Energy Proceedings
Vol 46, 2024
ISSN 2004-2965

Accounting of Greenhouse Gas Emissions from Wastewater Infrastructures on the Qinghai-Tibet Plateau

Yao Huang [1], Delin Fang [2], Saige Wang [1], Bin Chen [1*]

1 State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, P.R. China

2 Faculty of Geographical Science, Beijing Normal University, Beijing 100875, P.R. China
(*Corresponding Author: chenb@bnu.edu.cn)

ABSTRACT

The wastewater sector represents a significant contributor to greenhouse gas (GHG) emissions, and the issue of GHG emissions from wastewater infrastructures in the Qinghai-Tibet Plateau (QTP) has been overlooked. This study constructed a unified accounting framework based on the emission factors approach to quantify GHG emissions from wastewater infrastructures on the QTP, and identified the influencing factors of GHG emissions changes through Logarithmic Mean Divisia Index (LMDI). Within our accounting framework, we took into account the temperature coefficient to accurately represent the low water temperatures prevalent on the QTP. Furthermore, we revised the emission factor for electricity consumption by considering the local energy structure based on the development of clean energy. Spatial and temporal differences were analyzed using the GHG emissions accounting results spanning from 2014 to 2018. The results show that total GHG emissions from QTP's wastewater infrastructures increased from 0.25 Mt CO_2e to 0.43 Mt CO_2e between 2014 and 2018, with the cities along the edge in the east exhibiting noticeably higher GHG emissions. The development of clean energy on the QTP has led to a reduction in the electricity emission factor, thereby slowing down the growth of GHG emissions by 18.7%. The increase in sludge yield and electricity intensity of WWTPs contributed 10.3% and 9.6% to the overall growth of GHG emissions, and reducing these two influencing factors can effectively decelerate the upward trajectory of GHG emissions in the wastewater sector.

Keywords: Wastewater treatment, greenhouse gas emissions, clean energy, influencing factors, Qinghai-Tibet Plateau

1. INTRODUCTION

The wastewater utilities, as critical infrastructure, can remove pollutants from wastewater and improve the urban water environment[1]. In 2017, China's annual greenhouse gas (GHG) emissions from wastewater infrastructures amounted to 9.6 billion tons CO_2e, constituting for 8% of the nation's total GHG emissions[2]. The wastewater sector has become an important source of China's GHG emissions. Over the past nine years, the wastewater treatment plants (WWTPs) construction of Qinghai-Tibet Plateau (QTP) has witnessed an acceleration, and the total processing capacity of WWTPs in Qinghai and Tibet has increased by 157%[3, 4]. In contrast to the eastern plains of China, WWTPs situated in high-altitude areas typically contend with issues such as diminished treatment efficiency, sludge expansion, and increased electricity consumption during operation[5]. These challenges contribute to a distinctly different GHG emissions characteristics from the QTP's wastewater sector. The issue of GHG emissions from Wastewater infrastructures on the QTP demands serious attention. Controlling GHG emissions of the QTP's wastewater sector holds significance in mitigating climate warming and aligning with national goals for carbon neutrality.

Numerous studies have been conducted to account for GHG emissions in the wastewater sector. Some scholars used the experiment approach[6] and the modelling method[7] to measure the GHG emissions of a limited number of WWTPs or a single type of GHG emissions. The application of these two methods causes challenges in large-scale research areas due to their stringent data and experimental condition requirements. The emission factors approach established by the IPCC is widely used because the data is easy to obtain and the

---

This is a paper for 15th International Conference on Applied Energy (ICAE2023), Dec. 3-7, 2023, Doha, Qatar.

operation is simple. Chen et al. applied the emission factors approach to calculate GHG emissions during the construction and operation stages of wastewater infrastructures across China based on a life cycle perspective[8]. Current researches on GHG emissions from China's wastewater sector provide a cursory analysis of the QTP. These studies often utilize standardized parameters for calculation, overlooking the distinctive features of local natural conditions and energy development on the QTP. Consequently, there exists a lack in GHG emissions accounting specifically for the QTP[9]. The prevailing natural conditions characterized by low pressure and low temperatures in the high-altitude regions of the QTP give rise to common operational challenges in WWTPs, including issues such as sludge expansion and elevated energy consumption. The low-temperature environmental conditions of QTP will affect direct GHG emissions during wastewater treatment[10].The sludge expansion augments sludge yield, consequently leading to an escalation in GHG emissions during the sludge disposal process. The local clean energy has been rapid in recent years[11], which will affect indirect emissions of electricity consumption in the wastewater sector. Considering the unique energy industry structure and cold environmental conditions of the QTP, accounting for GHG emissions from wastewater utilities in this region can yield results that are more in line with the local reality. Moreover, identifying the influencing factors affecting the variation in GHG emissions and clarifying the contributions of different factors can provide guidance for the future development of GHG emissions reduction in the QTP's wastewater sector.

This study formulates a comprehensive framework for GHG emissions accounting in wastewater infrastructures, specifically addressing the low-temperature climatic conditions prevalent in the QTP. Moreover, adjustments are made to the GHG emission factors related to electricity consumption, considering the development of clean energy industries within the QTP. Utilizing the Logarithmic Mean Divisia Index (LMDI), this study reveals the impact of key factors in changes in wastewater infrastructures GHG emissions. Accurate estimation of the GHG emissions characteristics in the wastewater sector of the QTP is imperative for the formulation of appropriate mitigation strategies.

2. MATERIAL AND METHODS

2.1 Data sources

Annual operational data for 175 WWTPs in the QTP were collected from the National Urban Wastewater Management Information System, including the wastewater treatment capacity, average inflow and outflow pollutant concentrations, treatment process type, sludge generation and electricity consumption, and the time range of this database is from 2014 to 2018. Qinghai Province energy production data is obtained from Qinghai Province Statistical Yearbook.

2.2 Accounting approach

According to IPCC 2019 Guidelines for National Greenhouse Gas Inventories and the Guidelines for Carbon Accounting and Emission Reduction in the Urban Water Sector (GCAER), we use the emission factors approach to calculate GHG emissions from the wastewater sector in the QTP. This study calculated the direct and indirect GHG emissions in four stages: wastewater collection stage (WC), wastewater treatment stage (WT), sludge disposal stage (SD), and the discharge of treated wastewater into receiving water bodies (Re).

Direct emissions of fossil CO_2, CH_4, and N_2O generated during the four stages, as well as the indirect emissions of electricity consumption and chemicals use can be calculated by equation (1). The CH_4 and N_2O emission factors in the WT are selected based on the WWTPs treatment process type. The direct emission factors in the WT and Re refer to GCAER. Sludge disposal considers four methods: land use, landfill, incineration, and building materials utilization. The direct GHG emissions generated by SD is calculated based on the proportion of sludge from various disposal methods and the corresponding direct emission factors[12]. In addition, the electricity emission factor is the weighted sum of emission factors from different energy sources[9], and the weight is the proportion of power generation from different energy sources.

$$E_{i,j}=y_{i,j}\times EF_{i,j}\times GWP_j/Q \qquad (1)$$

Where $E_{i,j}$ denotes the emissions intensity of type j GHG (CH_4, N_2O, fossil CO_2 or indirect emissions) in stage i (kg CO_2e/m^3); $y_{i,j}$ represents the activity amount (kWh for emissions from electricity use, kg for sludge disposal and chemicals use, and mg/L for other emissions sources); $EF_{i,j}$ indicates the type j GHG emissions factor of stage i (kg CO_2e/(kWh or kg y)); Q is the wastewater treatment capacity (m^3); GWP_j is the global warming potential, the GWP of CH_4 and N_2O are 25 and 298, and the GWP of indirect emissions from electricity consumption and chemical consumption are both 1.

2.3 Influencing factors

We used the Logarithmic Mean Divisia Index (LMDI) to quantify the influencing factors of changes in GHG emissions from the wastewater sector on the QTP. The GHG emissions variables are decomposed into 12 influencing factors using the expand Kaya identity. The total GHG emissions from WWTPs of Qinghai-Tibet Plateau are decomposed as in Eq. (2).

$$\begin{aligned}GHG_{total} &= GHG_{WC}+GHG_{WT}+GHG_{sludge} \\ &\quad +GHG_{Re}+GHG_{elec}+GHG_{chem} \\ &= P\times\frac{V}{P}\times\frac{M}{V}\times\Big(\frac{GHG_{WC}}{M}+\frac{GHG_{WT}}{M} \\ &\quad +\frac{S}{M}\times\frac{GHG_{sludge}}{M}+\frac{GHG_{Re}}{M} \\ &\quad +\frac{W}{M}\times\frac{GHG_{elec}}{W}+\frac{m}{M}\times\frac{GHG_{chem}}{m}\Big) \\ &= P\times Q\times C\times(F_{WC}+F_{W}+I_{sludge}\times F_{sludge} \\ &\quad +F_{Re}+I_{elec}\times F_{elec}+I_{chem}\times F_{chem})\end{aligned} \tag{2}$$

Where GHG_{total} is the total GHG emissions (kg CO_2e); GHG_{WC}, GHG_{WT}, GHG_{sludge}, GHG_{Re} are direct GHG emissions from wastewater collection, wastewater treatment, sludge disposal, and discharge into receiving bodies; GHG_{elec}, and GHG_{chem} are indirect emissions from electricity use and chemicals use (kg CO_2e); V is the amount of treated wastewater (m^3); M is the removed amount of COD; S is the amount of sludge (t); W is the electricity consumption (kWh); m is the amount of chemicals (kg).

The change in total GHG emissions in a year is calculated using the addition decomposition method of LMDI model. The details are shown in Eq. (3).

$$\begin{aligned}\Delta GHG_{total} &= GHG^{t}_{total}-GHG^{t-1}_{total} \\ &= \frac{GHG^{t}_{total}-GHG^{t-1}_{total}}{\ln GHG^{t}_{total}-\ln GHG^{t-1}_{total}}\times\frac{\ln GHG^{t}_{total}}{\ln GHG^{t-1}_{total}} \\ &= \Delta GHG_{P}+\Delta GHG_{Q}+\Delta GHG_{C}+\Delta GHG_{F_{WC}} \\ &\quad +\Delta GHG_{F_{WT}}+\Delta GHG_{I_{sludge}}+\Delta GHG_{F_{sludge}}+\Delta GHG_{F_{Re}} \\ &\quad +\Delta GHG_{I_{elec}}+\Delta GHG_{F_{elec}}+\Delta GHG_{I_{chem}}+\Delta GHG_{F_{chem}}\end{aligned} \tag{3}$$

Where ΔGHG_{total} is the change in total GHG emissions from year t-1 to year t; ΔGHG_{P}, ΔGHG_{Q}, ΔGHG_{C}, $\Delta GHG_{F_{WC}}$, $\Delta GHG_{F_{WT}}$, $\Delta GHG_{I_{sludge}}$, $\Delta GHG_{F_{Re}}$, $\Delta GHG_{I_{elec}}$, $\Delta GHG_{F_{elec}}$, $\Delta GHG_{I_{chem}}$, $\Delta GHG_{F_{chem}}$ are the corresponding changes in total GHG emissions caused by the changes in the above 12 influencing factors.

3. RESULTS

The GHG emissions from the wastewater sector in QTP increased by 72.2% during 2014– 2018 (from 0.25 to 0.43 Mt CO_2e). Analyzing the evolving trend of GHG emissions from wastewater sectors in prefecture-level cities on the QTP (refer to Fig. 1), it is discerned that the GHG emissions from wastewater sectors in most areas have shown a consistent annual increase. The GHG emissions from wastewater infrastructures in the eastern edge areas of the QTP surpass those in the interior regions of southwest China. Notably, annual GHG emissions from wastewater departments in locations such as Mianyang City in Sichuan, Kashgar Prefecture in Xinjiang, Xining City in Qinghai, and Ningxia City in Gansu exceed 30,000 tCO_2e.

For GHG emissions from the QTP wastewater sector, the LMDI method was employed to quantify the contributions of 12 GHG emission-driving factors. The decomposition results are illustrated in Figure 2.

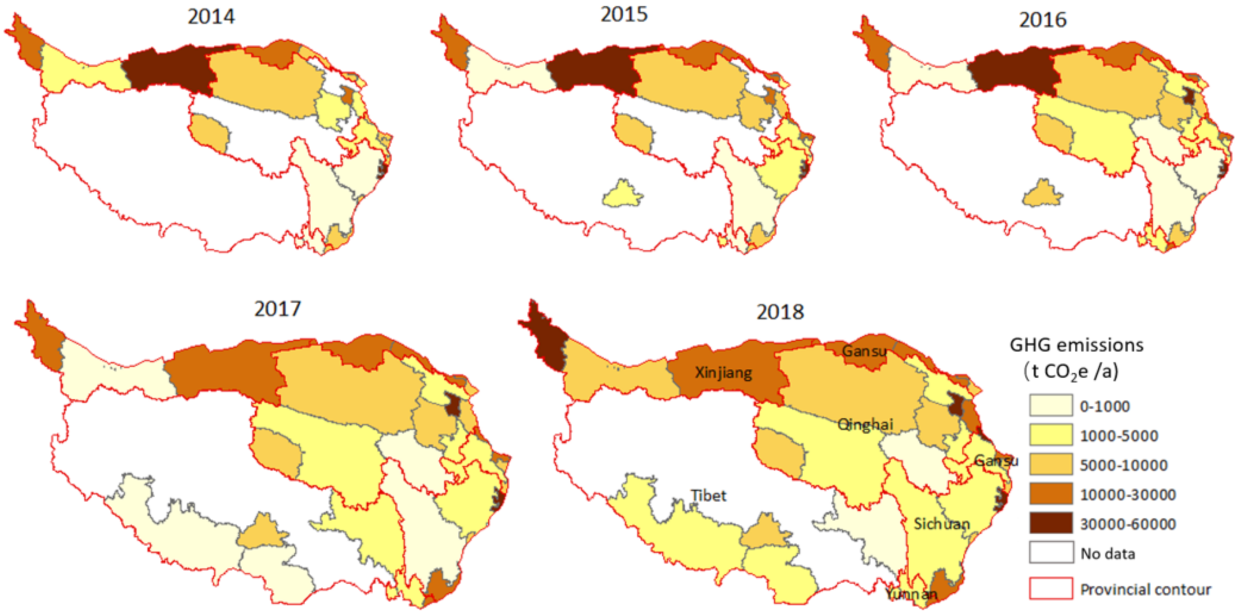

Fig. 1. GHG emissions induced by urban WWTPs during 2014-2018

Population (P), wastewater per capita (Q), chemicals intensity (I_{chem}), electricity intensity (I_{elec}), and sludge yield (I_{sludge}) were found to be the contributors of increased GHG emissions during the entire studied period. From 2014 to 2018, P, Q, I_{chem}, I_{sludge}, and Ielec contributed 68.5%, 56.7%, 40.1%, 10.3%, and 9.6% respectively to the growth of GHG emissions. On the contrary, the receiving water body emission factor (F_{Re}), electricity emission factor (F_{elec}), and chemicals emission factor (F_{chem}) serve as key factors inhibiting the growth of GHG emissions, resulting in a deceleration of GHG emissions growth by 17.4%, 18.7%, and 35.2%.

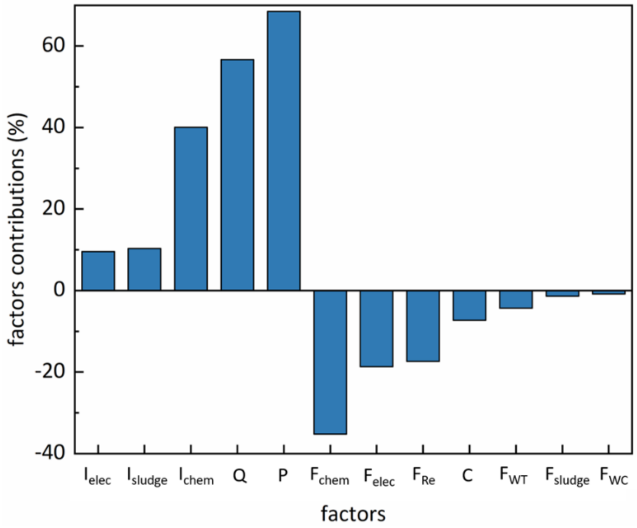

Fig. 2. The contribution of influencing factors to total GHG emissions from 2014 to 2018

4. DISCUSSION AND CONCLUSIONS

The annual GHG emissions from the wastewater sector in the QTP range from approximately 0.25 to 0.43 $MtCO_2e$, showing a consistent year-on-year increase. The findings from the influencing factor analysis indicate that fostering the expansion of clean energy in QTP proves advantageous in mitigating the escalation of GHG emissions originating from wastewater infrastructures. Moreover, the study suggests that local WWTPs can curb the upward trajectory of GHG emissions in the wastewater sector by selecting chemicals characterized by lower emission factors, and enhancing operational efficiency to diminish sludge yield and decrease electricity intensity.

ACKNOWLEDGEMENT

This work was supported by the Second Tibetan Plateau Scientific Expedition and Research Program (STEP, No. 2019QZKK1005), Beijing Outstanding Scientist Program (BJJWZYJH01201910027031), the National Natural Science Foundation of China (Nos.72091511, 72091510, 72174029) and Beijing Natural Science Foundation (9222017).

REFERENCE

[1] Gaona À, Solís B, Guerrero J, Guisasola A, Baeza J A. Nitrite pathway in A2/O WWTPs: Modelling organic matter reduction, operational cost and N_2O emissions [J]. Journal of Cleaner Production, 2023, 414: 137453.

[2] The People’s Republic of China Fourth National Communication on Climate Change [R]. Beijing China, MEE, 2023.

[3] Mohurd. China Urban and Rural Construction Statistical Yearbook [M]. Beijing China, China Statistics Press, 2013.

[4] Mohurd. China Urban and Rural Construction Statistical Yearbook [M]. Beijing China, China Statistics Press, 2022.

[5] Han Z P, Zhu G C, Lu Y Z, Chen S P, Chen Y. Research status and development demands of urban wastewater treatment in the Qinghai-Tibet Plateau region [J]. Water Purification Technology, 2022, 41(11): 76-84.

[6] Solís B, Guisasola A, Pijuan M, Baeza J A. Exploring GHG emissions in the mainstream SCEPPHAR configuration during wastewater resource recovery [J]. Science of The Total Environment, 2022, 849: 157626.

[7] Mannina G, Ekama G, Caniani D, Cosenza A, Esposito G, Gori R, Garrido-Baserba M, Rosso D, Olsson G. Greenhouse gases from wastewater treatment — A review of modelling tools [J]. Science of The Total Environment, 2016, 551-552: 254-70.

[8] Chen S, Zhang L, Liu B, Yi H, Su H, Kharrazi A, Jiang F, Lu Z, Crittenden J C, Chen B. Decoupling wastewater-related greenhouse gas emissions and water stress alleviation across 300 cities in China is challenging yet plausible by 2030 [J]. Nature Water, 2023, 1(6): 534-46.

[9] Huang Y, Meng F, Liu S, Sun S, Smith K. China's enhanced urban wastewater treatment increases greenhouse gas emissions and regional inequality [J]. Water Research, 2023, 230: 119536.

[10] Ji J, Ni J, Ohtsu A, Isozumi N, Hu Y, Du R, Chen Y, Qin Y, Kubota K, Li Y-Y. Important effects of temperature on treating real municipal wastewater by a submerged anaerobic membrane bioreactor: Removal efficiency, biogas, and microbial community [J]. Bioresource Technology, 2021, 336: 125306.

[11] Tang W, Xu S, Zhou X, Yang K, Wang Y, Qin J, Wang H, Li X. Meeting China’s electricity demand with renewable energy over Tibetan Plateau [J]. Science Bulletin, 2023, 68(1): 39-42.

[12] Wei L, Zhu F, Li Q, Xue C, Xia X, Yu H, Zhao Q, Jiang J, Bai S. Development, current state and future trends of sludge management in China: Based on exploratory data and CO2-equivaient emissions analysis [J]. Environment International, 2020, 144: 106093.