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Odor emission impact assessment of Zhengwangfen wastewater treatment plant in Beijing

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ABSTRACT

An odor impact assessment had been carried out in order to evaluate the negative impact on the population living in the neighborhood of Zhengwangfen wastewater treatment plant (WWTP) in Beijing. The results indicated that the discharged NH_3 and H_2S concentrations were highest in the pretreatment and biological treatment units, while the discharged odor index was highest in the pretreatment, biological, and sludge treatment units in the two existing WWTPs. Using the method of the odor index evaluation for H_2S and NH_3, we concluded that the maximum concentrations of NH_3 and H_2S in Zhengwangfen WWTP were 0.0043 and 0.059 mg/m^3, respectively. On the basis of Gaussian point source diffusion model, the maximum protective distance of different treatment units was 196.43 m, which indicated that the 200 m setback distance for WWTPs, dictated by local regulation, appeared to be sufficient under usual operating and normal weather conditions.

Keywords: Odor; Odor treatment; Wastewater treatment plants; Air emission; Environmental impact assessment

1. Introduction

As the capital of China, Beijing covers an area of 1,6410.54 km^2, its population was about 20.693 million in the year 2012. With social and economic development, Beijing's urban infrastructure is developing rapidly. Over the past several decades, Beijing has taken great efforts in wastewater treatment. However, the newly built wastewater treatment plants (WWTPs), which used to be far away from downtowns, were gradually surrounded by residential areas. During the treatment process of WWTPs, emissions of disgusting odors have a negative impact on the nearby local population. In particular, in the following conditions, such as high humidity and stable atmospheric class, the odors would be increasingly strong [1]. More and more complaints about unpleasant odor emitted from WWTP have continued to rise. Beijing Municipal Environmental Protection Advocacy Center released survey results of the 10th public environmental awareness

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survey in the year 2013. It showed that Beijing residents were most concerned about air quality accounted for 90.2%, while over 70% respondents who lived nearby WWTPs said they had been influenced by the odors.

WWTPs are public projects for environmental protection, which can reduce the discharge of hazardous substances and wastewater emissions, and improve the ecological environment. However, if not properly managed, the processed liquid or gaseous waste will generate malodorous compounds (e.g. ammonia and aliphatic amines, sulfidric acid, mercaptanes and sulfides, aldehydes and ketones, organic acids etc.) in WWTPs [2].

Some former studies have stated that the unpleasant odors from WWTPs may cause the symptoms, such as nausea, headache, lack of appetite, and more seriously and rarely, other acute and even chronic health effects [3,4]. Therefore, it is important to predict and assess the odor emissions from WWTPs for protecting the human health. Different methods have been applied to assess the odor emissions of WWTPs. A well-known tool for odor impact assessment and prediction is odor emission factors [5]. Recently, a dispersion model was used to assess the odor emissions from a WWTP through an inverse dispersion technique using ambient concentration measurements and meteorological parameters as inputs [6].

In this paper, in order to ensure safety of the neighborhood, an odor impact assessment process of a WWTP was provided. Odor emission data in two existing WWTPs (Xiaohongmen and Beixiaohe WWTP) were used to predict the odor emission in Zhengwangfen WWTP. Gaussian point source diffusion model was used for assessing the suitability of setback distance. Along with the collection and analysis of data, it could be seen that the distribution and diffusion of the odor of WWTPs could provide scientific basis for the odor control in WWTPs.

2. Materials and methods

2.1. Plant description

Planned Zhengwangfen WWTP, which treats approximately 450,000 m^3/d municipal sewage from 5,000,000 local inhabitants, is located in the south-west area in Beijing city and occupies about 303,400 m^2 in a flat. In this paper, the odor emission data in two existing WWTPs (Xiaohongmen and Beixiaohe WWTP) were used to predict the odor emission in Zhengwangfen WWTP. Fig. 1 shows the site location of Zhengwangfen, Xiaohongmen, and Beixiaohe WWTPs in Beijing. The overview of above three WWTPs are shown in Table 1. It can be seen that the water and sludge treatment processes of three WWTPs are basically the same in that all use the CAS and ozone. Actually, the principle of the MBR is similar to that of BAF + UF, which are all based on the biological oxidation and retention of suspended solids. The main theory of sludge treatment unit is anaerobic digestion and dewatering. The capacity and area of Zhengwangfen and Xiaohongmen is almost alike, the location of them are all in the south and within the fifth ring road of Beijing. At the same time, the influent quality of three WWTPs is municipal sewage water. Therefore, it is feasible to make an analogy with these two existing WWTPs.

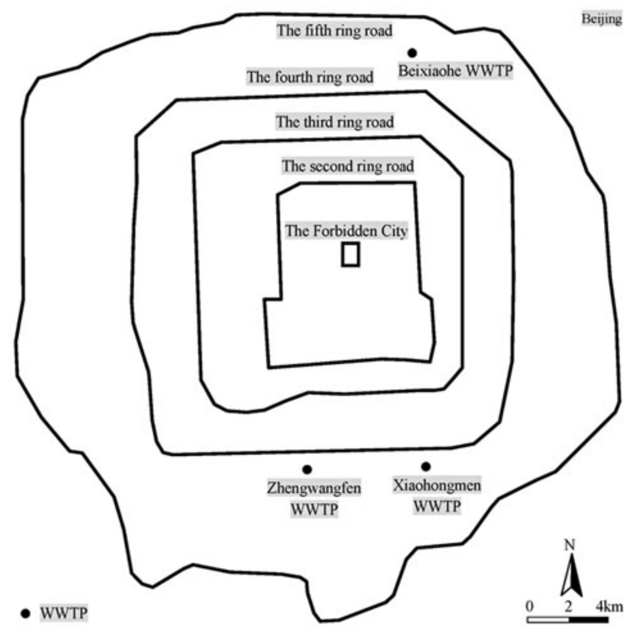


Fig. 1. Site location of Zhengwangfen, Xiaohongmen, and Beixiaohe WWTPs.

The layout of Zhengwangfen WWTP is shown in Fig. 2. It can be seen from Fig. 2 that the nearest residential distance from Zhengwangfen WWTP is 550 m.

2.2. Odor assessment

During the operation process of WWTPs, there exists the possibility of odor emissions. In typical large-scale WWTPs, the treatment processes mainly include pretreatment, biological treatment, sedimentation, advanced treatment, disinfection, and sludge treatment units. Most of odor emissions generally come from the pretreatment and sludge treatment units [7–9]. Odor emissions are caused by a wide variety of components. Overall, there are three of

Table 1
The overview of 3 WWTPs in Beijing

No.	WWTPs	Founding time	Capacity (10^4 m^3/d)	Area (m^2)	Treatment process
1	Zhengwangfen	2015	60	313,600	Wastewater: CAS[a] + MBR[b] + O_3[c] Sludge: Thermal hydrolysis + anaerobic digestion + dewatering and drying
2	Xiaohongmen	2005	60	490,900	Wastewater: CAS + BAF[d] + UF[e] + O_3 Sludge: Mesophilic anaerobic digestion + dewatering and drying
3	Beixiaohe	1990	10	58,500	Wastewater: CAS + MBR + O_3 Sludge: Concentration + dewatering and drying

[a]Cyclic activated sludge.
[b]Membrane bioreactor.
[c]Ozone oxidation.
[d]Biological aerated filter.
[e]Ultrafiltration.

categories compounds: sulfur-based compounds, such as hydrogen sulfide, methyl mercaptan, and dimethyl sulfide etc.; nitrogen-based compounds, such as ammonia, diamines, and methyl indole etc.; compounds containing carbon, hydrogen, or oxygen elements, such as lower alcohols, aldehydes, and fatty acids etc. According to the literature, the highest concentrations of odor emissions from WWTPs are ammonia and hydrogen sulfide, while the maximum odor intensity compounds are methyl mercaptan and hydrogen sulfide [10,11]. These irritating odor gases can endanger human health. In addition, H_2S can combine with oxygen in the air, after that it may be oxidized to sulfuric acid under the action of sulfur bacteria. It will lead to corrosion of concrete or cast iron. Meanwhile, the high concentrations of sulfur-containing and nitrogen-containing compounds can inhibit the nitration reaction, which will reduce the nitrogen removal efficiencies in WWTPs. Therefore, H_2S and NH_3 are used as the key elements in the field of odor evaluation for WWTPs [12].

By monitoring the WWTPs odor, it can be seen that the situation is constantly changing. Beijing belongs to the warm and semi-humid continental monsoon climate and has significant seasonal weather conditions. Due to the changes in different seasons, there are obvious differences for the WWTPs odor situation, which is much more serious in summer and autumn than others. Therefore, the summer and autumn is the optimal reason to control the WWTPs odor to avoid complaints occurring [13]. In this paper, the odors emitted from Xiaohongmen and Beixiaohe WWTPs were detected in August and September of the year 2013. According to the plant layout and process characteristics in the factory district, there were eight monitoring points in each WWTP, for odor detection of four times a month. Thermometer, hygrometer, barometer, and anemometer instruments are used to monitor air temperature, air humidity, atmospheric pressure, and wind speed, respectively.

In this paper, the odor emission impacts from WWTPs are evaluated by odor index, the concentrations and emission rates of H_2S and NH_3. The collection and detection of odor samples are in accordance with the triangle odor bag method (GB/T14675-1993) [14], which has been described in the former study [15]. Sampling on point source is collected by means of a vacuum pump and a sampling bag realized with a suitable material. H_2S is analyzed by using methylene blue spectrophotometric method and NH_3 is analyzed by using Nessler's reagent spectrophotometry according to the Standard Analysis Methods of China [16]. To predict the odor emissions from Zhengwangfen WWTP, the odor must first be quantified. In this research, analogy survey method is applied to quantify the odor source [17].

With regard to odor dispersion, it is mainly affected by meteorological factors (i.e. season, atmospheric conditions, such as wind speed and direction, humidity, temperature etc.), and physical obstacles (high buildings, tall and large trees etc.) [18]. Fig. 3 shows the annual and seasonal wind rises in Beijing area, indicating an appreciable percentage (12.3%) of the calm (windless weather or with the wind speed less than 0.5 m/s at a height of 10 m in the air), with a slight prevalence of Southwest winds. To predict the odor impact on the surrounding environment and human health, modeling has been accepted widely as a useful tool for assessing the potential odor dispersion from WWTPs [19].

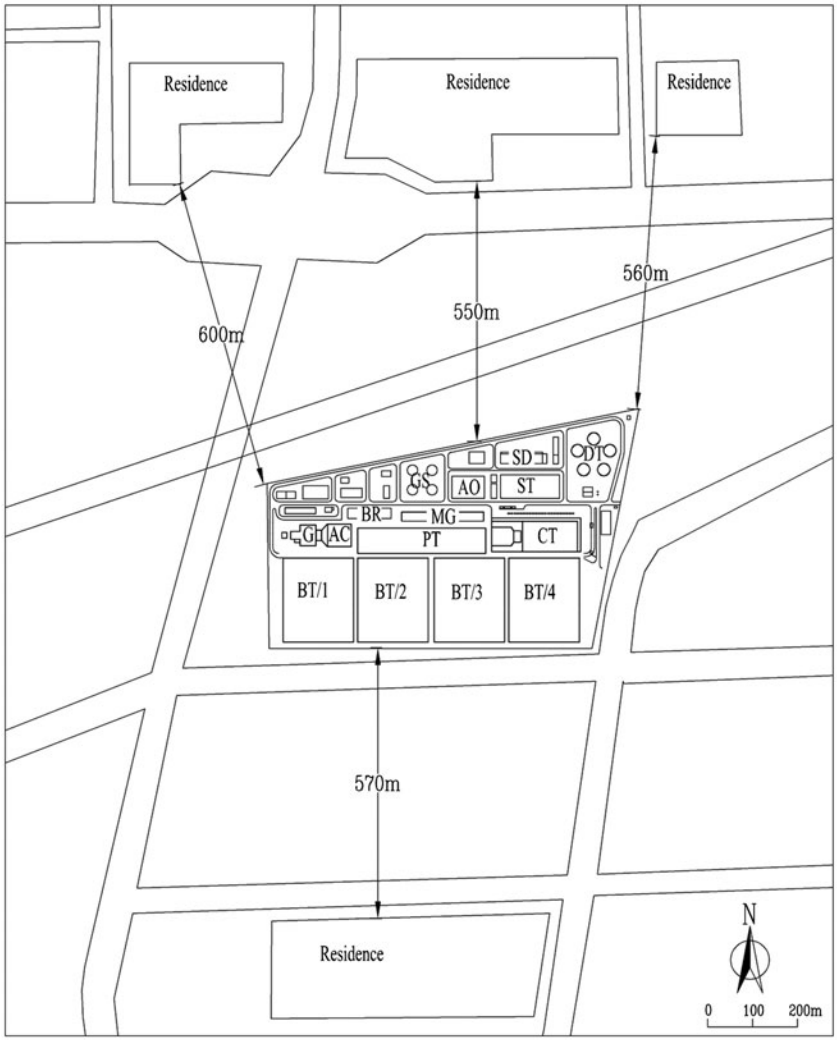


Fig. 2. Layout of Zhengwangfen WWTP (G—grille, BR—blower room, AC—aerated grit chamber, PT—primary settling tank, MG—membrane grille, BT/1–4—biological tank, CT—clear water tank, GS—gas storage, AO—anaerobic ammonium oxidation, SD—sludge drying, ST—sludge comprehensive treatment, DT—digestion tank).

Gaussian diffusion model is based on the statistical theory of turbulence with a large number of experimental data analysis and normal distribution assumptions. It is a kind of mathematical model that simulates the spread of pollutants in the atmosphere, including the Gaussian point source diffusion model, a closed point source diffusion model, Gaussian surface source (virtual point source) diffusion model, and a variety of weather conditions, small and complex terrain conditions. Due to its easy and small amount of computation and high consistency between calculation results and experimental values, Gaussian diffusion model has been widely used in various countries.

In Beijing, in order to prevent the spread of odors from affecting the surrounding residents, municipal administration claims that the unit of the WWTPs must be covered all like vinyl resin plate, under which the odor will flow to a chimney, then release to air. Gaussian point source diffusion model was utilized to estimate odor diffusion in this study [20].

3. Results and discussion

3.1. Odor source quantification

In order to ensure the representativeness of the air sample and reduce the interaction between the odor samples, the unified sample points were set at approximately 1 m from above open surface of different treatment units in WWTPs. Table 2 reports the results of the odor concentration measurements for each odor source being considered at each treatment

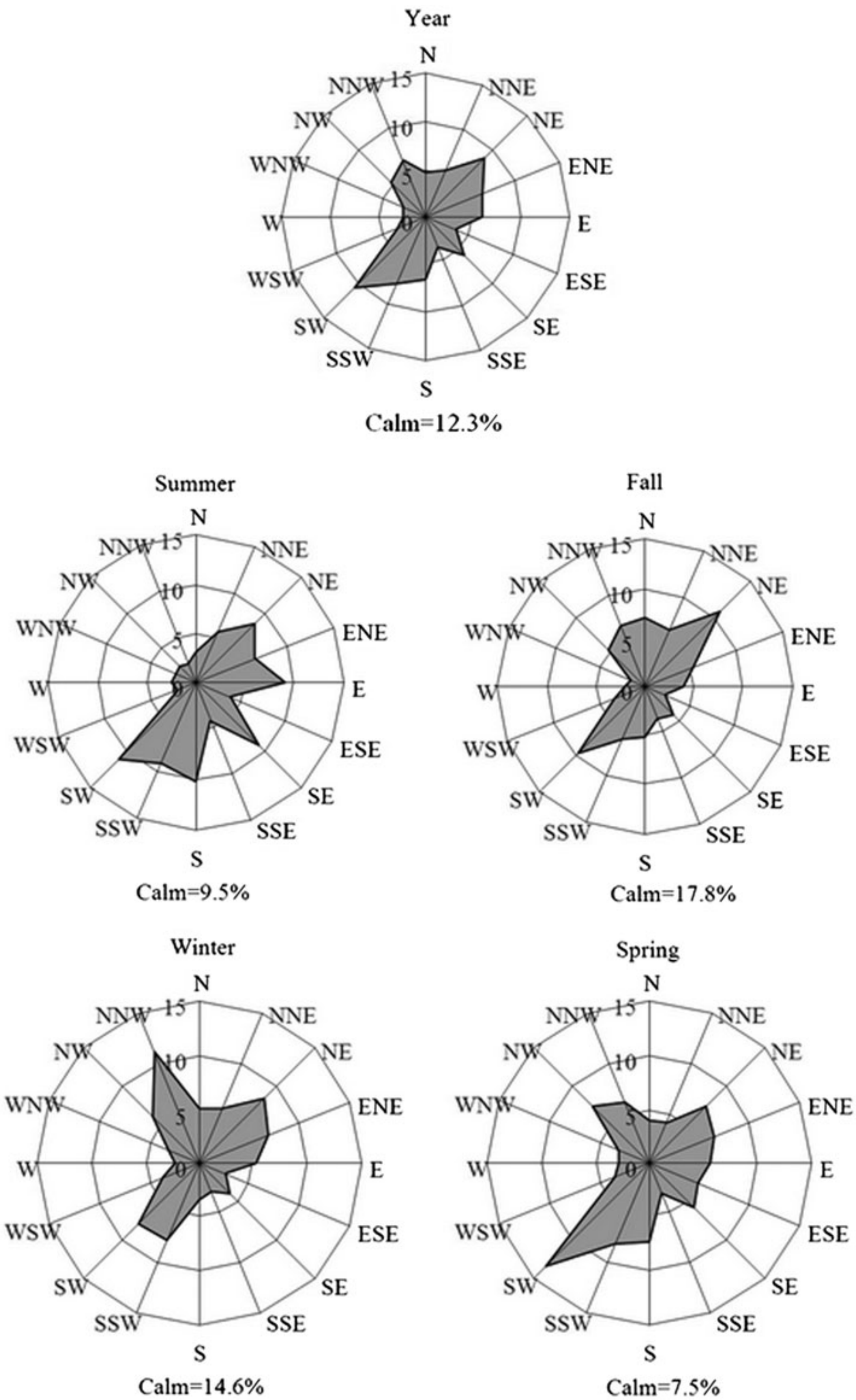


Fig. 3. Annual and seasonal wind rises in Beijing area.

phase. The comparison of the data showed no significant differences between the concentration values that were relevant to the same process step. The first column of each group represents the arithmetic mean of the odor concentrations. In order to highlight the variability of the data, the second column reports the

Table 2
The odor concentration results in WWTPs

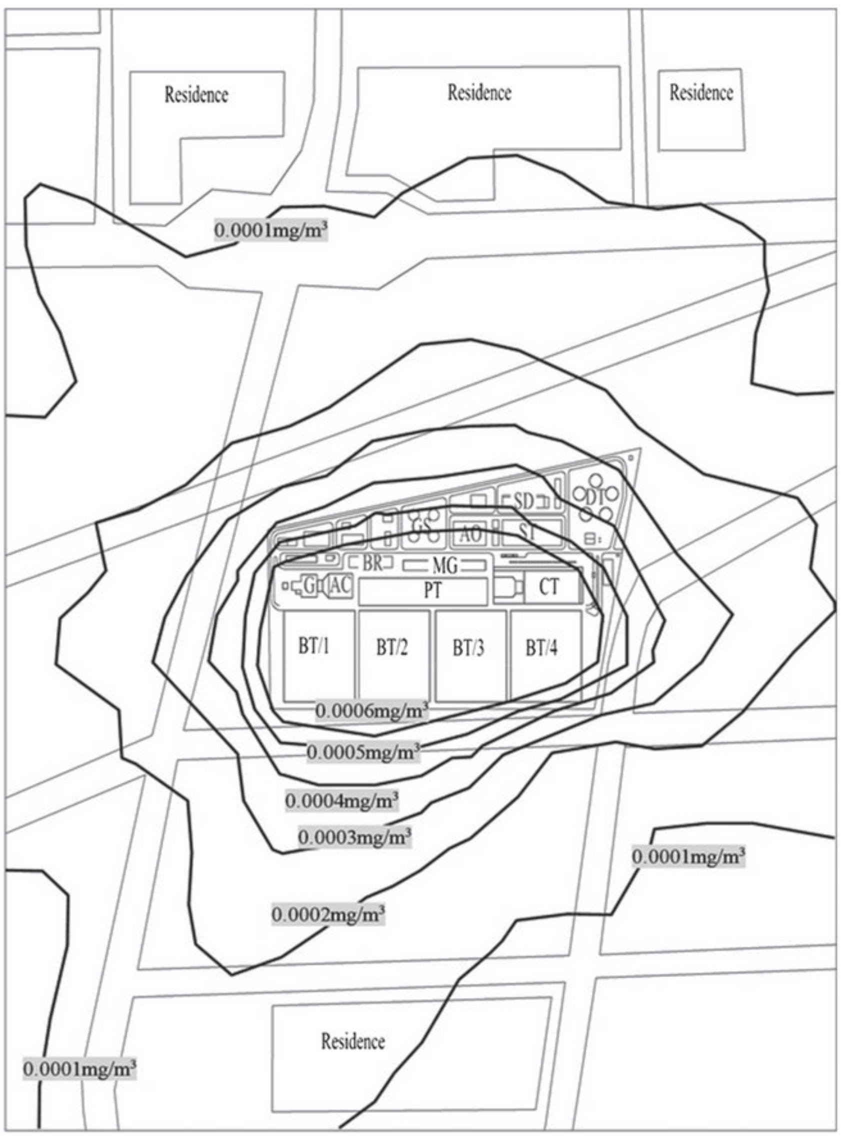
Units		Xiaohongmen WWTP								Beixiaohe WWTP							
		NH_3			H_2S					NH_3			H_2S				
		Concentration (mg/m^3)		Emission rate (kg/h)	Concentration (mg/m^3)		Emission rate (kg/h)	odor index		Concentration (mg/m^3)		Emission rate (kg/h)	Concentration (mg/m^3)		Emission rate (kg/h)	odor index	
		Mean	SD		Mean	SD		Mean	SD	Mean	SD		Mean	SD		Mean	SD
Pretreatment	Grids	0.44	0.1042	2.0×10^{-3}	5.62	0.8608	0.063	94	15.71	0.53	0.0920	2.7×10^{-3}	8.25	1.762	0.075	162	22.02
Biological treatment	Anaerobic	0.21	0.0497	3.8×10^{-3}	0.05	0.0245	4.2×10^{-3}	115	27.02								
	Anoxic	0.11	0.0282	4.5×10^{-3}	0.032	0.0067	6.2×10^{-3}	76	15.30	0.28	0.0959	4.6×10^{-3}	0.063	0.0068	5.6×10^{-3}	95	16.53
	Aerobic	0.10	0.0216	9.2×10^{-3}	0.022	0.0073	8.6×10^{-3}	28	7.53	0.15	0.0383	9.3×10^{-3}	0.036	0.0069	8.7×10^{-3}	38	9.31
Advanced treatment	BAF	0.08	0.0294	5.6×10^{-4}	0.015	0.0037	5.3×10^{-4}	16	3.74								
	UF	0.06	0.0245	8.2×10^{-4}	0.021	0.0039	7.8×10^{-4}	13	4.55								
	MBR									0.12	0.0316	5.5×10^{-4}	0.024	0.0073	6.2×10^{-4}	29	10.80
Sludge treatment		0.092	0.0135	8.9×10^{-4}	0	0	0	49	15.08	0.125	0.0167	9.6×10^{-4}	0	0	0	66	19.03

Note: The number of samples analyzed for NH_3 and H_2S concentrations and odor index: 8.

Table 3
Estimated odor source strength in Zhengwangfen WWTP

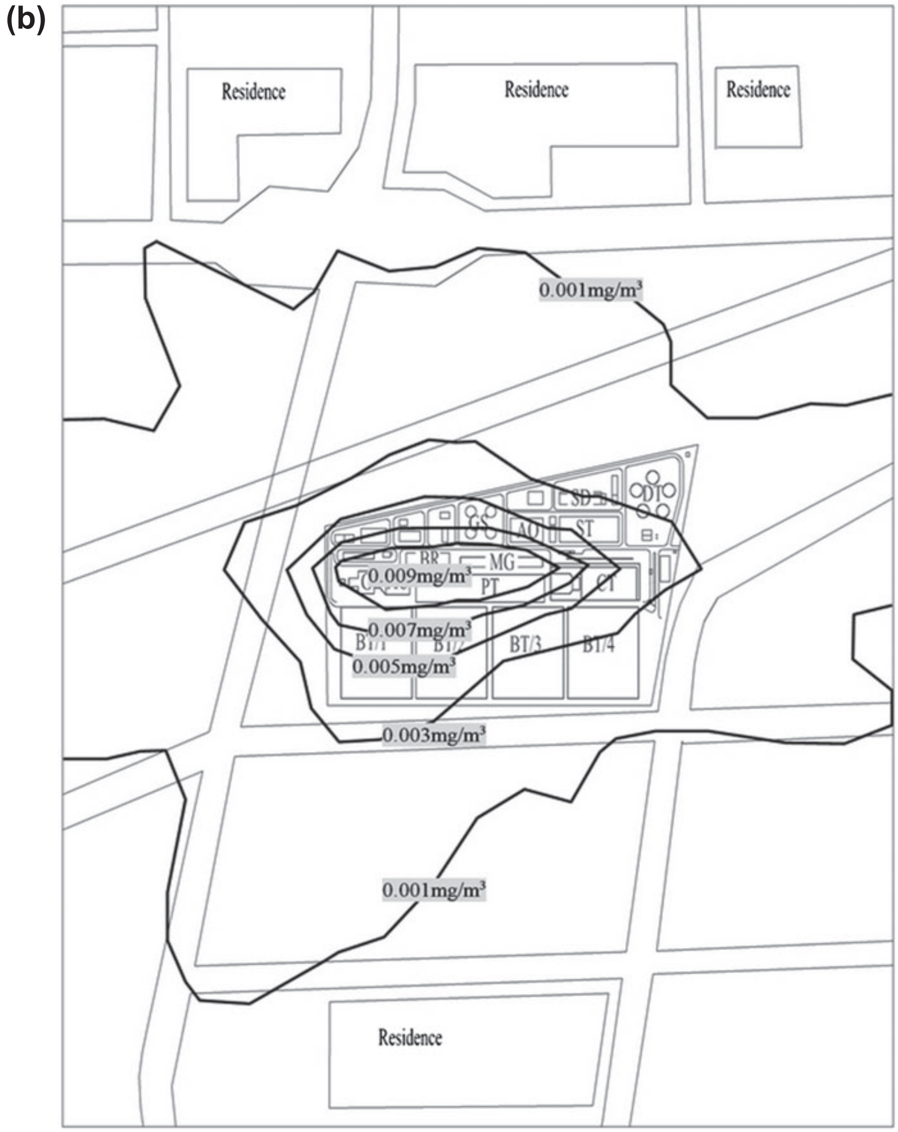
	NH_3		H_2S		
Units	Concentration (mg/m^3)	Emission rate (kg/h)	Concentration (mg/m^3)	Emission rate (kg/h)	Odour index
Pretreatment	0.53	2.7×10^{-3}	8.25	0.075	162
Biological treatment	0.28	9.3×10^{-3}	0.05	8.7×10^{-3}	115
Advanced treatment	0.12	8.2×10^{-4}	0.015	7.8×10^{-4}	29
Sludge treatment	0.125	9.6×10^{-4}	0	0	66

(a)



NH_3

Fig. 4. Estimated odor emissions: maximum air isoconcentration curves at ground level in the worst weather condition. (a) NH_3 and (b) H_2S.



H_2S

Fig. 4. (*Continued*).

standard deviation of these values. The third column refers to the emission rate of NH_3 and H_2S in two WWTPs. As shown in Table 2, the discharged NH_3 and H_2S concentrations are the highest in the pretreatment and biological treatment units, while the discharged odor index is the highest in pretreatment, biological, and sludge treatment units in two WWTPs. There are some inevitable reasons that the above treatment phases require optimal residence time, tank deepness, and anaerobic treatment process along with controllable factors like inadequate aeration.

Considering the worst situation, based on the measured data in two WWTPs, we estimated the odor source strength of Zhengwangfen WWTP as follows (Table 3).

Table 4
The maximum protective distance of different treatment units (m)

Units	NH_3	H_2S
Pretreatment	0.14	196.43
Biological treatment	0.15	4.79
Advanced treatment	0.05	1.45
Sludge treatment	0.10	0

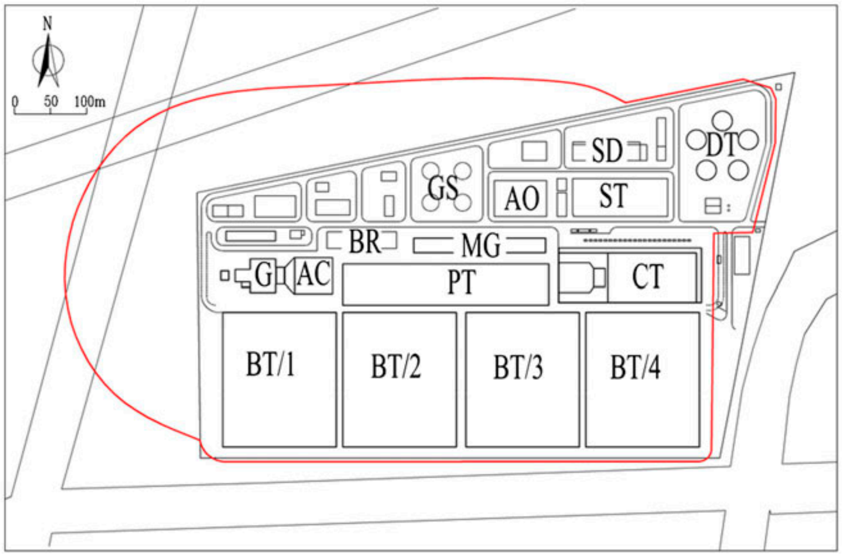


Fig. 5. The atmospheric environment protection distance of Zhengwangfen WWTP.

3.2. Odor emission prediction

Under the worst weather conditions (i.e. moderate to extremely stable atmospheric conditions and slight breeze), the Gaussian point source diffusion model was used to estimate the maximum odor concentrations from Zhengwangfen WWTP under normal plant operating conditions, reported in Fig. 4.

Having applied the technical methods for making local emission stands of air pollutants in China [21], we determined the maximum protective distance of different treatment units in Zhengwangfen WWTP (Table 4).

In view of the atmospheric protection distance of above treatment units, combined with the layout plan of Zhengwangfen WWTP, the atmospheric environment protection distance envelope of Zhengwangfen WWTP was determined with each treatment unit center as a circle with the maximum protective distance as the radius (shown in Fig. 5).

4. Conclusion

In this study, the odor emission impacts from Zhengwangfen WWTP in Beijing were evaluated by odor index. The odor source strength was quantified using the analogy survey method according to the two existing WWTPs. It is concluded that the discharged NH_3 and H_2S concentrations were the highest in the pretreatment and biological treatment units, while the discharged odor index was the highest in the pretreatment, biological, and sludge treatment units in WWTPs.

On the basis of Gaussian point source diffusion model, the maximum concentration of NH_3 and H_2S from Zhengwangfen WWTP were 0.0043 and 0.059 mg/m^3, respectively. The 200 m setback distance for WWTPs dictated by local regulation appeared to be sufficient in usual operation and under normal weather conditions in the case of Beijing.

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References

[1] J.A. Nicell, Assessment and regulation of odour impacts, Atmos. Environ. 44 (2009) 354–360.
[2] X. Wang, G. Parcsi, E. Sivret, H. Le, B. Wang, R.M. Stuetz, Odour emission ability (OEA) and its application in assessing odour removal efficiency, Water Sci. Technol. 66 (2012) 1828–1833.
[3] M. Aatamila, P.K. Verkasalo, M.J. Korhonen, A.L. Suominen, M.R. Hirvonen, M.K. Viluksela, A. Nevalainen, Odour annoyance and physical symptoms among residents living near waste treatment centres, Environ. Res. 111 (2011) 164–170.
[4] J.E. Hayes, R.J. Stevenson, R.M. Stuetz, The impact of malodour on communities: A review of assessment techniques, Sci. Total Environ. 500–501 (2014) 395–407.
[5] Z.H. Duan, W.J. Lu, D. Li, H.T. Wang, Temporal variation of trace compound emission on the working surface of a landfill in Beijing, China, Atmos. Environ. 88 (2014) 230–238.

[6] G. Schauberger, M. Piringer, W. Knauder, E. Petz, Odour emissions from a waste treatment plant using an inverse dispersion technique, Atmos. Environ. 45 (2011) 1639–1647.
[7] C. Easter, C. Quigley, P. Burrowes, J. Witherspoon, D. Apgar, Odor and air emissions control using biotechnology for both collection and wastewater treatment systems, Chem. Eng. J. 113 (2005) 93–104.
[8] L. Zhao, W.M. Gu, P.J. He, L.M. Shao, Effect of air-flow rate and turning frequency on bio-drying of dewatered sludge, Water. Res. 44 (2010) 6144–6152.
[9] J.J. Fang, Y. Na, D.Y. Cen, L.M. Shao, P.J. He, Odor compounds from different sources of landfill: Characterization and source identification, Waste Manage. 32 (2011) 1401–1410.
[10] P. Gostelow, S.A. Parsons, Sewage treatmeent works odour measurements, Water Sci. Technol. 41 (2000) 33–40.
[11] L. Capelli, S. Sironi, R.D. Del Rosso, P. Céntola, Predicting odour emissions from wastewater treatment plants by means of odour emission factors, Water Res. 43 (2009) 1977–1985.
[12] S. Xue, H. He, L.R. Deng, J.J. Sun, Discussion on the control measures and environmental impact assessment of the stench of wastewater treatment plant, J. Qingdao Technol. Univ. 2 (2012) 98–103.
[13] J.Y. Xi, Y.H. Hu, B. Luo, C. Wang, Odorants emission characteristics in a municipal wastewater treatment plant, China Water Wastewater 22 (2006) 99–103.
[14] Environmental Protection Agency (EPA), Air Quality —Determination of Odor—Triangle Odor Bag Method, GB/T 14675-1993, Beijing, 1994.
[15] C.J. Shih, C.N. Li, J.K. Chan, C.Y. Syu, A practical odur index for evaluating de-odorant performance for mswi bottom ashes, J. Environ. Manage. 17 (2007) 97–101.
[16] D.L. Xi, Y.S. Sun, X.Y. Liu, Environmental Monitoring, Higher Education Press, Beijing, 2004.
[17] J. Guo, J. Liang, Y. Kuang, W. Shang, T.T. Ding, J.H. Li, Y.B. Zhu, Q.S. Wang, Y.Z. Chi, Wastewater treatment plant odor analysis and evaluation of pollution, China Water Wastewater 2 (2002) 41–42.
[18] P. Stellacci, L. Liberti, M. Notarnicola, C.N. Haas, Hygienic sustainability of site location of wastewater treatment plants, Desalination 253 (2010) 51–56.
[19] B.A. Sheridan, E.T. Hayes, T.P. Curran, V.A. Dodd, A dispersion modelling approach to determining the odour impact of intensive pig production units in Ireland, Bioresour. Technol. 91 (2004) 145–152.
[20] Environmental Protection Agency (EPA), Technical Guidelines for Environmental Impact Assessment—Atmospheric Environment, GB HJ/T 2.2-93, Beijing, 1993.
[21] Environmental Protection Agency (EPA), Technical Methods for Making Local Emission Stands of Air Pollutants. GB/T 3840-91, Beijing, 1992.