.066	0.083	0.100
May	0.112	0.140	0.168	0.093	0.117	0.140
Jun.	0.137	0.171	0.205	0.114	0.142	0.171
Jul.	0.148	0.185	0.222	0.123	0.154	0.185
Aug.	0.143	0.178	0.214	0.119	0.149	0.178
Sep.	0.116	0.145	0.174	0.097	0.121	0.145
Oct.	0.077	0.097	0.116	0.064	0.080	0.097
Nov.	0.028	0.035	0.042	0.024	0.029	0.035
Dec.	0.000	0.000	0.000	0.000	0.000	0.000

The precipitation

According to the meteorological data in 1980-2010 of the weather stations within Jinghai District and Jinnan District, the monthly precipitations in the study area and the Kuanhecao Wetland could be determined, respectively (see Table 4).

Table 4 The monthly precipitations in the study area and the Kuanhecao Wetland

Month	Precipitation in the study area ($\times 10^8$ m^3)	Precipitation within the Kuanhecao Wetland($\times 10^8$ m^3)
Jan.	0.007	0.004
Feb.	0.011	0.007
Mar.	0.022	0.014
Apr.	0.050	0.031
May	0.095	0.059
Jun.	0.191	0.119
Jul.	0.344	0.214
Aug.	0.283	0.176
Sep.	0.116	0.072
Oct.	0.065	0.040
Nov.	0.026	0.016
Dec.	0.007	0.005

The leakage of surface runoff

Based on a comprehensive literature analysis, the leakage of surface runoff was calculated at 10% of the annual water consumption.

The water demand forthe biological habitat

The ecological water demand for the maintenance of salinity

In considering that the bottom of the offshore area of Bohai Bay is relatively gentle, the average water depth of the outer boundary of the estuary was set at 8m based on literature reviewer and filed survey. As such, as can be seen in Table 5, The ecological water demand for the maintenance of salinity could therefore be calculated month by month.

Table 4 The monthly minimum, appropriate and maximum water demands of biological habitat

Month	Water demand for the biological habitat($\times 10^8$ m^3)		
	Min.	Appr.	Max.
Jan.	0.022	0.028	0.033
Feb.	0.024	0.030	0.035
Mar.	0.027	0.034	0.040
Apr.	0.028	0.035	0.043
May	0.032	0.039	0.047
Jun.	0.030	0.037	0.045
Jul.	0.028	0.035	0.043
Aug.	0.027	0.034	0.040
Sep.	0.022	0.028	0.033
Oct.	0.019	0.024	0.028
Nov.	0.158	0.197	0.237
Dec.	0.012	0.015	0.018

The ecological water demand for sediment transport

The calculating formula of the ecological water demand for sediment transport was

$$F_s = Q_i / C_i \qquad \text{Eq. (3)},$$

where F_s is the ecological water demand for sediment transport, Q_i is annual sediment accumulation and C_i is the discharge capacity of the river which can be expressed by the sediment carrying capacity of water flow. The saturated sediment concentration is closely related to the characteristics of silt deposition, the minimum, appropriate and maximum sediment transport capacities were set at 3.0kg/m^3, 15.0kg/m^3 and 30.0kg/m^{3}in this research, respectively. Since the construction of Gongnongbing Gate in 1967, the annual sediment accumulation was about 4.35×10^4m^3, which could be converted into 6.3×10^7kg in mass. Then, the maximum, appropriate and minimum ecological water demand for sediment transport could therefore be generated as 0.210×10^8m^3, 0.042×10^8m^3 and 0.021×10^8m^3, respectively.

DISCUSSION AND CONCLUSION

Based on the calculated results of the water demand for the water circulation in section 3 and the water demand for the biological habitat in section 4, the ecological water demands of the whole Duliujian River as well as the Kuanhecao Wetland alone could be obtained by adding the consumable water to the maximum value of the compatible non-consumptive water. The final results of the ecological water demand of the Duliujian River and the Kuanhecao Wetland calculated in this research were listed in Table 6. It can be seen in the table, the annual minimum, appropriate and maximum ecological water demands of the Duliujian River were 1.239×10^8m^3, 2.611×10^8m^3 and 3.982×10^8m^3, while the values were

$1.106\times10^8 m^3$, $2.071\times10^8 m^3$ and $3.037\times10^8 m^3$ for the Kuanhecao Wetland, respectively. No matter from any angle, the ecological water demands of the Kuanhecao Wetland accounted for more than 75% of that for the whole Duliujian River.

Table 6 The minimum, appropriate and maximum ecological water demands of the Duliujian River and the Kuanhecao Wetland

Month	Ecological water demand of Duliujian River ($\times10^8 m^3$)			Ecological water demand of Kuanhecao Wetland ($\times10^8 m^3$)		
	Min.	Appr.	Max.	Min.	Appr.	Max.
Jan.	0.089	0.160	0.230	0.070	0.126	0.181
Feb.	0.088	0.160	0.232	0.070	0.126	0.182
Mar.	0.125	0.217	0.310	0.097	0.164	0.232
Apr.	0.175	0.310	0.445	0.128	0.214	0.300
May	0.169	0.317	0.464	0.132	0.226	0.321
Jun.	0.096	0.249	0.402	0.091	0.190	0.289
Jul.	(0.062)	0.078	0.219	(0.001)	0.096	0.193
Aug.	(0.009)	0.130	0.268	0.031	0.126	0.221
Sep.	0.121	0.246	0.371	0.106	0.193	0.280
Oct.	0.127	0.238	0.349	0.102	0.179	0.256
Nov.	0.241	0.360	0.478	0.220	0.317	0.414
Dec.	0.079	0.146	0.214	0.060	0.113	0.166
Annual	1.239	2.611	3.982	1.106	2.071	3.037

According to the statistical data of annual surface average runoff flowing into sea of the rivers in Tianjin, the annual average flow discharge of the Duliujian River flowing into Bohai Bay was $36.60\times10^8 m^3$in 1956-1959. In 2001-2008, this value has been reduced more than 99% to $0.219\times10^8 m^3$. And in recent years, the annual surface runoff of the Duliujian River flowing into the sea was still continued to decline, and was almost negligible in 2014-2016.

In comparison with the calculated results of this study, the annual average surface runoff of the Duliujian Riverin recent years was far lower than the minimum annual ecological water demand. As such, the surface runoff of the Duliujian River flowing into the sea cannot match the ecological requirement of the river estuary. In summary, the ecosystem of the Duliujian River would be seriously damaged and the estuary would be destroyed or even disappeared if the ecological water supplement cannot be carried out with external water sources.

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Author Contributions

Z.W., W.X., X.S. and T.H. were responsible for the research design; Z.W. and W.X. drafted the main text and prepared the figures/tables; H.H. provided the financial and logistical support; All authors discussed the results, reviewed and revised the manuscript.

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