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Point source pollution and climate change impact from sequential batch reactor wastewater treatment plant

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Abstract

Since sequential batch reactor (SBR) system is sequentially removes carbon, nitrogen and phosphorous in a single reactor by maintaining anoxic and aerobic stages, it recently has attracted a great deal of interest. This study evaluates the impact of wastewater treatment plant (WWTP) with a SBR system on a creek which is the influent tributary to Aegean Sea. Accordingly, this study demonstrates (1) the treatment efficiency of full-scale WWTP; (2) how WWTP influences creek's water quality from 2012 to 2015; (3) how creek influences receiving body's water quality; and (4) the potential climate change impact of a SBR treatment system. The study shows that SBR treatment plant complies with standards set by Turkish Legislations with 4-year average of 62 % SS, 71 %BOD, 62 % COD, 32 % TN and 31 % TP removal but the accumulation of pollutants occurs during low flows when point source is dominant. This is the case in the downstream of treated WWTP discharge point. The potential impact of treatment plant on climate change was calculated in terms of greenhouse gas emissions (GHG). The annual methane emissions from SBR alternated from minimum of 68.71 to maximum 248.99 tCO_2e. Total emissions (CH_4, N_2O and emission due to electricity usage) from a full-scale SBR were calculated as 144.22 tCO_2e, 318.34 tCO_2e, 474.79 tCO_2e and 996.62 tCO_2e from 2012 to 2015, respectively.

Keywords: wastewater treatment, point source, sequential batch reactor, receiving body, greenhouse gas, emissions.

1. Introduction

Since SBR (Sequential Batch Reactor) system is sequentially removes carbon, nitrogen and phosphorous in a single reactor by maintaining anoxic and aerobic stages, it recently has attracted a great deal of interest. The WWTP in question operated with SBR in which all the reactions and separation takes place in one tank and in a well-defined and continuously repeated time sequence. SBR process used in this plant for high nitrogen and phosphorus removal achieved by a combination of aerobic tank, anoxic tank (fill, react, settle, draw and idle). Denitrification occurs at the beginning of the fill step taking usually 25 % of the total cycling time where raw wastewater is added to the reactor. The step taking up 35 % of the total cycle time is called react step where the reactions were finalized. The main purpose of third step (settle) is to allow solids separation and provide a supernatant ready to be discharged as effluent. The purpose of fourth step (draw step) ranging from 5 to 30 % of the total cycle time is to remove clarified treated water from the reactor. The purpose of last step "idle" is to provide time for one reactor to complete its fill cycle before switching to another unit.

The greenhouse effect of major greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) all produced in wastewater treatment operations is weighted by their Global Warming Potentials (GWP). Over a period of 100 years one ton of methane and nitrous oxide will have a warming effect equivalent to 25 and 298 ton of CO_2, respectively (IPCC, 2006). In the same direction, Ravishankara *et al.,* (2009) stated that nitrous oxide (N_2O) is a significant greenhouse gas with a lifetime of 114 years with a 298-fold stronger effect of global warming than carbon dioxide and is responsible for also ozone depletion in the stratosphere. In SBR processes, ammonium is transformed into N_2 gas via nitrification and denitrification. N_2O is generated as a by-product or an intermediate due to insufficient oxygen during nitrification in the aeration step and due to insufficient carbon during denitrification in settling and decanting steps (Itokawa *et al.*, 2001). Law *et al.*, (2012) stated that wastewater treatment facilities are anthropogenic sources of N_2O to the atmosphere, taking account of 3.2–10% of the total emission. In this paper, only methane and nitrous oxide are calculated since carbon that present in wastewater is biogenic and it is assumed that it is returning the carbon to the atmosphere as CO_2 represents no net flux to the system (IPCC, 2006).

Wang *et al.*, (2011) reported that based on field measurements the maximum methane flux was occurred in sludge screw conveyor with 823 $g/m^2/d$ and CH_4 emission occurred in every processing unit. Bousquet *et al.,* (2006) stated that management and treatment of domestic and industrial wastewater have been identified as an important source of CH_4. Methane is produced by methanogens due to low O_2 and nitrate/nitrite concentration during the anaerobic and anoxic processes. In the same direction, IPPC, (2007) reported that more than

50% of global methane emissions are related to human-related activities like landfill, wastewater treatment, agriculture and certain industrial process.

It is thought that this paper will make a significant contribution to the literature at least will fill space on the wastewater treatment plant's effect on climate change. This study demonstrates 1) the treatment efficiency of full-scale WWTP; (2) how WWTP influences creek's water quality from 2012 to 2015; (3) how creek influences receiving body's water quality and (4) the potential climate change impact of a SBR treatment system treating domestic wastewater by calculating its GHG emissions.

2. Materials and methods

2.1 Sampling points and chemical analysis

A four-year data set is used to evaluate the efficiency and effect of full-scale SBR WWTP on receiving body's water quality. Monthly water samples taken from (see Fig.1) inlet (sampling station 1, S1) and outlet (sampling station 2, S2) of the treatment plant, upstream of discharge point (sampling station 3, S3), downstream of discharge point (sampling station 4, S4) and the point where creek flows into the sea (sampling station 5, S5) were covered to prevent exposure to direct sunlight, stored in ice and then analyzed in the laboratory within 24 hours. Standard methods, equipment and method of measurement used in analysis are presented in Table 1.

Table 1. Standard methods, equipments and method of measurement used in analysis

Param.	Equipment	Standard Method	Method
DO	Portable HACH Sension156	TS 5677 EN 25814-1996	Electrochemical
pH	Portable HACH Sension156	TS 3263 ISO 10523-1999	Electrochemical
Temp.	Portable HACH Sension156	TS 3263 ISO 10523-1999	Electrochemical
EC	Portable HACH Sension156	TS 5677 EN 25814-1996	Electrochemical
TP	DRLANGE–XION500 spectrophotometer	TS ISO 8466-1:1997TS EN ISO 10304-2:1997	Spectrophotometric
TN	DRLANGE–XION500 spectrophotometer	TS ISO 8466-1:1997T TS ISO 8466-1:1997	Spectrophotometric
COD	DRLANGE–XION500 spectrophotometer	TS 2789 ISO 6060:2000 TS 7094 EN 872:1999	Spectrophotometric
BOD	HACH- BODTrak ™ II	APHA, AWWA, WEF SM 5210 D	Respirometric
SS	SARTORIUS vacuum filter	TS 7094 EN 872:1999	Membrane Filtration
TC, FC, FS	SARTORIUS vacuum filter	TS EN ISO 9308-1: 2004	Membrane Filtration

Figure 1. Study area and sampling points

2.2 Methane (CH_4) emission calculating principles

Estimation of organically degradable material in domestic wastewater, estimation of methane emission factor for domestic wastewater and estimation of CH_4 emissions from domestic wastewater are steps for calculating CH_4 emissions.

The direct methane emissions are a function of the amount of degradable carbon in the wastewater and sludge, and an emission factor. The emission factor (EF) is a function of the maximum CH_4 producing potential (B_o) and the methane correction factor (MCF) for the wastewater treatment and discharge system (see Equation 1). The B_o is the maximum amount of CH_4 that can be produced from a given quantity of organics in the wastewater. IPPC, (2006) recommends

the B_o value to be 0.6 kg CH_4/kg BOD removal and the uncertainty range to be ±30%. The MCF indicates that the extent to which the CH_4 producing capacity (Bo) is realized in each type of treatment and discharge pathway and system taken as 0.05 (Eqn 1: Eqn 6.2 of IPCC, 2006:CH4 emission factor for each domestic wastewater treatment/discharge pathway or system).

TOW (total organics in wastewater in inventory year, kg BOD/yr) is a function of human population and BOD generation per person and it is expressed in terms of biochemical oxygen demand (kg BOD/year). TOW was calculated by using Equation 2 (Eqn 2: Eqn 6.3 of IPCC, 2006: Total organically degradable material in domestic wastewater).

EQUATION 6.2
CH_4 EMISSION FACTOR FOR
EACH DOMESTIC WASTEWATER TREATMENT/DISCHARGE PATHWAY OR SYSTEM

$$EF_j = B_o \bullet MCF_j$$

Equation 1

Where:

EF_j = emission factor, kg CH_4/kg BOD
j = each treatment/discharge pathway or system
B_o = maximum CH_4 producing capacity, kg CH_4/kg BOD
MCF_j = methane correction factor (fraction), See Table 6.3.

EQUATION 6.3
TOTAL ORGANICALLY DEGRADABLE MATERIAL IN DOMESTIC WASTEWATER

$$TOW = P \bullet BOD \bullet 0.001 \bullet I \bullet 365$$

Equation 2

Where:

TOW = total organics in wastewater in inventory year, kg BOD/yr
P = country population in inventory year, (person)

BOD = country-specific per capita BOD in inventory year, g/person/day, See Table 6.4.
0.001 = conversion from grams BOD to kg BOD
I = correction factor for additional industrial BOD discharged into sewers (for collected the default is 1.25, for uncollected the default is 1.00.)

The general equation for estimating CH_4 emissions from domestic wastewater was calculated by using equation 3.

EQUATION 6.1
TOTAL CH_4 EMISSIONS FROM DOMESTIC WASTEWATER

$$CH_4\ Emissions = \left[\sum_{i,j}\left(U_i \bullet T_{i,j} \bullet EF_j\right)\right](TOW - S) - R$$

Equation 3

Where:

CH_4 Emissions = CH_4 emissions in inventory year, kg CH_4/yr
TOW = total organics in wastewater in inventory year, kg BOD/yr
S = organic component removed as sludge in inventory year, kg BOD/yr
U_i = fraction of population in income group *i* in inventory year, See Table 6.5.
$T_{i,j}$ = degree of utilisation of treatment/discharge pathway or system, *j*, for each income group fraction *i* in inventory year, See Table 6.5.
i = income group: rural, urban high income and urban low income
j = each treatment/discharge pathway or system
EF_j = emission factor, kg CH_4 / kg BOD
R = amount of CH_4 recovered in inventory year, kg CH_4/yr

2.3 Nitrous oxide (N_2O) emission calculating principles

Estimation of nitrogen in effluent, and estimation of emission factor and emissions of indirect N_2O emissions from wastewater are steps for calculating N_2O emissions. It is associated with the microbial conversion of nitrogen compound in the wastewater. It occurs as emissions from treatment plants or from wastewater after disposal of effluent into waterways, lakes or the sea. The emission factor (0.005) is taken for domestic wastewater nitrogen effluent, referring to the default value recommended by IPCC (2006). The factor 44/28 is the conversion of kg N_2O–N into kg N_2O. A simplified equation is given in Equation 5. Emission factors of N_2O were evaluated by incorporating N loads in influent of the SBR WWTP.

EQUATION 6.8
TOTAL NITROGEN IN THE EFFLUENT

$$N_{EFFLUENT} = (P \bullet Protein \bullet F_{NPR} \bullet F_{NON-CON} \bullet F_{IND-COM}) - N_{SLUDGE}$$

Equation 4

Where:

$N_{EFFLUENT}$ = total annual amount of nitrogen in the wastewater effluent, kg N/yr
P = human population
Protein = annual per capita protein consumption, kg/person/yr
F_{NPR} = fraction of nitrogen in protein, default = 0.16, kg N/kg protein
$F_{NON-CON}$ = factor for non-consumed protein added to the wastewater
$F_{IND-COM}$ = factor for industrial and commercial co-discharged protein into the sewer system
N_{SLUDGE} = nitrogen removed with sludge (default = zero), kg N/yr

EQUATION 6.7
N_2O EMISSIONS FROM WASTEWATER EFFLUENT

$$N_2O\ Emissions = N_{EFFLUENT} \bullet EF_{EFFLUENT} \bullet 44/28$$

Equation 5

Where:

N_2O emissions = N_2O emissions in inventory year, kg N_2O/yr
$N_{EFFLUENT}$ = nitrogen in the effluent discharged to aquatic environments, kg N/yr
$EF_{EFFLUENT}$ = emission factor for N_2O emissions from discharged to wastewater, kg N_2O-N/kg N
The factor 44/28 is the conversion of kg N_2O-N into kg N_2O.

2.4 Carbon dioxide (CO_2) emission calculating principles

Two main factors causing CO_2 production from wastewater treatment plants are type treatment process and electricity consumption. During anaerobic process the BOD_5 of wastewater is either incorporated into biomass or it is converted to CO_2 and CH_4. A fraction of biomass is further converted to CO_2 and CH_4 via endogenous respiration. Other emission sources of carbon dioxide are sludge digesters and from digester gas combustion. In the aerobic process CO_2 is produced through the breakdown of organic matter in the activated sludge process and some through the primary clarifiers. CO_2 emissions from WWTP are not considered in the IPCC Guidelines because these are of biogenic origin and should not be included in national total emissions. Biogenic to origin means short cycle or natural sources of atmospheric CO_2 which cycles from plants to animals to humans as part of the natural carbon cycle and food chain do not contribute to global warming. Photosynthesis produced short-cycle CO_2, removes an equal mass of CO_2 from the atmosphere that returns during respiration or wastewater treatment.

2.5 Indirect GHG emissions from electricity production

Indirect GHG emissions were calculated by multiplying total MWh used annually and emission factor 0.91 tCO_2e/MW (IPCC, 2006). I have followed IPCC Guidelines for National Greenhouse Gas Inventories, 2006 for calculating GHG emissions from 2012 to 2015 from SBR WWTP.

3. Results and discussion

3.1 Wastewater treatment efficacy of full-scale SBR wastewater treatment plant

A four-year data set (EPASA 2012, 2013, 2014 and 2015) were examined to investigate the present status of and the monthly and yearly (2012–2015) changes in, the efficiency of WWTP and its effect on receiving body. COD and BOD are the most important parameters for monitoring studies and control of waste water treatment plants. In Turkey as Urban Wastewater Treatment Directive (UWWTD, 2006) states, acceptable wastewater treatment plant effluent BOD and COD concentration is 25 mg/l and 125 mg/l, respectively. Figure 2 reveals that the WWTP's effluent BOD and COD values are in accordance with the Turkish UWWTD (2006). As can be seen from Figure 2 both effluent TN and TP concentrations are complying with the standards set by Turkish UWWTD. These results indicate that WWTP in question operated with 62 % SS, 71% BOD, 62 % COD, 32 % TN and 31 % TP removal.

3.2 Impact of full-scale SBR wastewater treatment plant discharge on the primary receiving body (creek)

In order to investigate the effect of plant discharge on the receiving body's water quality, water quality classes are compared in the downstream and upstream of discharge point. The water quality of creeks in the Turkish Water Pollution Control Regulation (TWPCR, 2004) has four primary designations (Class I-IV).

Table 2 gives annual variations in the physico-chemical and bacteriological parameters at downstream (S3) and upstream (S4) discharge point of WWTP. It is clear from table that creek in which effluent discharged was dry in 2012, 2013, 2014 and the stream flow was detected only in 2015. The creek was in Class I designation for all years in terms of pH parameter.

Table 2. Annual variations in the physico-chemical and bacteriological parameters

Parameter	Year	S3	S4	Water quality class
pH	2012	DRY	8	I (high quality water)
	2013	DRY	7.92	I
	2014	DRY	7.77	I
	2015	8.1	6.95	I
Temp. (°C)	2012	DRY	24.8	II (minimally polluted water)
	2013	DRY	23	II
	2014	DRY	23.87	II
	2015	23	21.5	II
DO (mg L^{-1})	2012	DRY	4.4	III (polluted water)
	2013	DRY	5.5	III
	2014	DRY	6.7	II
	2015	8.39	6.5	II
COD (mg L^{-1})	2012	DRY	20.1	I
	2013	DRY	61	III
	2014	DRY	59.5	III
	2015	30.48	42.85	II
TP (mg L^{-1})	2012	DRY	1.3	IV (highly polluted water)
	2013	DRY	1.07	IV
	2014	DRY	0.21	III
	2015	0.17	0.25	III
Total Coliforms (CFU 100 mL^{1})	2012	DRY	2356	II
	2013	DRY	3033	II
	2014	DRY	151000	III
	2015	55000	175555	III
Fecal Coliforms (CFU 100 mL^{-1})	2012	DRY	891	II
	2013	DRY	188	II
	2014	DRY	81800	IV
	2015	24000	72555	IV

As Table 2 reveals in 2015 at the upstream discharge point pH was 8.1 whereas it drastically decreased to 6.95 in the downstream of discharge point showing the adverse effect of the wastewater treatment plant effluent. The DO concentrations in unpolluted waters (Class I) is >8 mg l^{-1} and Class II are typically in the range of 6 to 8 mg l^{-1} and Class III is between 3-6 mg l^{-1} (TWPCR, 2004). Primary receiving body, a creek, was in Class II designation for all years in terms of DO parameter which is an essential element for almost all aquatic life. The creek's water quality in terms of DO was Class IV in 2012 and 2013 whereas its water quality increased to Class III in 2014 and 2015. In 2015 at the upstream discharge point DO was 8.39 mg l^{-1} whereas it drastically decreased to 6.5 mg l^{-1} showing the adverse effect of the wastewater treatment plant discharge. In addition, SS and COD concentration increased from 2.6 to 7.76 mg l^{-1}, and 30.48 to 42.85 mg l^{-1} both indicating Class III water quality and both indicating the effect of WWTP effluent discharge. In 2015, TN increased from 0.21 to 3.28 mg l^{-1} in the downstream of discharge point and this high nitrate levels in waste effluents will contribute to the nutrient load of receiving waters and will enhance eutrophication effects. The creek's water quality in terms of TP designated as Class IV in 2012 and 2013 and Class III in 2014 and 2015. Phosphates are undesirable anions in receiving waters and act as the most important growth-limiting factor in eutrophication and result in a variety of adverse ecological effects. Yearly average number total coliforms ranged from 55,000 to 175,555 (CFU 100ml^{-1}) in 2015 designated as Class III water quality in downstream of discharge point. The number fecal coliforms ranged from 24,000 to 72,555 (CFU 100ml^{-1}) indicating Class IV water quality in downstream of discharge point.

3.3 Water quality of ultimate receiving body the point where creek flows into the sea

It is clear that although WWTP efficiently treats domestic wastewater, it still has adverse effect on creek and this is even worse when there is no flow in creek. Another question is how creek effects receiving bodies' water quality.

The water quality of sea is investigated in terms of pH, transparency, temperature, saturated oxygen concentration, total phenol concentration, ammonia concentration, total coliform, fecal coliforms and fecal streptococci at the point where a creek flows into the sea (S5). Receiving body was in accordance with the standards given by Bathing Water Quality Regulation BWQR, (2004) in terms of pH, temperature, phenol concentration and ammonia concentration. Saturation oxygen values ranged from 78 to 97% in 2012 to 2015. Transparency is well under the limit of 2 m (0.8 m. in 2012, 1.5m. in 2014 and 0.3 m. in 2015) probably due to high SS carried by a creek to the

ultimate receiving body. The high values of biological parameters in 2012-2015 are believed to be lack of disinfection unit, but now plant has UV disinfection system.

3.4 Estimated wastewater treatment plant methane (CH_4) emissions

Organically degradable material in domestic wastewater was calculated by IPCC guidelines (Table 6.2 of IPCC, (2006): Default max. CH_4 producing capacity (B_0) for domestic wastewater of) and estimated emissions from domestic wastewater was calculated by using Table 6.5 of IPCC, (2006): Suggested values for urbanization and degree of utilization of treatment discharge pathway or method ($T_{i,j}$) for each income group for selected countries. Table 3 gives calculated methane emissions from domestic wastewater.

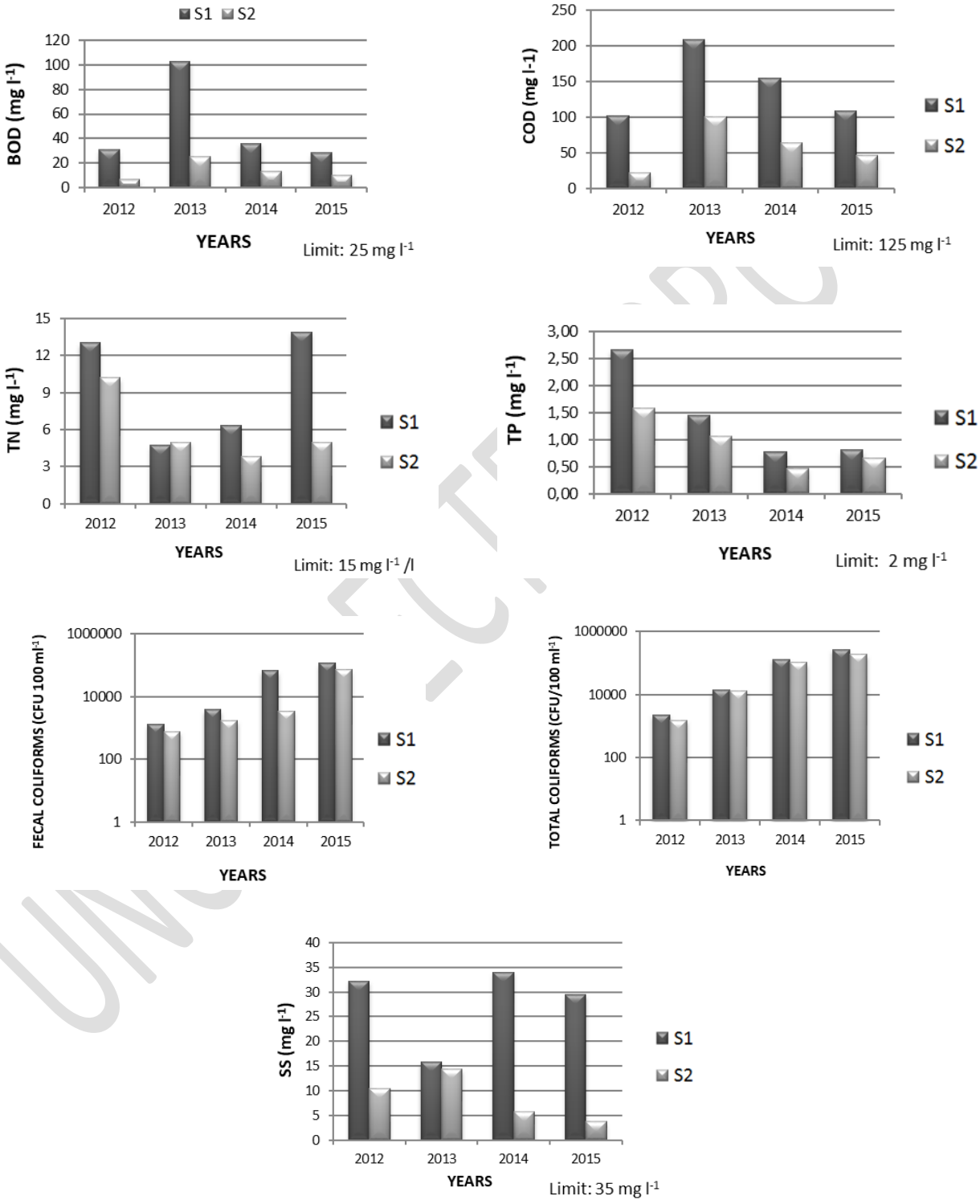

Figure 2. Annual variations in the physico-chemical and bacteriological parameters before and after treatment

Table 3. Methane emissions from domestic wastewater

Year	Income group	Pop. income group fraction (U) **(a)**	Fraction of degree of utilization (T_{ij}) **(b)**	Net methane emissions (kg/CH_4/yr) g=[(a*b*c)*(d-e)]-f **(g)**	GWP for CH_4 **(h)**	Total CO_2e ($kgCO_2e$/yr) (i=g*h) **(i)**	Total CO_2e (tCO_2e/yr) **(j)**
2012	Rural	0.32	0.58	2994.684	25	74867.1	74.87
	Urban high income	0.68	0.96				
	Urban low income	0.00	NA				
	Total	1	0.77				
2013	Rural	0.32	0.58	9959.7498	25	248993.745	248.99
	Urban high income	0.68	0.96				
	Urban low income	0.00	NA				
	Total	1	0.77				
2014	Rural	0.32	0.58	3507.2037	25	87680.0925	87.68
	Urban high income	0.68	0.96				
	Urban low income	0.00	NA				
	Total	1	0.77				
2015	Rural	0.32	0.58	2736.5184	25	68412.96	68.41
	Urban high income	0.68	0.96				
	Urban low income	0.00	NA				
	Total	1	0.77				

d: TOW (total organics in WWTP influent) kg BOD yr^{-1}, e: Sludge removed, f: methane recovered and flared both taken as 0.

3.5 Estimated wastewater treatment plant nitrous oxide (N_2O) emissions

Table 4 gives calculated N in effluent by using Table 6.11 of IPCC, (2006): N_2O methodology default data of IPCC, (2006) was used for calculations for estimation of nitrogen in effluent whereas Table 5 estimates emission factor and emissions of indirect N_2O emissions from wastewater.

3.6 Estimated wastewater treatment plant indirect emissions

Indirect GHG emissions from the consumption of electricity at WWTP was calculated by the use of emission factor of 0.91 tCO_2e Mwh^{-1} and provided in Table 6. Finally, total emissions of full-scale SBR WWTP were given in Table 7.

4. Conclusions

One of the aims of the study is to provide scientific data on the impact of wastewater treatment plants on climate change. Other aims are to demonstrate 1) the treatment efficiency of full-scale WWTP; (2) how WWTP influences creek's water quality from 2012 to 2015; (3) how creek influences receiving body's water quality and (4) the potential climate change impact of a SBR treatment system treating domestic wastewater by calculating its GHG emissions.

The findings obtained from measurements and calculations show that the wastewater treatment plant meets the Turkish discharge standards. However, since there is no summer flow before the stream where the treated water is discharged, there is a decrease in the water quality of the final receiving body especially in terms of bacteriological parameters. Between 2012 and 2015 the effect of WWTP on receiving bodies' bacteriological quality was severe but with a newly added UV disinfection unit the problem has already been solved. This research proved that an increase in concentration of pollutants will occur during low flows when point sources dominate.

The study is also used for estimating energy use and GHG emissions from a SBR WWTP. The annual methane emissions from SBR WWTP ranged from minimum of 68.71 to maximum 248.99 tCO_2e. Total emissions (CH_4, N_2O and emission due to electricity usage) from a full-scale SBR wastewater treatment plant (WWTP) were calculated as 144.22 tCO_2e, 318.34 tCO_2e, 474.79 tCO_2e and 996.62 tCO_2e from 2012 to 2015, respectively.

The reason behind the increase in total emissions is mainly increase in electricity usage which had the highest value in 2015. It would be feasible to capture CH_4 produced in the treatment process or used for generation of electricity or used as a fuel at site.

Table 4. Estimation of nitrogen in effluent

Year	Pop. **(a)**	Annual per capita protein consumption (protein) (kg/person/yr) **(b)**	Fraction of nitrogen in protein (F_{NPR}) (kgN/kg protein) **(c)**	Fraction of non-consumption protein ($F_{non\text{-}cons.}$) **(d)**	Fraction of industrial and and commercial co-discharged protein ($F_{ind\text{-}com.}$) **(e)**	Nitrogen removed with sludge (N_{sludge}) **(f)**	Total nitrogen in effluent (kgN/yr) g=(a*b*c*d*e)-f **(g)**
2012-2015	4186	0.052	0.16	1.4	1.25	0	60.95

Table 5. Estimation of emission factor and emissions of indirect N_2O emissions from wastewater

Year	Nitrogen in effluent (kgN/yr) **(a)**	Emission factor (kg N_2O-N/kgN) **(b)**	Conversion factor of kg N_2O-N into kg N_2O-N 44/28 **(c)**	Emission from wastewater plants (default as zero) **(d)**	Total N_2O emissions/yr **(e)**	GWP for N_2O **(f)**	Total CO_2e (kg CO_2e /yr) **(g)**	Total CO_2e (t CO_2e /yr) **(h)**
2012-2015	60.95	0.005	1.57	0	0.478	298	142.58	0.143

Table 6. Electricity consumption of the wastewater treatment plant

Year	Total Mwh used yearly **(a)**	Emission factor $tCO_2e\ Mwh^{-1}$ **(b)**	Emission tCO_2e **(c=a*b)**
2012	76.2	0.91	69.34
2013	76.2	0.91	69.34
2014	425	0.91	387.1
2015	1020	0.91	928.2

Table 7. Total emissions of the wastewater treatment plant

Year	CH_4 (tCO_2e)	N_2O (tCO_2e)	Electricity usage $tCO_2e\ Mwh^{-1}$	**TOTAL (tCO_2e)**
2012	74.87	0.0143	69.34	**144.22**
2013	248.99	0.0143	69.34	**318.34**
2014	87.68	0.0143	387.1	**474.79**
2015	68.41	0.0143	928.2	**996.62**

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Disclaimer

Any opinions, findings, conclusions, or recommendations expressed herein are those of the author and do not necessarily reflect the view of The Authority for the Protection of Special Areas.

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