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CH_4 and CO_2 emissions rate of Iranian municipal wastewater treatment plants using IPCC and USEPA approaches

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Abstract

Background: Wastewater treatment plants are important sources of emissions of greenhouse gases (GHSs) such as carbon dioxide and methane in the atmosphere. Also, energy consumption in the wastewater treatment process causes indirect carbon dioxide emissions.

Methods: One hundred thirty-three operating wastewater treatment plants in Iran treat municipal wastewater. The carbon dioxide and methane emissions from the wastewater treatment plants for the year 2022 were estimated by establishing a calculation model according to the methods recommended by the Intergovernmental Panel on Climate Change for National Greenhouse Gas Inventories (2006) and United States Environmental Protection Agency (USEPA) guidelines.

Results: Based on the Intergovernmental Panel on Climate Change guideline, the total methane emission was 158.63 tons. Based on the USEPA guideline, the total emissions of methane and carbon dioxide were 47.61 and 351.47 tons, respectively. This amount is 3.2% of all the methane and carbon dioxide emissions of Iran. Isfahan and Tehran provinces have the highest emissions rates of methane at 31.85 and 22.91 tons, respectively. While South Khorasan and Kerman provinces have the lowest methane emissions rates of 0.46 and 0.67 tons, respectively.

Conclusion: The results will provide a scientific basis and effective strategies for policymakers to reduce the methane and carbon dioxide emissions from the wastewater treatment plants of Iran.

Keywords: Methane, Carbon dioxide, Greenhouse gases, Wastewater, Iran

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Introduction

Various human activities have led to a significant increase in greenhouse gas (GHG) emissions in the atmosphere (1,2). Since 1800, the atmospheric concentrations of carbon dioxide (CO_2) and methane (CH_4) have increased about 30% and 145%, respectively (3). GHSs act as a reflector of heat from the ground, which obstructs the escape of heat in the atmosphere, causing an increase in the global average temperature (4,5). GHSs from anthropological activities such as agriculture, industry, waste disposal deforestation, and most especially burning of fossil fuels are the leading causes of climate change (6-8). Excessive GHS emissions pose risks such as floods, droughts, the spread of disease in the tropics, global warming, and the rise of storms, tsunamis, and volcanoes (9). Wastewater treatment plants (WWTPs) are known as one of the most common sub-sources of GHS emissions (10-12). Zhao et al reported that cities with a higher gross domestic product produced more degradable organics in wastewater, thus, more GHGs emissions (13). The primary methods used for wastewater treatment, including aerobic processes like activated sludge-based processes, and significant anaerobic processes, both make significant contributions to the production and emission of GHGs (14). WWTPs produce three main types of GHSs, including CO_2, CH_4, and N_2O (15). Koutsou et al reported that emissions from Greek WWTPs were about 0.9% of total GHGs emissions in Greece each year (12). Yan et al observed that overall GHGs emissions from Chinese municipal WWTPs increased from 326.54 to 1294.03 Gg (16). Therefore, the determination of GHGs emissions by applying various estimation techniques has increased in recent years. One of the emission estimation techniques in the environment is the emission coefficient method used to estimate GHGs in the air, land, and water (17). Emission coefficients have long been considered essential tools for air quality management (18). Emission coefficients, despite their specific limitations, are the best or only available method for estimating GHGs emissions (19). These coefficients provide an average of all available data of acceptable quality (20,21). As Iran is a member of various conventions in the field of environmental protection and climate change, it is necessary to determine the share of wastewater treatment in this country in the production of CH_4 and CO_2 gases. The present study aimed to evaluate the emission rate of CH_4 and CO_2 from municipal WWTPs in Iran using a calculation model established by the Intergovernmental Panel on Climate Change for National Greenhouse Gas Inventories 2006 (IPCC2006) and the United States Environmental Protection Agency (USEPA) guidelines. Emission zoning maps prepared using geographic information system (GIS). This study as the first study in this field in our country provides emission reduction scenarios.

Materials and Methods

Study area

Iran is the 16th largest globally, with a total land area of 1 648 195 km^2. The combined population of the 32 provinces is 82.91 million people. In the present study, CH_4 and CO_2 emission rates from 137 municipal WWTPs in all provinces of Iran were considered.

Data collection and estimation of CH_4 and CO_2 emissions

To estimate CH_4 and CO_2 emissions from municipal WWTPs in all provinces of Iran, the basic information, including the type of treatment process, the total population covered, and the discharge rate of 137 WWTPs in all provinces, were collected from wastewater and water companies of each province. The rate of CH_4 and CO_2 emissions in different provinces were estimated according to the emission factors recommended by the 2006 IPCC for National Greenhouse Gas Inventories (the 2006 IPCC Guidelines for short; IPCC, 2006) and the USEPA (US EPA, 2006) guidelines (22). The CH_4 and CO_2 emissions from a municipal WWTP are calculated using equations 1 and 2.

$$ECH4 = (TOW \times EF) - R \quad (1)$$

$$ECO2 = (TOW \times EF) - R \quad (2)$$

Where ECH_4 is the total amount of CH_4 emissions (tons CH_4/year), ECO_2 is the total amount of CO_2 emissions (tons CO_2/year), TOW is total organic matter emissions of living wastewater treatment (kg BOD/year), EF is the emission factor (kg (CH_4, CO_2)/kg BOD), and R is the volume of recovered CH_4, CO_2 (kg (CH_4, CO_2)/ year). The formula of the emission factor (EF) is shown in Eq. (3):

$$EF = B0 \times MCF \quad (3)$$

Where B_0 is the maximum production capacity (kg (CH_4, CO_2)/kg BOD). Since there is still no large-scale recovery of CH_4 and CO_2 in Iran, the amount of R is assumed to be zero. MCF is the correction factor of CH_4 and CO_2. According to the actual situation in our country and using the related parameters, it is concluded that the national average MCF is 0.165.

The emission coefficients used for the emission sources related to WWTPs are presented in Table 1.

Preparation of zoning maps

After estimating CH_4 and CO_2 emissions rates using IPCC 2006 and USEPA approaches, classified zoning maps of the studied greenhouse gas emissions in municipal WWTPs in all studied provinces were prepared and drawn using GIS 10.2 software.

Results

The main wastewater treatment processes in the studied treatment plants included activated sludge, stabilization pond, and aeration lagoon. These processes are operated aerobically. The results of greenhouse gas emissions (CH_4 and CO_2) from WWTPs based on emission coefficients (IPCC 2006 and USEPA 2006) in the studied provinces are presented in Table 2.

The difference in estimated emission rates for CH_4 using IPCC 2006 and USEPA approaches is shown in Figure 1.

As shown in Figure 1, the emission rate estimated by the IPCC 2006 method is higher than USEPA. This difference can be related to the higher emission coefficients of this method than the USEPA. The zoning maps based on the emission coefficient of IPCC 2006 and USEPA are shown in Figures 2 and 3, respectively. In all zoning maps, CO_2

Table 1. The maximum production capacity emission coefficients based on the IPCC 2006 and USEPA (23,24)

Approach	B_0(kg (CH_4, CO_2)/kg BOD)	
	CO_2	CH_4
IPCC 2006	-	kg CH_4/kg BOD 0.06
USEPA	1.375 kg CO_2/kg BOD	0.06 kg CH_4/kg[a]

[a] BOD by applying the CH_4 correction factor (0.3) for central aerobic treatment.

Table 2. The total amount of CH_4 and CO_2 emissions (tons/year) from municipal WWTPs in all provinces of Iran in 2022

Provinces	IPCC 2006:0.6 kg CH_4. kg BOD	USEPA, 0.6 kg CH_4.kg BOD by applying the CH_4 correction factor for central aerobic treatment (0.3)	USEPA, 1.375 Kg CO_2. Kg BOD
East Azerbaijan	10.39	3.11	23.81
West Azerbaijan	8.37	2.51	19.2
Isfahan	31.85	9.64	74.07
Ardabil	2.09	0.63	4.80
Alborz	1.82	0.55	4.17
Ilam	8.40	2.52	19.25
Bushehr	1.81	0.54	4.16
Tehran	22.91	6.87	52.51
Chaharmahal and Bakhtiari	2.37	0.71	5.44
North Khorasan	0.85	0.25	1.95
Razavi Khorasan	2.35	1.99	15.26
South Khorasan	0.46	0.14	1.04
Khuzestan	5.32	1.30	11.42
Zanjan	1.40	0.42	3.20
Semnan	2.65	0.79	6.06
Sistan and Baluchestan	2.95	0.88	6.76
Fars	4.26	1.23	9.75
Qom	2.99	0.90	6.86
Qazvin	1.94	0.58	4.44
Kurdistan	8.73	2.62	20.01
Kerman	0.67	0.20	1.55
Kermanshah	3.93	1.18	9.00
Kohgiluyeh and Boyer-Ahmad	1.91	0.57	4.38
Gilan	0.94	0.28	2.15
Lorestan	5.71	1.71	13.10
Mazandaran	2.68	0.82	5.96
Markazi	2.09	0.63	4.79
Hormozgan	5.10	1.53	11.68
Hamadan	0.72	0.22	1.65
Yazd	10.97	2.29	3.05
Total	158.63	47.61	351.47

emissions were higher than CH_4 emissions.

Discussion

Based on the emission coefficient of IPCC 2006, municipal WWTPs of Isfahan and Tehran provinces have the highest emissions rates of CH_4, 31.85, and 22.91 tons/year, respectively. WWTPs of South Khorasan and Kerman provinces have the lowest emissions rates of CH_4, 0.46, and 0.67 tons/year, respectively. Based on the IPCC 2006 coefficient, the total CH_4 released from Iran's municipal WWTPs was calculated at 158.63 tons/year. Based on the emission coefficient of the USEPA, Isfahan provinces WWTP has the highest emissions rate of CH_4 and CO_2, 9.64 and 74.07 tons/year, respectively. The lowest emission rates of CH_4 and CO_2 were related to South Khorasan, 0.14 and 1.04 tons/year, respectively. The total estimated emissions rates of CH_4 and CO_2 were 47.61 and 351.47 tons/year, respectively. Isfahan and Tehran are the two most populated cities. The common feature of these cities is that they are the economic centers of the country and have a higher level of prosperity. These two metropolises have a total share of 34.52% of the total emissions of CH_4 and 35.9% of the total emissions of CO_2 from the 133 investigated WWTPs (Table 2). Larger cities with larger populations emit more GHG from their WWTPs because they tend to produce more municipal wastewater. The present study found that cities with more population have more GHG emissions per capita. The study by Zhao et al has shown a significant relationship between population, level of prosperity, and economy of society with the amount of GHG emissions in China (13). The share of Iran's GHG emissions from total world GHG emissions is 1.58% (14171 tons/year), which according to the results of this study, 2.82-3.59% of this amount is related to CH_4 and CO_2 emissions from WWTPS in Iran. According to a study by Daelman et al, the total emissions of the WWTPs are 2,728 tons/year, and the excess CO_2 emissions are related to electricity and natural gas consumption. CH_4 emissions were much lower than CO_2 in two Dutch WWTPs (25). At the Kortenoord WWTPs, annual CH_4 emissions were 960 tons/year, while CO_2 emissions were estimated at 500 tons/year. At the Papendrecht WWTPs, CH_4 emissions were 730 tons/year, and CO_2 emissions were 3458 tons/year (26). Yerushalmi et al reported that in aerobic, anaerobic, and hybrid treatment systems, the total CO_2 emissions are 1.6, 3.3, and 3.6 tons/year, respectively (27,28). In Iran, per capita emission of GHG resulting from urban wastewater treatment is equal to 0.5 g/year for CH_4, 4.1 g/year for CO_2 (based on USEPA), and 1.82 g/year for CH_4 (based on IPCC). Zhao et al stated that the per capita production of GHG in China is 4.3 kg per capita on average (13). The chemical and physical characteristics of treated wastewater, the population covered by wastewater collection systems, per capita production of wastewater, the type of process used for wastewater treatment, and different climatic conditions can be the reasons for differences in the estimated GHG emission rates with other studies.

Conclusion

This research estimated CH_4 and CO_2 emissions in municipal WWTPs in Iran based on a calculation model established by the IPCC 2006 and USEPA guidelines. The estimated CH_4 emission from WWTPs based on the IPCC 2006 and USEPA guidelines was 158.63 and 47.61 tons, respectively. Also, based on the USEPA guideline, CO_2 emission was estimated to be 351.47 tons in 2022.

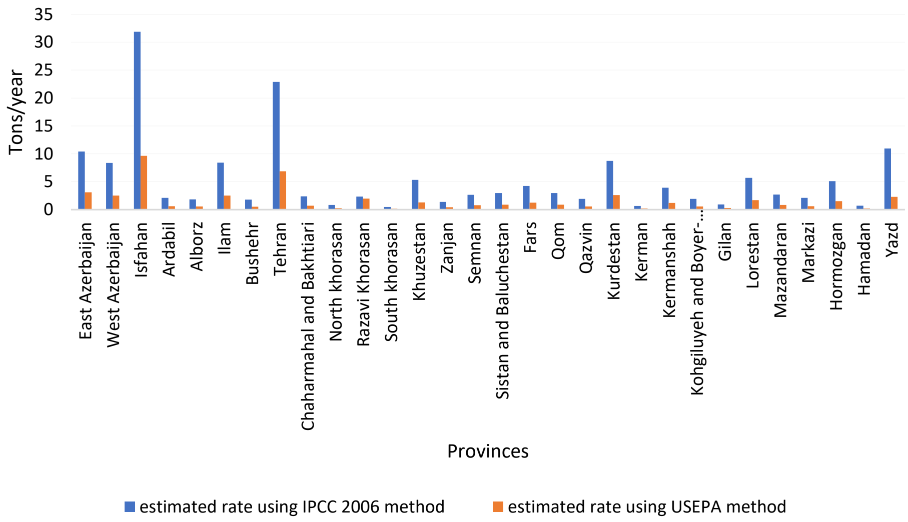

Figure 1. Estimated CH_4 emission rates from $WWTP_s$ using IPCC 2006 and USEPA approaches

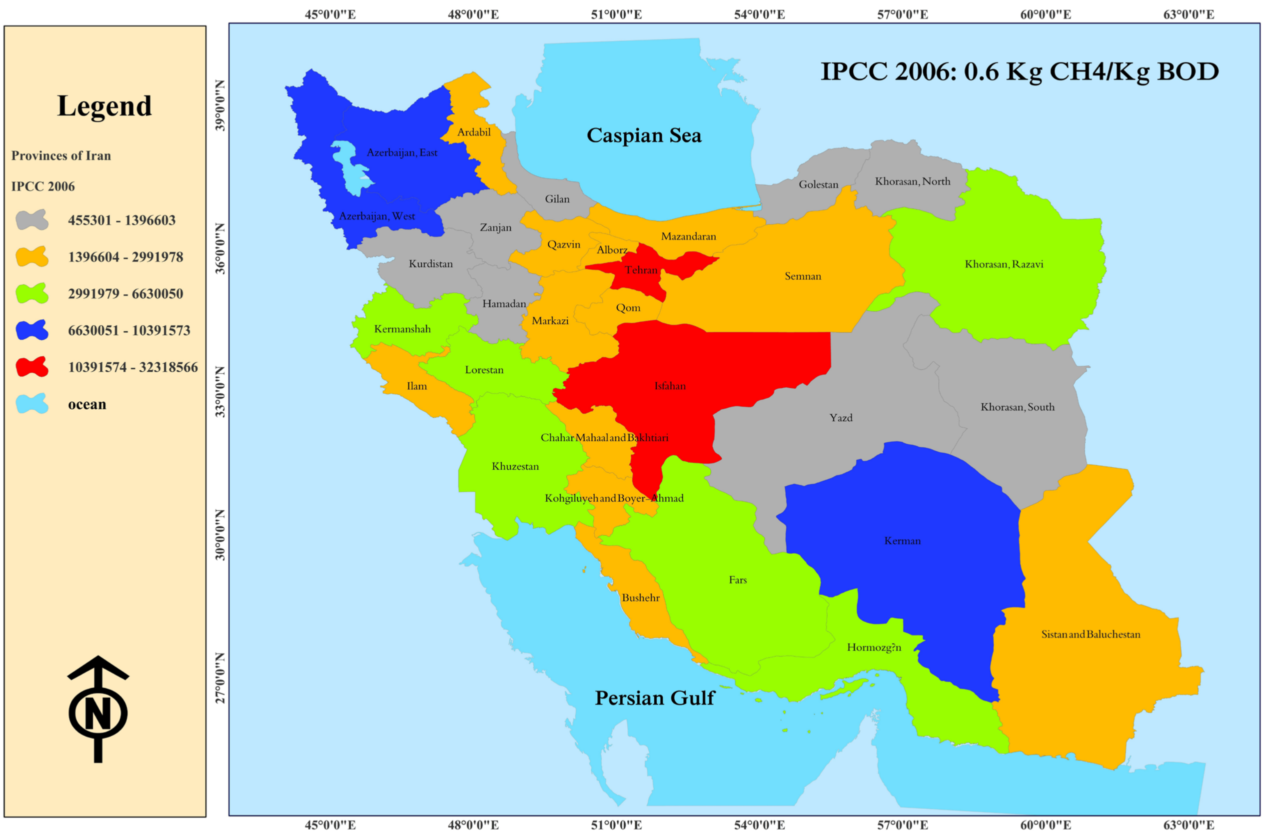

Figure 2. The classified zoning map of CH_4 based on the emission coefficient of IPCC 2006

Iran is a developing country and with the possibility of an exponential increase in the number of WWTPs in the near future, it is necessary to adopt appropriate policies to manage GHGs emissions from WWTPs. The following strategies are recommended to reduce GHGs emissions in the WWTPs of Iran: 1- Reduce the need for heating energy in WWTPs by running anaerobic reactors and digesters at lower temperatures, 2- Increasing anaerobic digestion efficiency to produce more biogas, and capture GHGs by hoods and burn together with the biogas, 3- Reducing the use of fossil fuels by supplying the required heating energy of WWTPs through recovering energy from biogas, 4- Use of available technologies to eliminate GHGs, 5- To remove more organic matter, future generations of WWTPs must use more anaerobic processes.

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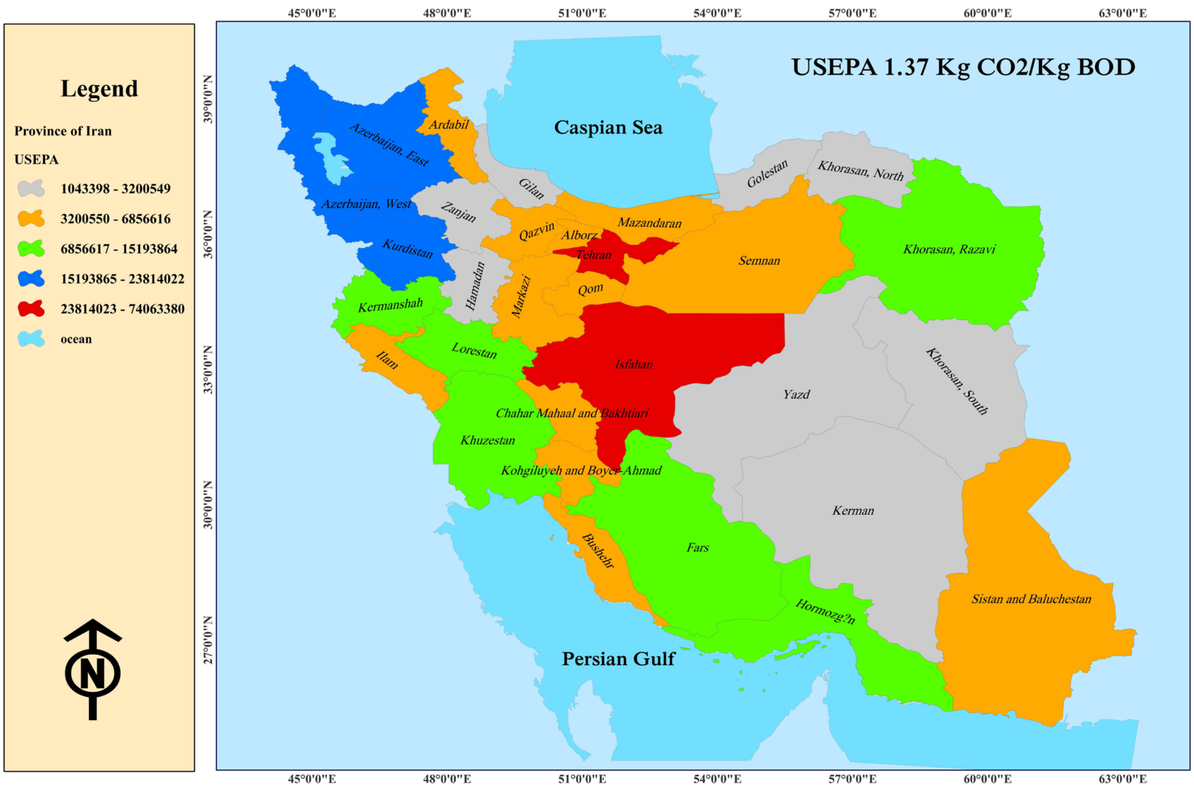

Figure 3. The classified zoning map of CH_4 and CO_2 based on the emission coefficient of USEPA

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Authors' contributions

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Visualization: No Applicable.
Writing–original draft: Rozhan Feizi.
Writing–review & editing: Masoud Panahi Fard.

Competing interests

The authors declare that they have no conflict of interests regarding the publication of the present article.

Ethical issues

Not applicable.

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References

1. Kazancoglu Y, Ozbiltekin-Pala M, Ozkan-Ozen YD. Prediction and evaluation of greenhouse gas emissions for sustainable road transport within Europe. Sustain Cities Soc. 2021;70:102924. doi: 10.1016/j.scs.2021.102924.
2. Tang YH, Luan XB, Sun JX, Zhao JF, Yin YL, Wang YB, et al. Impact assessment of climate change and human activities on GHG emissions and agricultural water use. Agric For Meteorol. 2021;296:108218. doi: 10.1016/j.agrformet.2020.108218.
3. Prather MJ, Holmes CD, Hsu J. Reactive greenhouse gas scenarios: systematic exploration of uncertainties and the role of atmospheric chemistry. Geophys Res Lett. 2012;39(9):1-5. doi: 10.1029/2012gl051440.
4. El-Fadel M, Massoud M. Methane emissions from wastewater management. Environ Pollut. 2001;114(2):177-85. doi: 10.1016/s0269-7491(00)00222-0.
5. Mikhaylov A, Moiseev N, Aleshin K, Burkhardt T. Global climate change and greenhouse effect. Entrep Sustain Issues. 2020;7(4):2897-913. doi: 10.9770/jesi.2020.7.4(21).
6. Chang J, Kyung D, Lee W. Estimation of greenhouse gas (GHG) emission from wastewater treatment plants and effect of biogas reuse on GHG mitigation. Adv Environ Res. 201;3(2):173-83. doi: 10.12989/aer.2014.3.2.173.
7. Gupta D, Singh SK. Greenhouse gas emissions from wastewater treatment plants: a case study of Noida. Journal of Water Sustainability. 2012;2(2):131-9.

8. Ahmadi Moghadam M, Feizi R, Panahi Fard M, Jaafarzadeh Haghighi Fard N, Omidinasab M, Faraji M, et al. Estimating greenhouse emissions from sanitary landfills using Land-GEM and IPCC model based on realistic scenarios of different urban areas: a case study of Iran. J Environ Health Sci Eng. 2021;19(1):819-30. doi: 10.1007/s40201-021-00649-2.
9. Nguyen TK, Ngo HH, Guo W, Chang SW, Nguyen DD, Nghiem LD, et al. Insight into greenhouse gases emissions from the two popular treatment technologies in municipal wastewater treatment processes. Sci Total Environ. 2019;671:1302-13. doi: 10.1016/j.scitotenv.2019.03.386.
10. Corominas L, Flores-Alsina X, Snip L, Vanrolleghem PA. Comparison of different modeling approaches to better evaluate greenhouse gas emissions from whole wastewater treatment plants. Biotechnol Bioeng. 2012;109(11):2854-63. doi: 10.1002/bit.24544.
11. Kim H, Cheon Y, Lee HK, Lee IB. Effects of greenhouse gas emission on decentralized wastewater treatment and reuse system. Comput Aided Chem Eng. 2012;31:515-9. doi: 10.1016/b978-0-444-59507-2.50095-0.
12. Koutsou OP, Gatidou G, Stasinakis AS. Domestic wastewater management in Greece: greenhouse gas emissions estimation at country scale. J Clean Prod. 2018;188:851-9. doi: 10.1016/j.jclepro.2018.04.039.
13. Zhao X, Jin XK, Guo W, Zhang C, Shan YL, Du MX, et al. China's urban methane emissions from municipal wastewater treatment plant. Earths Future. 2019;7(4):480-90. doi: 10.1029/2018ef001113.
14. Chen S, Harb M, Sinha P, Smith AL. Emerging investigators series: revisiting greenhouse gas mitigation from conventional activated sludge and anaerobic-based wastewater treatment systems. Environ Sci Water Res Technol. 2018;4(11):1739-58. doi: 10.1039/c8ew00545a.
15. Ashrafi O, Yerushalmi L, Haghighat F. Greenhouse gas emission and energy consumption in wastewater treatment plants: impact of operating parameters. Clean (Weinh). 2014;42(3):207-20. doi: 10.1002/clen.201200158.
16. Yan X, Zhang W, Wang Z, Zhou Z, Han Y, Cao Y. Spatial and Temporal Distribution of Greenhouse Gas Emissions from Rural Sewage Treatment in China. Available at SSRN 4435740. doi:10.21203/rs.3.rs-3470580/v1
17. Shrestha A, Bhattarai TN, Ghimire S, Mainali B, Treichel H, Paudel SR. Estimation of greenhouse gases emission from domestic wastewater in Nepal: a scenario-based analysis applicable for developing countries. Chemosphere. 2022;300:134501. doi: 10.1016/j.chemosphere.2022.134501.
18. Ahmed OY, Ries MJ, Northrop WF. Emissions factors from distributed, small-scale biomass gasification power generation: comparison to open burning and large-scale biomass power generation. Atmos Environ. 2019;200:221-7. doi: 10.1016/j.atmosenv.2018.12.024.
19. Salami HA, Adegite JO, Olalekan HI, Ahmed MO. Estimation of pollutants' emission rates and associated impact on local air quality: a case study of cottage industry in Ibadan metropolis. Niger J Technol. 2021;40(1):146-53. doi: 10.4314/njt.v40i1.19.
20. Environmental Protection Agency (EPA). Air Emissions Factors and Quantification. EPA; 2009. p. 1-10.
21. Ahmadi Moghadam M, Ghodrati S, Jaafarzadeh Haghighi Fard N. CO2 and CH4 emission estimation using emission factors from sugarcane development company. Jentashapir J Cell Mol Biol. 2013:9-17. [Persian].
22. Liu B, Zhao W, Zhang Y. Status of methane emission in sewage treatment process and emissions estimate in Henan province. Int J Environ Agric Res. 2017;3(12):23-6.
23. Xi J, Gong H, Zhang Y, Dai X, Chen L. The evaluation of GHG emissions from Shanghai municipal wastewater treatment plants based on IPCC and operational data integrated methods (ODIM). Sci Total Environ. 2021;797:148967. doi: 10.1016/j.scitotenv.2021.148967.
24. Anderson K, Moore PA Jr, Martin J, Ashworth AJ. Evaluation of a novel poultry litter amendment on greenhouse gas emissions. Atmosphere. 2021;12(5):563. doi: 10.3390/atmos12050563.
25. Daelman MR, van Voorthuizen EM, van Dongen UG, Volcke EI, van Loosdrecht MC. Methane emission during municipal wastewater treatment. Water Res. 2012;46(11):3657-70. doi: 10.1016/j.watres.2012.04.024.
26. Guo Z, Sun Y, Pan SY, Chiang PC. Integration of green energy and advanced energy-efficient technologies for municipal wastewater treatment plants. Int J Environ Res Public Health. 2019;16(7):1282. doi: 10.3390/ijerph16071282.
27. Yerushalmi L, Haghighat F, Bani Shahabadi M. Contribution of on-site and off-site processes to greenhouse gas (GHG) emissions by wastewater treatment plants. Int J Environ Ecol Eng. 2009;3(6):144-8. doi: 10.5281/zenodo.1073323.
28. Maktabifard M, Zaborowska E, Makinia J. Evaluating the effect of different operational strategies on the carbon footprint of wastewater treatment plants - case studies from northern Poland. Water Sci Technol. 2019;79(11):2211-20. doi: 10.2166/wst.2019.224.