Nature Environment and Pollution Technology
An International Quarterly Scientific Journal | ISSN: 0972-6268 | Vol. 14 | No. 4 | pp. 989-993 | 2015

Original Research Paper

Analyses of Diversion Water Input's Influence on Water Quality of Dahuofang Reservoir

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com
Received: 18-08-2015
Accepted: 20-09-2015

Key Words:
Dahuofang Reservoir
Diversion water input
Water quality

ABSTRACT

This paper selected Dahuofang Reservoir as the research area, analysed the relationship between water quality and diversion water input, determined the right weight of each index affected the water quality based on correlation analysis and entropy weight method. The results showed that after the diversion water input, the DO is 6739.17t, COD_{Mn} is 1735.00t, BOD is 625.83t, NH_3-N is12.07t, TP is 12.5t, TN is 1860.75t, coliform-group is 1.38 $\times 10^{15}$. The correlation between the indexes of DO, COD_{Mn}, BOD, TN, coliform-group and water quality is significant after diversion water input. The affected right weights of the amount of TN, coliform-group and NH_3-N input are more than 0.1, the highest right weight is of TN input (0.1804), followed by coliform-group (0.1173) and NH_3-N (0.1165); the most slight one is TP (0.0164). In terms of comprehensive analysis, the influence of each index of diversion water input on water quality of Dahuofang reservoir, the order is TN>coliform-group>NH_3-N>BOD>DO>COD_{Mn}>TP.

INTRODUCTION

As water quality was severely damaged, water diversion, aiming at improving water quality, emerged in Japan. In order to improve the water quality of Sumida, 16.6m^3.s^{-1} of freshwater from Tone River and Arakawa River was discharged in 1964, which showed obviously positive effect (Tang et al. 1998). In 1975, Japan continued diverting water between rivers, more than 10 rivers, including Nakagawa River, Alata River, Utagawa River were purified by clean water in this way (Shanghai Water Conservancy Annals 1997). Afterwards, water diversion project from Mississippi River to Pontchartrain lake in America (Mccallum 1994) and water diversion project of Veluwemeert Lake in Holland (He et al. 2005) showed good results. China launched the south-to-north water diversion project in 2002, the operation started recently (Cheng et al. 2015). Carles & Narcis (2003) analysed the influence on environment of downstream of Ebro River, flow rate as well as the water quality change caused by Spain National Hydropower Plan in respect of salinization, biological species, and sediment transform capacity of water diversion over river basin. Ram et al. (2008) made the EIA of water diversion within the Melamchi water supply project in Nepal. Sharad et al. (2005) studied the water yield balance of domestic water diversion projects over four main river basins. Pei et al. (2004) found that the south-to-north water diversion project suppressed the worsening of aquatic ecological environment of Haihe River basin to some extent, however the water discharged into ocean was still in bad condition. Most of the research above concentrate on environmental impact of water diversion on environment of river valley, while research of relation between diversion water input and water quality in downstream reservoir was rarely carried out. This paper analyses the impact of water diversion on Dahuofang reservoir and came up with explicit conclusions of correlation of diversion water input and water quality of Dahuofang reservoir, based on diversion water volume and indexes from 2011 to 2013.

MATERIALS AND METHODS

Study area: Dahuofang reservoir, as a large (I) type reservoir locating on the main stream of Hun River, is one of the most important sources that provide drinking water in Liaoning Province, China. It is in Dongzhou district, Fushun, Liaoning Province, E123°00'~125°15', N41°00' ~42°15', and built in 1958. It is 35km long, with the widest point of 4km and the narrowest point of 0.3km, a ribbon shaped valley reservoir (Feng et al. 2011, Liu et al. 2013). Mountain area of east Liaoning is the water conservation area of Liaoning Province, it provides 62% of total water resource of the province. The conservation by forest resources mainly comprised of non-commercial forest, and wild forest is 12

$Bt \cdot a^{-1}$, providing 80% of agricultural and industrial water for 10 big cities which accounts for 94% of the economic capacity of Liaoning Province (Han et al. 2013). The mountain area of east Liaoning, as the diversion area and transmission line of Dahuofang water diversion project, has great importance on ecological safety and unique geological advantage (Zhang et al. 2012). The designed water volume is $70m^3 \cdot s^{-1}$, and average volume of $1.8Bm^3$. The water inlet was set 5.4km away from the right bank of Fengming Reservoir of Hengren, Benxi. The diversion water was directed to Suzi River (67km), which is a side stream of Hui River and then into the Dahuofang Reservoir during which it passed through the underground tunnel (85.3km) whose exit located 1.8km (1.5km from Zhangjing village) away from Mujia Power Plant of Suzi River in Xinbin, Fushun.

Data collection: The calculation was based on the data collected in water diversion area of Hengren Reservoir and water diversion data of 2011-2013, after the water diversion project started. Since diversion water volume was recorded annually, there was no monthly data. The total volume was evenly distributed to each month and used to calculate each water quality index of water in Dahuofang Reservoir after the project started operating, together with the monthly average indexes of water quality in 2011-2013 from water diversion area in Hengren Reservoir.

Calculations: With data above, the correlation between diversion water input from upstream of Dahuofang Reservoir and water quality was evaluated by correlation analysis. Also, entropy weight method was used to analyse the right weight of each main index, clarifying how each index influenced water quality. By preliminary analysing of major constituent and comparison with measured data, the main indexes that influenced water quality in Dahuofang Reservoir are NH_3-N, TP, TN, DO, COD_{Mn}, BOD, coliform-group, therefore these indexes are 7 key factors in this study.

RESULTS AND DISCUSSION

Calculation of diversion water input of Dahuofang Reservoir: The input water volume was $200Mm^3$, $200Mm^3$, $300Mm^3$ in 2011, 2012 and 2013 respectively. According to the method introduced, after water diversion, the total DO input is 6739.17t, total COD_{Mn} input is 1735.00t, total BOD input is 625.83t, total NH_3-N input is 12.07t, total TP input is 12.5t, total TN input is 1860.75t, total coliform-group input is 1.38×10^{15}. The annual input data are given in Table 1.

Relation between diversion water input and water quality in reservoir sections: Three central representative monitoring sections of Dahuofang Reservoir (section 37, section 73, section 7) were set to measure water quality indexes.

***Response to diversion water input of water quality in section 37*:** As can be seen in Table 2, the correlation exists between water quality in section 37 and diversion water input. DO input is obviously in positive correlation with NH_3-N, TP and TN, in other words, NH_3-N, TP, TN were raised in section 37 because of the water diversion. DO is in positive proportion with coliform-group and in negative proportion with COD_{Mn}, which means DO came with water diversion to some extent lifted the coliform-group in section 37, while reduced COD_{Mn} at the same time. COD_{Mn} input is in positive proportion with TP and TN, which is the evidence that COD_{Mn} input to some extent made TP, TN of original water to increase. The negative correlation with coliform-group leads to the conclusion that COD_{Mn} input caused coliform-group reduction in reservoir to some extent. Input BOD is in positive correlation with TP, TN and in negative correlation with COD_{Mn}, which means that BOD came with water diversion to some extent lifted TP, TN in section 37, while reduced COD_{Mn} at the same time. Input TN is obviously positively correlated with TP, TN in reservoir and negatively correlated with COD_{Mn} in reservoir. This can be explained by a lifting effect on TP, TN and decreasing effect on COD_{Mn}. TP input is in negative proportion with BOD as it caused BOD declination in the reservoir. NH_3-N input is positively correlated with DO and COD_{Mn} in section 37. The increased amount of DO and COD_{Mn} can be resulted from NH_3-N input. Coliform-group input is positively correlated with TP, TN and negatively correlated with DO in section 37. To some extent the increased TP, TN and declined DO can be accounted to the input coliform-group.

***Response to diversion water input of water quality in section 37*:** As Table 3 shows, diversion water input is correlated with water quality indexes of section 73 of Dahuofang Reservoir after diversion. Respectively, DO input is in significant positive correlation with TN and BOD, and is positively correlated with TP, which means DO input caused increasing content of TP, TN, BOD to some extent. COD_{Mn} input is significantly positively correlated with TP and TN. It raised the TP, TN content to some extent. BOD input is in positive proportion with TP. The BOD and fluoride content increased because of extra BOD input, which to some extend also raised TP content. On the other hand, it is negative correlated with COD_{Mn}, which means the BOD input caused COD_{Mn} depletion. Input of coliform-group is significantly in positive correlation with NH_3-N, and is less obvious positively-correlated with TN. The input of coliform-group together with the diversion water increased the coliform-group in section 73, to some extent raised NH_3-N and TN content. For NH_3-N, TP and TN input, no significant correlation with water indexes of section 73 was found.

Response to diversion water input of water quality in

Table 1: Results of water diversion exogenous inputs in Dahuofang reservoir.

Year	DO (t)	COD_{Mn}(t)	BOD(t)	NH_3-N(t)	TP(t)	TN(t)	Coliform-group (*10000)
2011	2832.50	685.00	327.50	1.75	3.50	722.75	7.09E+10
2012	1915.00	528.33	120.00	2.70	4.67	564.83	5.75E+10
2013	1991.67	521.67	178.33	7.62	4.33	573.17	9.18E+09
Sum	6739.17	1735.00	625.83	12.07	12.50	1860.75	1.38E+11

***section 7*:** From Table 4, it can be concluded that water quality indexes of section 7 are correlated with diversion water input. Among which DO, BOD and TN input are significantly positively-correlated with TP and TN content. Therefore, exogenous input of DO, BOD and TN caused TP, TN content to increase. DO input is in obvious positive correlation with DO content, and also positively correlated with coliform-group and negatively correlated with COD_{Mn}. The increasing of coliform-group and decreasing of COD_{Mn} can be accounted to exogenous input of DO. As for COD_{Mn} input, it is in significantly positively correlation with TP, TN, and negatively correlated with BOD and coliform-group. This input of COD_{Mn} caused increasing of TP, TN content and depletion of BOD and coliform-group to some extent. Exogenous input of BOD is significantly correlated with BOD and COD_{Mn}. To some extent it caused depletion of these two indexes in section 7. TP input is negatively correlated with BOD and DO in a significant way. This correlation shows that the TP input to some extent caused decreasing of BOD and DO in section 7. Coliform-group on the other hand is significantly positively correlated with COD_{Mn}. It is also negatively correlated with DO and with BOD in a significant way. As exogenous coliform-group recharged, it caused increasing of COD_{Mn} and decreasing of DO and BOD. No obvious correlation of NH_3-N and any other indexes was found in section 7.

Right weight analyses of impact of each index of exogenous water diversion: This paper used entropy weight method to calculate impact of each index of exogenous diversion water recharged to Dahuofang Reservoir to its water quality based on water quality data from section 37, section 73 and section 7. The calculations were processed as following.

***1. Normalization of data*:** Data used for normalization are average annual indexes of diversion water from 2011 to 2013. The original data were handled by maximum difference normalization method. The normalizing equation is:

$$X_{ij} = \frac{x_{ij} - x_{jmin}}{x_{jmax} - x_{jmin}} \quad ...(1)$$

Where, X_{ij} is the normalized value of j^{th} index in i^{th} factor, x_{ij} is the real value of j^{th} index in i^{th} factor, x_{jmax} is the maximum real value of j^{th} index in i^{th} factor, x_{jmin} is the minimum real value of j^{th} index in i^{th} factor.

2. Integrated normalization of the indexes is made and the proportion of j^{th} in i^{th} factor is calculated: Then apply integrated normalization to the normalized indexes. The equation used for calculating j^{th} index right weight of i^{th} factor is:

$$p_{ij} = \frac{X_{ij}}{\sum_{i=1}^{n} X_{ij}} \quad ...(2)$$

Where, P_{ij} is the value after integrated normalization, X_{ij} is index value after normalization, of which = i 1,2,…, n; j = 1,2,..., m.

3. The entropy of index is calculated as:

$$e_j = -k\sum_{i=1}^{n} P_{ij} \times lnP_{ij} \quad ...(3)$$

in which $k = 1/lnn$, $0 \le e_j \le 1$

4. The coefficient of variance of j^{th} index is calculated as:

$$g_j = 1 - e_j \quad ...(4)$$

5. Calculation of right weight of j^{th} index:

$$W_j = \frac{g_j}{\sum_{j=1}^{m} g_j} \quad ...(5)$$

According to methods illustrated above, the right weight of impact of exogenous diversion water to water quality of Dahuofang Reservoir is analysed by entropy weight method. The results are listed in Table 5. As can be seen in Table 5, by entropy weight method, exogenous diversion water input shows various influences on water quality of Dahuofang Reservoir. Among which TN has the maximum right weight (0.1804). Second important factors are coliform-group and NH_3-N, with right weight of 0.1173 and 0.1165 respectively.

The minimum right weight is 0.0164, which belongs to TP. Overall, the right weight of exogenous water input impacting on water quality of Dahuofang Reservoir can be shown as follows: TN > Coli-group > NH_3-N > BOD > DO > COD_{Mn} > TP. After operation, the exogenous input of TN, coliform-group, NH_3-N have right weights over 0.1, which means that these factors have main impact on water quality of reservoir water, in other words, they significantly changed water quality indexes, which agrees with the analyses above. The rest indexes have smaller right weight; right weight of TP is the minimum, which means it has least impact on water quality of Dahuofang Reservoir.

CONCLUSIONS

After water was diverted to Dahuofang Reservoir, total DO input was 6739.17t, total COD_{Mn} input was 1735.00t, total BOD input reached 625.83t, NH_3-N input was 12.07t, TP input was 12.5t, TN input was 1860.75t, and coliform-group reached 1.38×10^{15}.

Each diversion water input index is significantly correlated with water quality of Dahuofang Reservoir. DO input is positively correlated with TN and TP in all the three sections; positively correlated with coliform-group in section 37 and section 7 and with BOD, while negatively correlated with COD_{Mn}. COD_{Mn} input is in significant positive correlation with TP and TN in the three sections, and in negative correlation with BOD in section 7. BOD input is positively correlated with TP in the three sections, with TN in section 37 and section 7, while in negative correlation with COD_{Mn} in three sections. TN input is in significant positive correlation with TP and TN in the three sections, and in negative correlation with COD_{Mn} in Section 37. TP is in significant negative correlation with BOD in section 7 and section 37 as well as DO in section 7. NH_3-N input is in

Table 2: Correlation between water diversion exogenous inputs and Section 37 water quality. *indicates a significance level of 0.05, **indicates a significance level of 0.01.

Input water indexes	TP	TN	NH_3-N	DO	COD_{Mn}	BOD	Coliform-group
DO	0.372**	0.461**	0.321**	0.199	- 0.238*	0.023	0.278*
COD_{Mn}	0.525**	0.731**	- 0.068	- 0.113	- 0.187	0.065	- 0.308**
BOD	0.532**	0.639**	- 0.087	- 0.178	- 0.472**	- 0.153	- 0.165
NH_3-N	0.018	- 0.222	- 0.253	0.339**	0.235*	0.006	- 0.220
TP	- 0.099	- 0.072	- 0.260*	- 0.157	0.104	- 0.405**	0.020
TN	0.468**	0.590**	0.126	- 0.023	- 0.413**	- 0.022	- 0.122
Coliform-group	0.048	0.305**	0.056	- 0.279*	0.278	- 0.110	- 0.044

Table 3: Correlation between water diversion exogenous inputs and Section 73 water quality. *indicates a significance level of 0.05, **indicates a significance level of 0.01.

Input water indexes	TP	TN	NH_3-N	DO	COD_{Mn}	BOD	Coliform-group
DO	0.543*	0.589**	- 0.026	0.047	- 0.394	- 0.739**	0.248
COD_{Mn}	0.774**	0.585**	0.073	- 0.116	- 0.329	- 0.341	- 0.241
BOD	0.538*	0.176	- 0.256	- 0.280	- 0.475*	- 0.407	- 0.006
NH_3-N	- 0.141	- 0.163	- 0.305	- 0.226	- 0.009	0.157	- 0.188
TP	- 0.344	- 0.396	0.097	0.218	0.240	- 0.021	0.140
TN	0.415	0.302	- 0.431	0.284	- 0.034	- 0.314	- 0.056
Coliform-group	0.379	0.451*	0.606**	- 0.086	0.024	0.153	0.096

Table 4: Correlation between water diversion exogenous inputs and section 7 water quality.* indicates a significance level of 0.05, ** indicates a significance level of 0.01.

Input water indexes	TP	TN	NH_3-N	DO	COD_{Mn}	BOD	Coliform-group
DO	0.373**	0.492**	0.125	0.437**	- 0.301**	0.002	0.210*
COD_{Mn}	0.482**	0.652**	- 0.066	- 0.163	- 0.119	- 0.216*	- 0.230*
BOD	0.450**	0.528**	- 0.255*	- 0.122	- 0.338**	- 0.299**	- 0.178
NH_3-N	- 0.165	- 0.125	- 0.115	0.128	0.096	0.094	- 0.177
TP	- 0.079	- 0.050	- 0.243*	- 0.375**	0.205	- 0.462**	- 0.023
TN	0.484**	0.722**	0.066	- 0.071	- 0.407**	- 0.167	0.037
Coliform-group	0.072	0.085	0.010	- 0.240*	0.397**	- 0.377**	- 0.134

Table 5: The weight right of water quality impact on water quality.

Indicator level	Influencing factor	Weight right
Diversion water input factor	TN	0.180421
	TP	0.016471
	NH_3-N	0.116513
	BOD	0.053381
	DO	0.035225
	COD_{MN}	0.023483
	Coli-group	0.117308

significant positive correlation with DO content in section 37. Coliform-group is in positive correlation with TN in both section 37 and section 73, and in a significant way with NH_3-N in section 73 and CODMn in section 7, as well as TP in section 37; it is negatively correlated with DO, BOD. Results show that DO, COD_{Mn}, BOD, TN and coliform-group are significantly correlated with TP, TN, which are key indexes of excessive pollutants in Dahuofang Reservoir. They are the main factors that change the water quality in reservoir. Exogenous input of TN, coliform-group and NH_3-N have right weights over 0.1, which means that these factors have main impact on water quality of reservoir water. Among these TN has the maximum right weight of 0.1804. Same conclusion can be drawn with the analyses of original data. Coliform-group ranks the second place with a right weight of 0.1173 followed by NH_3-N whose right weight is 0.1165. TP has least impact on water quality of Dahuofang Reservoir. Overall, the right weight of exogenous water input impacting on water quality of Dahuofang Reservoir can be shown as follows: TN > coliform-group > NH_3-N > BOD > DO > COD_{Mn} > TP.

According to the results, after operation of the project, exogenous input of DO, COD_{Mn}, BOD, TN and coliform-group have significant influence on water quality of reservoir, especially TN. Therefore, the importance of protection of reservoir water should be put on TN decreasing, together with decreasing other index, and draw up measures for protection.

ACKNOWLEDGEMENTS

This work was financially supported by the programs as follows: Research on Restoration in the Desertificated Parts of Main Stream Basin of Liaohe River Basedon Vegetation, NSFC (31470710); Studies on the Influence of Papermaking Wastewater on Liao River Delta Wetland Ecosystem and Ecological Restoration, NSFC (31100517); The State Water Pollution Control and Governance Science and Technology Major Project (2012ZX0720004); The Graduate Innovative Training Project of Shenyang Agricultural University (2013); The Talents Support Program of Liaoning, China (LJQ2011070) and the Major Science and Technology Project of Liaoning, China (2012212001).

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