OPEN ACCESS
Saudi Journal of Engineering and Technology
Abbreviated Key Title: Saudi J Eng Technol
ISSN 2415-6272 (Print) |ISSN 2415-6264 (Online)
Scholars Middle East Publishers, Dubai, United Arab Emirates
Journal homepage: http://scholarsmepub.com/sjet/

Original Research Article

A Research on the Performance of Industrial Wastewater Emission Reduction in Beijing, Tianjin and Hebei based on the Modified Kaya Identity

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DOI:10.21276/sjeat.2019.4.7.1 | **Received:** 29.06.2019 | **Accepted:** 10.07.2019 | **Published:** 23.07.2019

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Abstract

This paper analyses the driving for the emission reduction performance of industrial wastewater from 2008 to 2017 in Beijing, Tianjin and Hebei by utilizing the modified Kaya identity and the Logarithmic Mean Divisia Index (LMDI) method. As a result, we find that industrial water-saving technology and water consumption per unit of industrial GDP are the negative inhibitors of industrial wastewater discharge, while worker productivity and the scale of workers are the positive factors for industrial wastewater discharge. This study also shows that although the performance of industrial wastewater reduction in this area has improved in the last ten years, there is still room for improvement.

Keywords: modified Kaya identity; LMDI; industrial wastewater discharge; emission reduction.

INTRODUCTION

Water is not only the material basis to support regional socio-economic development, but also an essential natural resource to maintain the balance of the ecosystems. However, whilst the possession of water per capita in the area of Beijing, Tianjin and Hebei is scarce, the spatial and temporal distribution of these three regions is instead significantly different in excess. Along with the economic growth, both processes of industrialization and urbanization have also improved, but the total amount of industrial water, the low-efficiency of water-usage and the environmental pollution caused by wastewater discharge have functioned as a constraint for industrial development. Therefore, it is necessary to analyze the emission reduction of industrial wastewater in Beijing, Tianjin and Hebei to find a better way to use water resources.

In recent years, domestic and overseas scholars have carried out studies on resource consumption and emission reduction during economic development by utilizing methods such as Sample average division (SAD) [1], Adaptive weighting division (AWD) [2], LMDI [3], and Kaya identity [4]. They showed that economic development, industrial restructuring, and population increase have a positive impact on the increase in total water use. The increase in water intensity effects has an inhibitory effect on the increase in total water use [5-8]. Available works have far laid emphasis on the importance of carbon reduction [9]. Many researches were involved in the research of carbon dioxide (CO_2) emission and ecological efficiency based on input-output method [10-12], comprehensive index analysis method [13], analytic hierarchy process [14, 15], fuzzy comprehensive evaluation method [16], we could find that the standard of living and technological advances could greatly contribute to the decrease of CO_2 emission; the heavier industrial structure, extensive mode of growth and urbanization could increase CO_2 emission. Compared with other evaluation methods on the efficiency, Directional Distance Function (DDF) method has proved to be more accurate by taking the expected and undesired output [17], it could better measure emissions performance, DDF has been utilized in many researches, including measuring CO_2 emission efficiency and emission reduction potential in China [18], the ecological efficiency of Malaysian manufacturing [19], 10 cities in the Lancing River [20], and measurement of the ecological efficiency of 281 CWWTPs in 126 national industrial parks [21], these studies show that each region has a distinct efficiency and target value, and the region not on the production frontier should pay most attention to carbon dioxide emission reduction [22].

On the whole, the existing literature pays less attention to the positive impact of wastewater discharge performance improvement on national economic construction and ecological protection, and most of research objects are selected from provincial or municipal cities, and less involved in prefecture-level cities across the province. Based on the commonality of water resources and energy, this paper draws on the widely used theories, models and methods in the field of energy and carbon emissions. The difference between this paper and previous research is that this study will utilize the modified Kaya Identity model and the LMDI model to identify, quantify, and explain the effect of industrial water saving technology, the intensity of water consumption per unit of industrial GDP, worker productivity and population scale on industrial wastewater discharge in Beijing, Tianjin and Hebei. Finally, this study will estimate the emission reduction performance through using DDF.

MATERIAL AND METHODS

Modified Kaya identity

Kaya identity was firstly introduced by Japanese professor, Yoichi Kaya [23], which indicated that carbon emissions are associated with energy efficiency, energy structure, economic level and population. In this paper, we continue a macroscopic research on the influencing factors of industrial wastewater based on the Kaya identity. A Kaya framework for industrial wastewater was established to analyze the effects of industrial water-saving technology, water consumption intensity per unit of industrial output value, worker productivity and population on industrial wastewater discharge by selecting the total amount of industrial water use, total industrial output value and the number of employees of industrial enterprises. Then we establish a Kaya model for industrial wastewater discharge, the CO_2 emissions are replaced by industrial wastewater discharge, the general formula is:

$$W=\frac{W}{E}\times\frac{E}{GDP}\times\frac{GDP}{P}\times P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

LMDI model

LMDI was utilized to analyze the mechanism of various factors based on Kaya's identity [24]. In this study, LMDI is used to decompose as in equation (1) as follows:

$$\Delta W=\Delta\frac{W}{E}\times\Delta\frac{E}{GDP}\times\Delta\frac{GDP}{P}\times\Delta P \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

The actual value and contribution rate of each factor to industrial pollutant emission could be measured by these four change effect indicators; the calculation process is as follows:

$$\Delta W_{WE}=\frac{W^T\text{-}W^O}{\ln W^T-\ln W^O}\ln\left(\frac{WE^T}{WE^O}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

$$\Delta W_{EG}=\frac{W^T\text{-}W^O}{\ln W^T-\ln W^O}\ln\left(\frac{EG^T}{EG^O}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$\Delta W_{GP}=\frac{W^T\text{-}W^O}{\ln W^T-\ln W^O}\ln\left(\frac{GP^T}{GP^O}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

$$\Delta W_{P}=\frac{W^T\text{-}W^O}{\ln W^T-\ln W^O}\ln\left(\frac{P^T}{P^O}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (6)$$

ΔW refers to the change of industrial wastewater discharge caused by various factors. The superscripts T and O represent the beginning and the end of period.

Emission Reduction Measurement based on DDF

Fare *et al.*, [25] constructed the following DDF based on the Ellenberger shortage function:

$$D_0^t\left(x^t,y^t,b^t;g\right)=\sup\left\{\beta:\left(y^t,b^t\right)+\beta g\in p^t\left(x^t\right)\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7)$$

β could be obtained by solving the following linear programming:

$$\left(x^{t,k},y^{t,k},b^{t,k},-b^{t,k}\right)=Max\beta,s,t.\ \sum_{t=1}^{T}\sum_{k=1}^{K}Z_k^t,y_k^t\geq(1+\beta)y_k^t \quad \ldots\ldots\ldots\ (8)$$

$$\sum_{t=1}^{T}\sum_{k=1}^{K}Z_k^t,b_k^t=\left(1-\beta\right)b_k^t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (9)$$

Under the conditions of considering an undesired output of wastewater, the occurrence of industrial wastewater discharge could be obtained by the above method. Therefore this highlights the importance of DDF method when attempting to estimate the emission reduction performance.

Data collection

This paper collected an extensive amount of references from other journals such as the National Bureau of Statistics, China Urban Statistical Yearbook, and Hebei Statistical Yearbook, Hebei Province Water Resources Bulletin and the statistical yearbooks, environmental bulletins, water resources bulletin of various cities. The research period is set for 2008-2017 and the variable data is chosen and processed according to the characteristics of the research objects which are: Industrial wastewater discharge, total industrial water consumption industrial GDP and Employees in industrial enterprises.

RESULTS AND DISCUSSION

The Driving Factors Composition

In order to further analyze the mechanism of industrial water-saving technology, water consumption intensity per unit of industrial output value, worker productivity and the scale of workers on industrial wastewater discharge, this paper applies LMDI to calculate the contribution per unit of the four factors that correlates to the industrial wastewater discharge.

Industrial Water Saving Technology

The industrial water-saving technologies contributed to the reduction of industrial wastewater discharge during 2008-2017 as shown in Table-1. The discharge of industrial wastewater in Beijing and Tianjin was significantly reduced compared with other areas. Under the application of industrial water-saving technology, the discharge of industrial wastewater in Beijing has totally decreased by 126.63 million tons and the annual reduction has kept at around 1.3 billion tons in 2015-2017. Although the discharge of industrial wastewater in Tianjin varied greatly, it showed a general increase and subsequently it dropped by 818.637 million tons. By comparison, the discharge of industrial wastewater in Hebei Province was much smaller than that of Beijing and Tianjin. Among the eleven prefecture-level cities in Hebei, Tangshan had a remarkable drop reaching 231.34 million tons, following with Shijiazhuang, 2017.52 million tons. On the other hand, Xingtai only decreased by 18.624 million tons.

To conclude, the reduction of industrial wastewater discharge caused by industrial water-saving technology kept on an ascending trend, which signified a gradual improvement. However, the imbalance and difference of regional development still persists, especially in developed economic regions like Beijing and Shijiazhuang, where there was a remarkable reduction than those underdeveloped cities as Cangzhou and Hengshui. This demonstrates that economically developed regions could take advantage of their rapid growth to undertake a series of measures and all the measures had achieved a success in the reduction.

Table-1: Factor decomposition results of industrial water-saving technology on industrial wastewater discharge

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	-124663	-124942	-117006	-131385	-127513	-134166	-131417	-134528	-139623	-131385
Tianjin	-81735	-76408	-82529	-76162	-83579	-76733	-86622	-86039	-92667	-76162
Handan	-3813	-3957	-3999	-4156	-4610	-4924	-5202	-5238	-5174	-4156
Xingtai	-1533	-1611	-1628	-1688	-1733	-2028	-2114	-2188	-2412	-1688
Shijiazhuang	-16680	-17684	-17773	-18865	-21735	-21228	-22821	-22548	-23553	-18865
Baoding	-5202	-5329	-5620	-5697	-5681	-6085	-6100	-6281	-6898	-5697
Hengshui	-6450	-7296	-7461	-7005	-6910	-5875	-6155	-5871	-5734	-7005
Cangzhou	-2314	-2435	-2450	-2491	-2702	-3450	-3506	-3533	-3569	-2491
Langfang	-5962	-6280	-6478	-6696	-7126	-7064	-7220	-7203	-7168	-6696
Tangshan	-19053	-21416	-21884	-22408	-23443	-24079	-24910	-25248	-26495	-22408
Qinhuangdao	-3747	-3778	-3843	-3892	-4062	-3610	-3780	-3478	-3413	-3892
Zhangjiakou	-4749	-4924	-5070	-5181	-5201	-5861	-5328	-5368	-5327	-5181
Chengde	-5868	-6270	-6043	-6218	-6326	-6514	-6529	-6400	-6203	-6218

Water consumption per Unit of Industrial GDP

As shown in Table-2, water consumption per unit of industrial GDP had a great impact in reducing industrial wastewater discharge, decreasing to 834.87 million tons in Beijing and 456.08 million tons in Tianjin. In the province of Hebei, the discharge of industrial wastewater reduction caused by the water consumption per unit of industrial production in Shijiazhuang decreased by 624.39 million tons, marking the most significant drop.

As time went by, there were a certain spatial differences among cities which were due to the economic development, the industrial structure, the resource endowment. By comparison, Handan, Xingtai, Baoding and Cangzhou did not experience the same drop under the same conditions, Shijiazhuang and Tangshan remained highly dependent on the intensity of water consumption per unit industrial GDP. However, one of the positive factors to reside was that water consumption of per unit industrial GDP would keep increasing with economic growth, which would also lead to a significant reduction of the discharge of the industrial wastewater.

Table-2: Factor decomposition results of industrial water production intensity and industrial wastewater discharge

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	-60042	-63639	-73844	-83076	-86136	-88731	-89714	-93651	-96798	-99241
Tianjin	-31340	-33700	-34896	-38401	-41914	-47240	-53529	-56232	-58961	-59869
Handan	-435	-475	-494	-565	-672	-787	-816	-853	-910	-960
Xingtai	-278	-303	-317	-349	-483	-636	-679	-699	-745	-813
Shijiazhuang	-3853	-4543	-4940	-5444	-5888	-6389	-6786	-7336	-8283	-8977
Baoding	-950	-1058	-1089	-1119	-1205	-1289	-1386	-1530	-1591	-1671
Hengshui	-832	-1037	-1054	-1069	-970	-880	-905	-874	-885	-855
Cangzhou	-180	-197	-211	-229	-282	-357	-413	-466	-523	-508
Langfang	-1509	-1714	-1877	-2125	-2336	-2498	-2694	-2837	-3055	-3073
Tangshan	-4476	-5135	-5185	-5567	-5885	-6383	-7006	-7339	-7483	-7329
Qinhuangdao	-1043	-1073	-1088	-1175	-1163	-1118	-1145	-1200	-1222	-1244
Zhangjiakou	-848	-927	-990	-1039	-1221	-1309	-1204	-1237	-1257	-1241
Chengde	-1438	-1582	-1701	-1867	-2074	-2172	-2205	-2235	-2317	-2406

The Worker Productivity

As shown in Table-3, worker productivity increased the discharge of industrial wastewater, and Beijing is the epitome. The worker productivity led to an increase of 693.51 million tons in industrial wastewater discharge. Moreover, the discharge of industrial wastewater in Tianjin increased by 4096.39 million tons. However, both Beijing and Tianjin experienced a drop in 2014. It was argued that what led to such results is correlated to policies set in place by the municipal governments, and it was proved successful in controlling and reducing the industrial wastewater discharge in Chengde, which had an increase of 373.47 million tons, followed by Langfang with 351.68 million tons, whereas, Handan had the least increase with only 24.06 million tons.

Furthermore, the discharge of industrial wastewater showed a trend of increase under the influence of worker productivity. In fact, it was found that the worker productivity had a significant positive impact on reducing the discharge of industrial wastewater in Beijing, Tianjin, Shijiazhuang and Tangshan. However, it was proved significant in those areas, the results were insignificant in Zhangjiakou, Xingtai, Handan and Cangzhou. With the rapid economic development, industrial wastewater discharge would increase at a faster pace in the regions of Beijing, Tianjin and Hebei. As a result, the government should take further action to attempt to hold up the economic growth and prevent the discharge of industrial wastewater from increasing.

Table-3: Factor decomposition results of workers' production efficiency on industrial wastewater discharge

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	50362	63020	65370	78026	85794	87407	83647	76390	59546	43946
Tianjin	23111	20489	27037	47501	58054	58054	41068	41858	44414	48054
Handan	805	781	767	762	731	510	726	853	896	1005
Xingtai	698	611	597	498	442	382	545	612	701	771
Shijiazhuang	1106	1814	2157	2781	3483	3947	4447	4798	5194	5441
Baoding	775	1278	960	906	841	753	1044	1200	999	1012
Hengshui	234	201	171	548	115	281	403	542	620	707
Cangzhou	785	666	672	511	513	453	341	298	345	361
Langfang	2055	2156	2033	2496	2590	2368	2396	2465	2421	2533
Tangshan	1818	2354	2468	3202	4027	4331	4444	4662	4831	5210
Qinhuangdao	514	533	528	597	593	640	648	673	652	670
Zhangjiakou	667	539	799	1331	1395	1349	1467	1819	1881	1928
Chengde	1363	1319	1470	1278	1595	1506	1267	1619	1681	1728

The Population

From these figures in Table-4, it could be asserted that population growth is proportional to the increase of the discharge of industrial wastewater. It indicated that the largest increase occurred in Beijing reaching 40.58 million tons, followed by Tianjin with an increase of 34.16 million tons. In the 11 prefecture-level cities of Hebei Province, Hengshui increased by 3.64 million tons, then Langfang with an increase of 2.23 million tons, and Tangshan with an increase of only 0.39 million tons.

The population growth is proportional to the increase of the discharge of industrial waste water and it has a slight impact on industrial wastewater discharge. Moreover, with social and economic development, the awareness of water-saving has been gradually reinforced leading people to pay more attention to energy-saving not only daily but also during peak production seasons. As a result, industrial wastewater discharges have started to drop.

Table-4: Factor decomposition results of population scale on industrial wastewater discharge

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	4869.45	6093.20	6204.35	7399.68	4034.90	3494.68	3131.64	2560.24	1329.29	1463.75
Tianjin	2114.42	3145.40	2614.89	3587.54	2856.13	3131.22	3416.12	2612.58	1785.42	1903.50
Handan	90.36	102.25	103.59	103.74	102.84	70.39	81.42	91.67	113.66	126.15
Xingtai	84.39	55.27	95.12	99.18	19.87	36.46	47.55	17.42	69.93	75.26
Shijiazhuang	51.42	55.95	49.79	47.29	62.15	62.46	71.45	69.99	63.52	69.71
Baoding	125.57	34.85	151.18	47.51	16.64	90.85	113.21	129.72	263.47	244.59
Hengshui	520.23	378.50	436.49	121.21	119.48	107.64	160.74	76.08	239.09	396.25
Cangzhou	55.27	53.67	52.67	60.68	73.86	90.87	93.05	90.22	97.90	108.03
Langfang	196.72	184.43	209.14	209.02	224.21	229.04	240.67	289.40	217.14	238.88
Tangshan	21.99	27.50	26.12	24.32	25.40	33.42	38.18	40.52	74.53	88.01
Qinhuangdao	115.34	124.77	120.41	186.29	136.76	102.55	122.78	100.92	101.18	46.01
Zhangjiakou	165.17	172.48	178.23	177.75	200.70	213.84	178.13	219.39	223.36	224.00
Chengde	293.16	332.98	268.84	166.69	200.42	185.51	185.21	164.26	193.23	179.91

The Unit Contribution Rate of Influencing Factors Analysis

This paper also calculated the unit contribution of the four above mentioned factors to the industrial wastewater discharge as shown in Figure-1. According to the result, we found that the industrial water-saving technology played the most important role in the reduction of the industrial wastewater discharge. Especially in Hebei province, the contribution of green technology to the decrease of discharge was to 50%, while the function of the remaining 3 factors did not exceed 30%. Comparatively speaking, both the industrial water-saving technology and the water consumption per unit of industrial GDP had the same effect in Beijing and Tianjin. And the industrial water-saving technology proved to be successful in reducing industrial wastewater discharges.

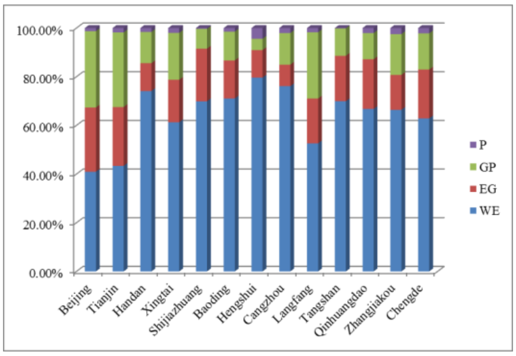

Fig-1: Analyze the contribution rate of influencing factors

Industrial Wastewater Discharge Performance Evolution

Based on DDF, an industrial wastewater discharge model was created to evaluate the performance of capital inputs, the industrial wastewater discharge performance in Beijing, Tianjin and Hebei during 2008-2017 is shown in Table-5. The table shows that the best performances of these four aspects are Beijing and Shijiazhuang and they were above 0.9. However, Zhangjiakou has the lowest average with 0.65.

Table-5: Industrial wastewater discharge performance of 2008-2017

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Beijing	0.98	0.85	0.82	0.87	0.84	0.87	0.91	0.91	1.00	0.99
Tianjin	0.66	0.64	0.73	0.72	0.89	0.91	0.96	1.00	0.98	0.89
Handan	0.87	0.87	0.93	0.99	1.00	0.80	0.78	0.77	0.60	0.78
Xingtai	0.80	0.84	1.00	0.77	0.86	0.91	0.86	0.66	0.89	0.86
Shijiazhuang	0.96	0.89	0.88	0.85	0.85	0.83	0.89	0.99	0.88	1.00
Baoding	0.74	0.74	0.97	0.75	0.80	0.82	0.76	1.00	1.00	0.88
Hengshui	0.90	0.92	0.68	0.70	0.72	0.66	1.00	0.69	0.70	0.65
Cangzhou	0.90	0.92	0.73	0.94	1.00	0.78	0.83	0.80	0.75	0.75
Langfang	0.74	0.74	0.81	1.00	0.85	0.81	0.70	0.82	0.78	0.79
Tangshan	0.71	0.75	1.00	0.74	0.81	0.69	0.69	0.57	0.63	0.72
Qinhuangdao	0.54	0.66	0.73	0.68	0.67	0.55	0.76	1.00	0.61	0.69
Zhangjiakou	0.59	0.68	0.65	0.68	0.56	0.56	0.57	0.67	1.00	0.59
Chengde	0.56	0.67	0.74	0.88	0.66	0.55	1.00	0.77	0.60	0.66

In order to observe the spatial distribution and analyze the dynamical evolution of industrial wastewater discharge in Beijing, Tianjin and Hebei, this paper compared and analyzed the regional distribution of industrial wastewater discharge of Beijing-Tianjin-Hebei region in 2008, 2011, 2014 and 2017 (see Figure-2). As shown in Figure-2, the regional distribution shows a gradual improvement. In 2008, there were still three prefecture-level cities whose values were under 0.65. However, there were no prefecture-level cities with values below 0.65 in 2011 and only one city between 2014 and 2017. Furthermore, none of the prefecture-level cities' values were below 0.5 between 2014 and 2017. Instead, it was indicated that changes occurred in Handan, Hengshui and Zhangjiakou. The average annual performance of Handan has decreased by 0.6 between 2012 and 2016. On the contrary, the annual average value of Baoding has improved significantly in 2008-2017.

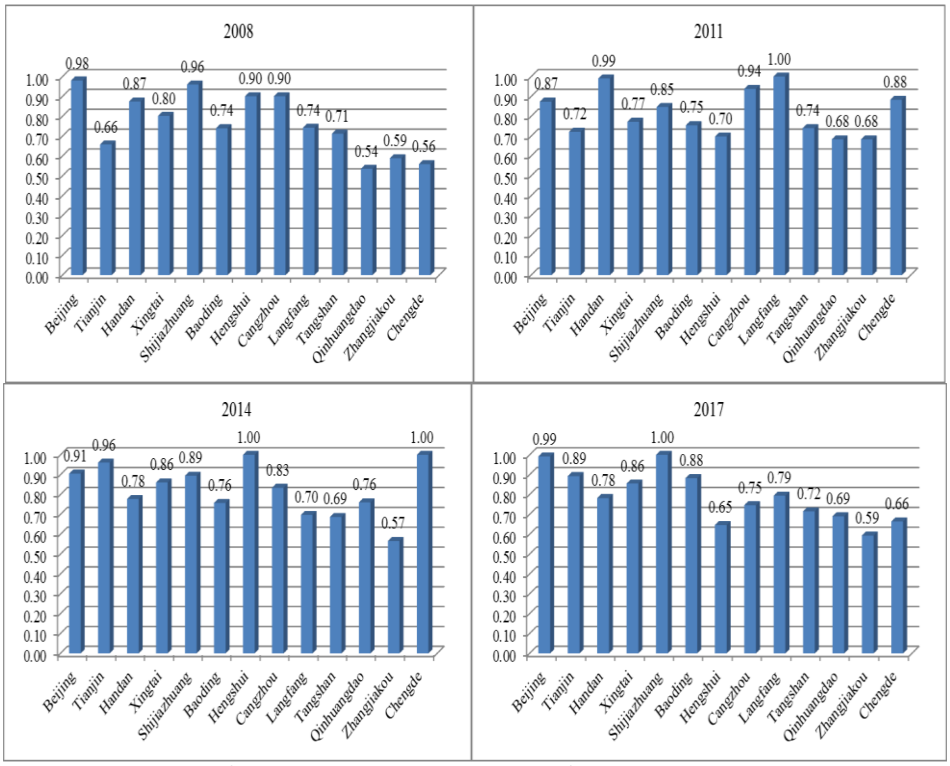

Fig-2: Spatial distribution of industrial wastewater discharge performance in the Beijing-Tianjin-Hebei region

Industrial Wastewater Reduction Potential Prediction

The annual average potential for industrial wastewater reduction in the region of Beijing, Tianjin and Hebei is shown in Figure-3, with Beijing achieving the best results at 0.61. It proved that areas with a faster economic growth are more inclined to utilize eco-friendly technology, thus reducing the amount of waste water discharge produced. This finding reinforces the notion that cities such as Tangshan and Shijiazhuang, which are the most economic developed areas in China, currently have a great potential for industrial wastewater reduction. The rapid development of industries has indeed raised concerns not only regarding water consumption but also regarding water-waste discharges, leading the government to express policies in action that favor environmental protection.

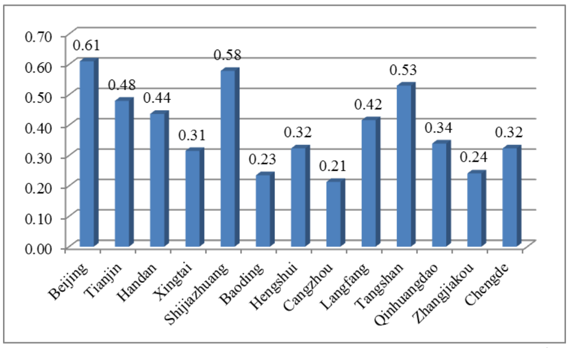

Fig-3: The potential annual average industrial wastewater reduction in the regions of Beijing, Tianjin and Hebei

CONCLUSION

This study attempts to reveal the causing factors of industrial wastewater discharges in the region of Beijing, Tianjin and Hebei through utilizing the Kaya model. This study estimates the potential of each region to reduce waste. Having deconstructed the causing factors, it could indeed be asserted that both the industrial water-saving technology and water consumption per unit of Industrial GDP are the deleterious factors that increase the amount of discharge of industrial wastewater produced, whilst the level of economic development along with the number of industrial workers proved to be successful at reducing it. Furthermore, although spatial differences among cities still exist, the predisposition towards reducing industrial wastewater discharges in Beijing-Tianjin-Hebei region is improving. Finally, there seems to be a great potential for reduction in Beijing, Tangshan and Shijiazhuang. However, this should be further reinforced by the implementation of policies that favor both economic growth and environmental protection.

ACKNOWLEDGMENTS

This study was supported by the Fundamental Research Funds for the Central Universities 2018 MS146.

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