Received: 9 May 2020 | Revised: 18 December 2020 | Accepted: 18 December 2020
DOI: 10.1002/ird.2565

RESEARCH ARTICLE

WILEY

Analytical study of carbon dioxide equivalent emission from agricultural drain surfaces — a case study from Egypt*

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Abstract

Methane emission is usually converted into equivalent carbon dioxide (CO_{2e}) in order to compare it with other sectoral emissions. Estimation of methane from 'agricultural drain surfaces' is not accounted for in most of the derivation methods. This research paper dealt with the estimation of CO_{2e} emission from 'surfaces of the agricultural drains network in Egypt' and then estimated the projected future CO_{2e} emission loads trend for the period 2046–2065. CO_{2e} emission was estimated using general circulation models for climate change under expected temperature variation in the coming decades. Annual average total CO_{2e} emission loads from the BHD surface and its surrounding areas to the atmosphere were about 3790 t eq. CO_{2e} yr¹ for the period 2046–2065. The 'additional' total emission of CO_{2e} from the agriculture drainage network surface in relation to total emissions from the agricultural sector in Egypt was about 13.8%. It also accounted for about 1.4% of overall CO_{2e} emission in Egypt. This research paper, furthermore, developed a methane indicative emission map for the Egyptian agricultural drainage network for the period 2046–2065, through which it is possible to estimate CO_{2e} emission loads at any segment on any agricultural drain in Egypt during the period 2046–2065.

KEYWORDS

agricultural drainage network of Egypt, Bahr Hadous drain (BHD), carbon dioxide emission, climate change, general circulation models (GCMs), GIS, methane emission

Résumé

Les émissions de méthane sont généralement converties en dioxyde de carbone équivalent (CO_{2e}) afin de les comparer aux autres émissions sectorielles. L'estimation du méthane provenant de la 'surface des drains agricoles' n'est pas prise en compte dans la plupart des méthodes de dérivation. Ce document de recherche portait sur l'estimation des émissions de CO_{2e} de la 'surface du réseau de drainage agricole en Égypte', puis a estimé la future tendance

* Étude analytique des émissions équivalentes de dioxyde de carbone à la surface des drains agricoles—une étude de cas en Égypte.

projetée des charges d'émission de CO_{2e} au cours de la période 2046–2065. Les émissions de CO_{2e} ont été estimées à l'aide des modèles de circulation générale pour le changement climatique en fonction de la variation de température prévue dans les décennies à venir. Les charges annuelles totales d'émissions de CO_{2e} de la surface du BHD et de ses environs vers l'atmosphère étaient d'environ 3790 t eq. CO_{2e}/an pendant la période 2046–2065. L'émission totale ‘supplémentaire’ de CO_{2e} de la surface du réseau de drainage agricole par rapport à l'émission totale du secteur agricole en Égypte était d'environ 13.8%. Il représentait également environ 1.4% des émissions globales de CO_{2e} en Égypte. Ce document de recherche a en outre développé la carte indicative des émissions de méthane pour le réseau de drainage agricole égyptien au cours de la période 2046–2065, à travers laquelle, il est possible d'estimer les charges d'émission de CO_{2e} sur n'importe quel segment de tout drain agricole en Égypte pendant la période 2046–2065.

MOTS CLÉS

émission de méthane, émission de dioxyde de carbone, réseau de drainage agricole de l'Égypte, drain de Bahr Hadous, changement climatique, SIG, modèles de circulation générale (GCM)

1 | INTRODUCTION

Greenhouse gas (GHG) emissions to the atmosphere should be minimized to maintain sustainable human life on Earth (United Nations Framework Convention on Climate Change (UNFCCC), 1992; World Meteorological Organization (WMO), 2018; World Water Assessment Programme (WWAP), 2020). GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbon compounds (HFCs), perfluorinated compounds (PFCs) and sulphur hexafluoride (SF_6) (US Environmental Protection Agency (USEPA), 2019). The Paris Agreement was issued with the future goal of limiting increasing temperature to a maximum of 2 °C above the pre-industrial period (UNFCCC, 2015). According to the United Nations Environment Programme (UNEP, 2016, 2017), GHG emissions continue to increase. Thomas *et al.* (2000) studied GHG indicators and noted that methane is produced from two main sources (landfill and wastewater). They then concluded that more scientific research is required to determine accurate indicators and estimates of CO_2 emission from all possible sources.

According to the Egyptian Environment Affairs Agency (EEAA, 1999), emissions of non-CO_2 gases such as methane were estimated from the biomass potentiality of agricultural residues and livestock. In Egypt, the majority of methane emissions is generated from flooded rice fields for about 4 months at a temperature about 19 °C (Hasan, 2013). According to the Intergovernmental Panel on Climate Change guidelines (IPCC, 2006), rice field methane emission is about 3.70 kg ha^{1} day^{1}. According to the EEAA (2016), Egypt's GHG emissions in 2005 were 248 million metric tons of carbon dioxide equivalent ($MtCO_{2e}$). Methane emission alone was 35 $MtCO_{2e}$, which represented about 14% of total emissions in Egypt in 2005. The World Research Institute (WRI, 2015) estimated the total annual GHG emissions in Egypt during the period 1990–2012 at 288 $MtCO_{2e}$, which was about 0.6% of the world's total (47 600 $MtCO_{2e}$). It was also estimated that the annual average total change in GHG emissions in Egypt during the period 1990–2012 was an increase of 133%, while the worldwide percentage during the same period increased by only 40%. Also, the United States Agency for International Development (USAID, 2016) agreed the same number, that total Egyptian emissions increases by 133% annually. USAID (2016) reported that Egypt's sectoral GHG emission distribution was: energy 74%, agriculture 10%, industrial 9% and wastewater 7%. The authors of this research paper reviewed the technical reports of the EEAA and USAID and the IPCC country report (Egypt) and found that estimation of methane emissions in Egypt did not take into consideration emissions from surfaces of the agricultural drainage network in Egypt.

Among the relevant technical applications worldwide to estimate CO_{2e} emission rather than from drainage water, were those from sewage water, wetlands, estuaries, coastal swamps, forested wetlands, rice fields, mangroves and salt marshes. Akumu *et al.* (2010) developed a model to estimate methane emission from wetlands in north-eastern New South Wales, Australia. They concluded that the projected increase in temperature by 1 °C in 2030 could increase methane emission from 0.0016 to 0.0022 teragrams in the wetland. Sun *et al.* (2017) estimated methane emissions from rice fields in the Sanjiang Plain in north-east China. The minimum and maximum temperature values were 18.3–27.6, 17.8–27.3 and 18.4–26.8 °C in 2000, 2006 and 2010, respectively. Thus, the temperature factor (FT) minimum and maximum values were 0.4–1.9, 0.4–2.1 and 0.5–2.0 in 2000, 2006 and 2010; respectively. Also, Sun *et al.* (2017) estimated methane emissions from rice fields with 0.30, 0.36, and 0.40 tera-grams in 2000, 2006, and 2010; respectively.

This research paper aims at drawing the attention of the decision makers to methane emission in equivalent CO_{2e} loads from an additional source: 'surfaces of the agricultural drainage network'. This paper estimated the annual methane emission from the surface of one of the largest water carriers of residual agricultural nutrients and organic matter in Egypt, the 'Bahr Hadous drain' (BHD) and its surrounding areas, to the atmosphere. The BHD carries not only agricultural drainage discharges, but also domestic waste and industrial effluent loads. Quantification of annual CO_{2e} emission loads resulting from all agricultural drainage water pollutants in the Egyptian agricultural drainage network up to 2065 is also accomplished. The proportion of the additional CO_{2e} emission loads to the total annual GHG emissions in Egypt is determined.

2 | MATERIALS AND METHODS

Data required for this research paper were collected mainly from the National Water Research Centre (NWRC), the Drainage Research Institute (DRI) of Egypt, the Ministry of Environment of Egypt (MoEE), the Intergovernmental Panel on Climate Change (IPCC) and UNFCCC resources. The authors applied authenticated public domain GIS-based climate change models for methane estimation, particularly models that deal with methane estimation from agricultural drain surfaces (Sun *et al.*, 2017).

Biological oxygen demand (BOD) was used as a measure of water quality. It is defined as the amount of oxygen required to remove organic matter in the process of decomposition by aerobic bacteria from water (those bacteria that live only in an environment containing oxygen). The computational method applied was linearly dependent on variation in temperature and BOD loads (Liu, 1996; Akumu *et al.,* 2010; Lee Chern, 2011; Zhan-Yun *et al*., 2015). According to data availability and global modelling requirements, the authors applied that method for the period 1961–2000 to estimate CO_{2e} emission loads for parameter adjustment and verification purposes and then predicted the trend of CO_{2e} emission loads in the future period 2046–2065 under the projected temperature variations.

2.1 | The study area

Egypt has long irrigation and agricultural drainage networks which extend longitudinally from Upper Egypt in the south and spread extensively from the Nile Delta north to the Mediterranean Sea. The agricultural drainage network of the eastern Nile Delta region in Egypt discharges a proportion of its water directly to the Mediterranean Sea, apart from a few drains which discharge their water to Lake Manzala in northern Egypt (Figure 1). The study area is about 132 km^2, which is the drainage catchment of the Bahr Hadous drain (BHD). It consists of several sub-catchments along the course of the BHD (approximately 64 km in length) from upstream to downstream at its outfall. The BHD has an annual average discharge of about 1.79 billion m^3 yr^1 of agricultural drainage water into Lake Manzala (DRI, 2016). This amount was equivalent to about 12% of the total agricultural drainage water discharged from the agricultural drainage network of Egypt. The selection of BHD for this research paper was because of its importance as a main contributor to the El-Salam Canal which is the carrier of irrigation water allocated for development of the Sinai Peninsula in all future national agricultural development plans in Egypt. The drainage and reuse pump stations located along the BHD's course and the nine segments used in estimating CO_{2e} emission loads are shown in Figure 2.

2.2 | Methane emission equations

The change of methane emission from agricultural drains surface used in the model was estimated according to the following two equations, modified after Akumu *et al.* (2010):

$$E_{CH4} = \sum_{i=1}^{n} \mathrm{BOD}_i \times \mathrm{CSA}_i \times L_i \times B_o \times P \times CO_{2e} \times \mathrm{FT}_i \times \mathrm{Fw}_i$$

and after Liu (1996):

$$\mathrm{FT} = \frac{\mathrm{F(Ts)}}{\overline{\mathrm{F(Ts)}}}, \mathrm{F(Ts)} = \frac{e^{0.334(\mathrm{Ts}-23)}}{1 + e^{0.334(\mathrm{Ts}-23)}}$$

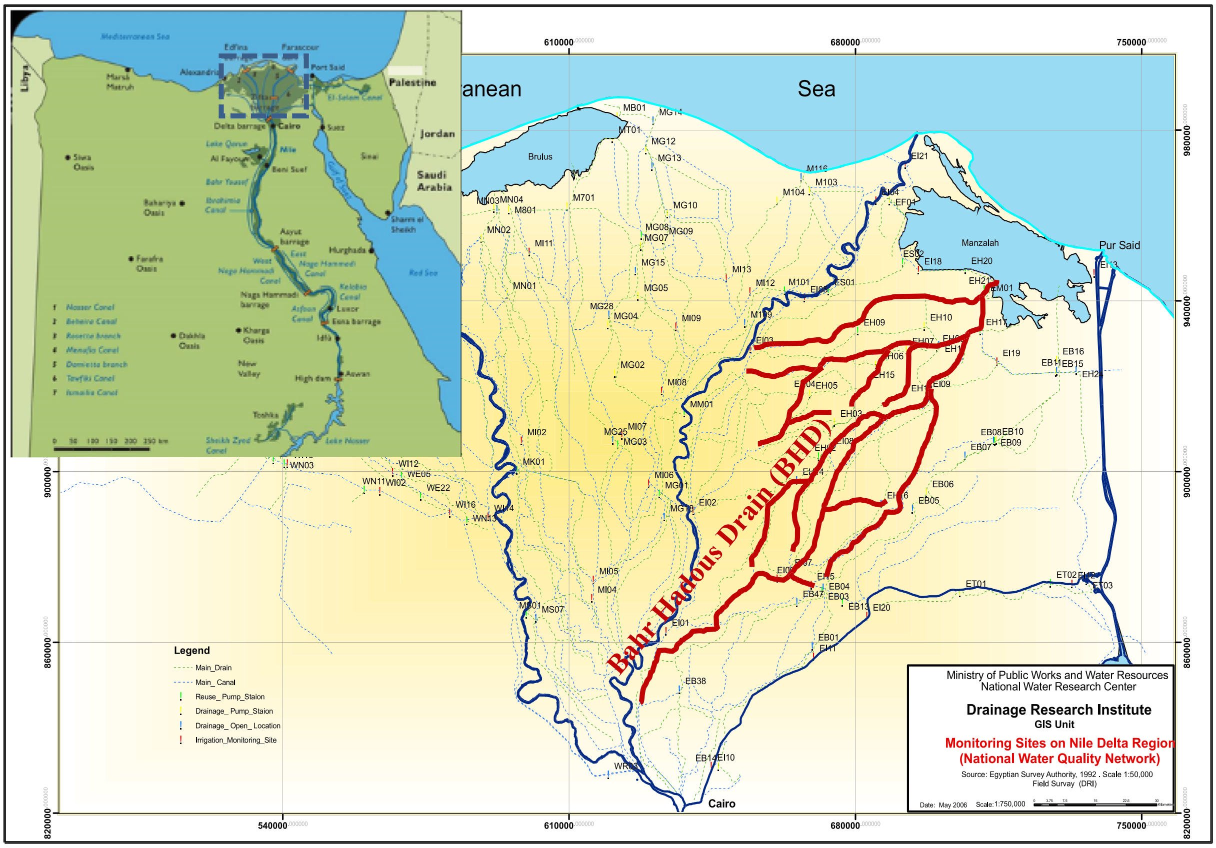


FIGURE 1 The Nile Delta showing the study area (Bahr Hadous drain (BHD) in the eastern Nile Delta region). Source: DRI (2016)

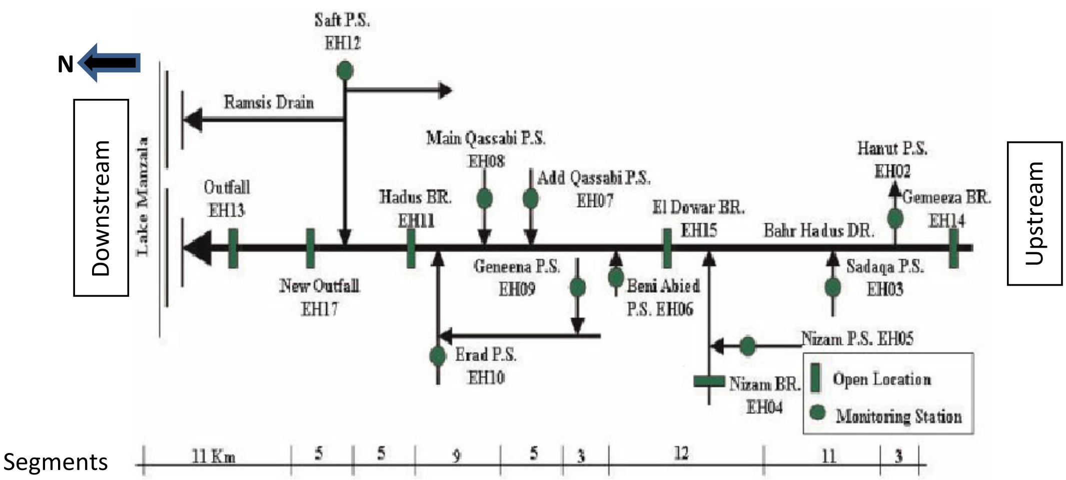


FIGURE 2 Schematic diagram of the BHD system (nine segments) showing the agricultural drainage and reuse pump stations. Source: DRI (2016). (a) areas emit CO_{2e} surrounding Bahr Hadous drain in eastern Nile Delta, (b) areas emit CO_{2e} surrounding the agricultural drains in the Nile Delta, (c) areas emit CO_{2e} surrounding the whole agricultural drainage network in Egypt

where

E_{CH4} = estimated methane emission (kg CO_2 eq. yr^{1})

i = drain segment number at each cross-sectional area change

n = number of drain segments

BOD = biochemical oxygen demand (kg m^3 yr^{1})

CSA = cross-sectional area of drain (m^2)

L = drain segment length (m)

B_o = CH_4 generation capacity (IPCC = 0.6 kg CH_4 kg ^{1} BOD).

P = productivity factor (0.25 for water)
CO_{2e} = equivalent CO_{2e} emission (range of 23–25 CO_{2e} kg¹ E_{CH4}) (Swiss Climate, 2010; Akhilesh, 2014; EEAA, 1999)
FT = temperature factor (–)
Fw = drain water factor, drain water level was assumed constant, then Fw = 1.0
$\bar{F}(Ts)$ = average temperature factor along the drain segment
Ts = land surface temperature (°C), assumed equal to air temperature

2.3 | Climate change data used

The Climate Information Portal on the internet (CIP, 2015) was used to download free climate change data for the two study periods 1961–2000 and 2046–2065. The CIP internet portal provides authenticated historical and future projected climate data sets for the African continent. The CIP used a combination of public domain global circulation models (GCMs) to estimate future projected temperature. In this research paper, one of the CIP's public domain GIS-based GCMs was applied to the study area to estimate CO_{2e} emission loads during the two periods 1961–2000 and 2046–2065. The model was called GIS-GCME in this research paper. The authors studied and applied relevant temperature variations for the periods 1961–2000 and 2046–2065 in Egypt. The future temperature data that were applied represented an optimistic scenario of temperature variation according to the representative concentration pathways (RCP4.5) of the IPCC (2019).

In that scenario, it was assumed that GHG emissions would not exceed 550 ppm (parts per million) up to the year 2065. Equations 1 and 2 above were used to estimate methane emission from the BHD surface under the expected temperature variations during the period 1961–2000 for parameter adjustment and model verification. Then same equations were used to estimate and predict the trend of CO_{2e} emission loads during the period 2046–2065.

2.4 | Assumptions used for estimating CO_{2e} emission loads from the agricultural drainage network surface and its surrounding areas

The authors used the following assumptions for estimating CO_{2e} emission loads from the agricultural drainage network surface in Egypt:

- the BHD was divided into nine consecutive segments between every two pump stations or water-measuring locations as shown in Figure 2;
- length of each segment was obtained from the database of DRI (2016);
- average geometry and cross-section area of each segment was obtained from the most updated database of the Egyptian Public Authority for Drainage Projects (EPADP) under the Ministry of Water Resources and Irrigation of Egypt;
- average BOD in each segment was obtained from the database of DRI (2016);
- digested BOD was considered as 0.25 of the total BOD load, and removal ranged between 69 and 84%, as indicated by Lee Chern (2011);
- methane emission (estimated on the basis of 1 kg of BOD being equivalent to 0.6 kg methane), as indicated by USEPA (2007), IPCC (2006) and Zhan-Yun *et al.* (2015);
- conversion of methane into equivalent carbon dioxide (CO_{2e}) on the basis of 1 kg of methane being equivalent to 23–25 kg of CO_{2e}, as described by Swiss Climate (2010), Akhilesh (2014) and EEAA (1999);
- static condition was assumed so that no additional CO_2 emissions were considered from dynamic movement of flow in the drain (CO_2 removal was estimated during self-purification and aeration states along its segments);
- based on the literature review, the estimated CO_{2e} emission load from the agricultural drainage network surface in Egypt due to organic matter decomposition (represented by BOD) was assumed to be half the CO_{2e} emission loads that could result from all other relevant drainage water pollutants (including aquatic weeds, algae, bacteria, pathogens, fine organisms, etc.). This assumption might need further investigation in the future.

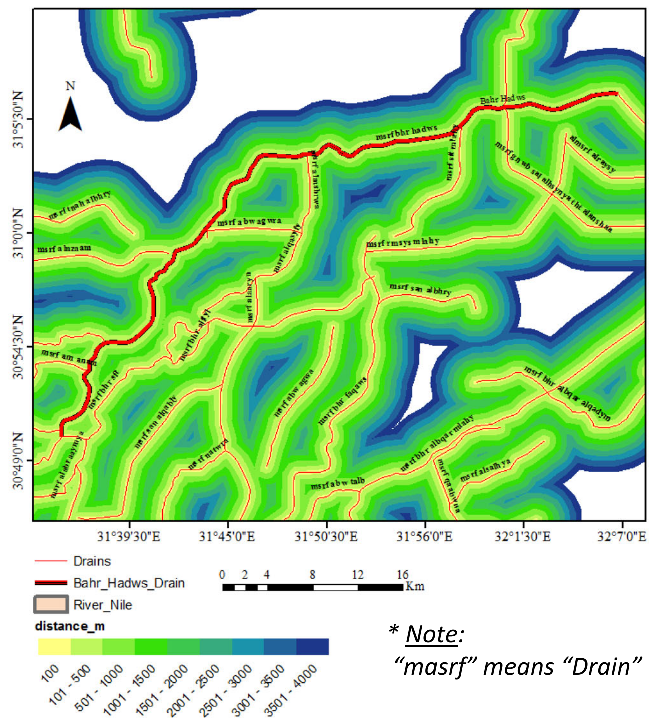
3 | RESULTS AND DISCUSSION

Methane in equivalent CO_{2e} emissions from agricultural drain surfaces and their surrounding areas to the

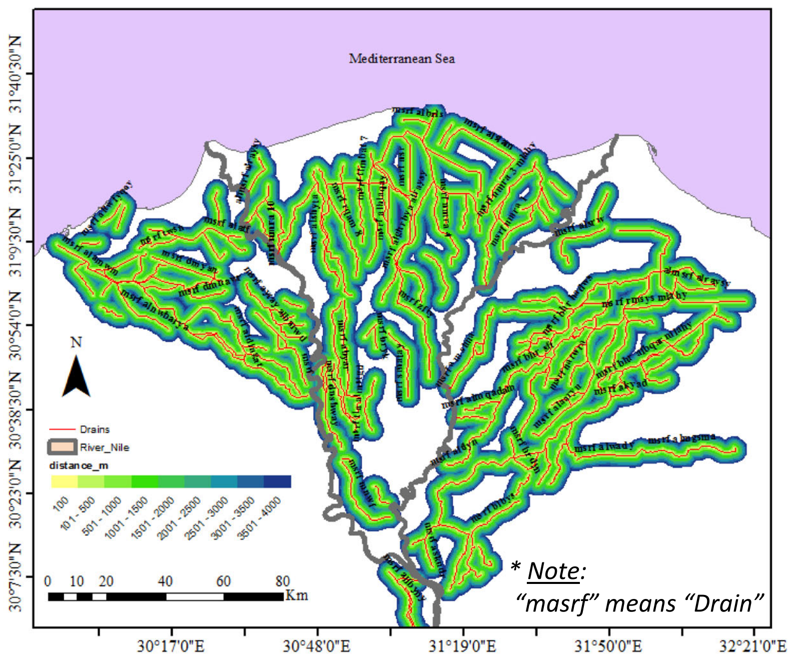
TABLE I Estimated areas surrounding typical agricultural drains in Egypt causing methane emission to the atmosphere

Distance (m)	Area (km^2)	Distance (m)	Area (km^2)
0–100	1 150	2 000–2 500	2 610
100–500	2 930	2 500–3 000	2 330
500–1 000	3 470	3 000–3 500	2 120
1 000–1 500	3 250	3 500–4 000	1 890
1 500–2 000	2 960	Sum	22 700

atmosphere involves complicated processes that are better dealt with through relevant digital simulation models. The GIS-CCME of CIP was applied to the study area for estimation of CO_{2e} emissions using the relevant CIP data for the two periods 1961–2000 and 2046–2065.



(a) ***Areas emit CO_{2e} surrounding Bahr Hadous Drain in Eastern Nile Delta***



(b) ***Areas emit CO_{2e} surrounding the agricultural drains in the Nile Delta***

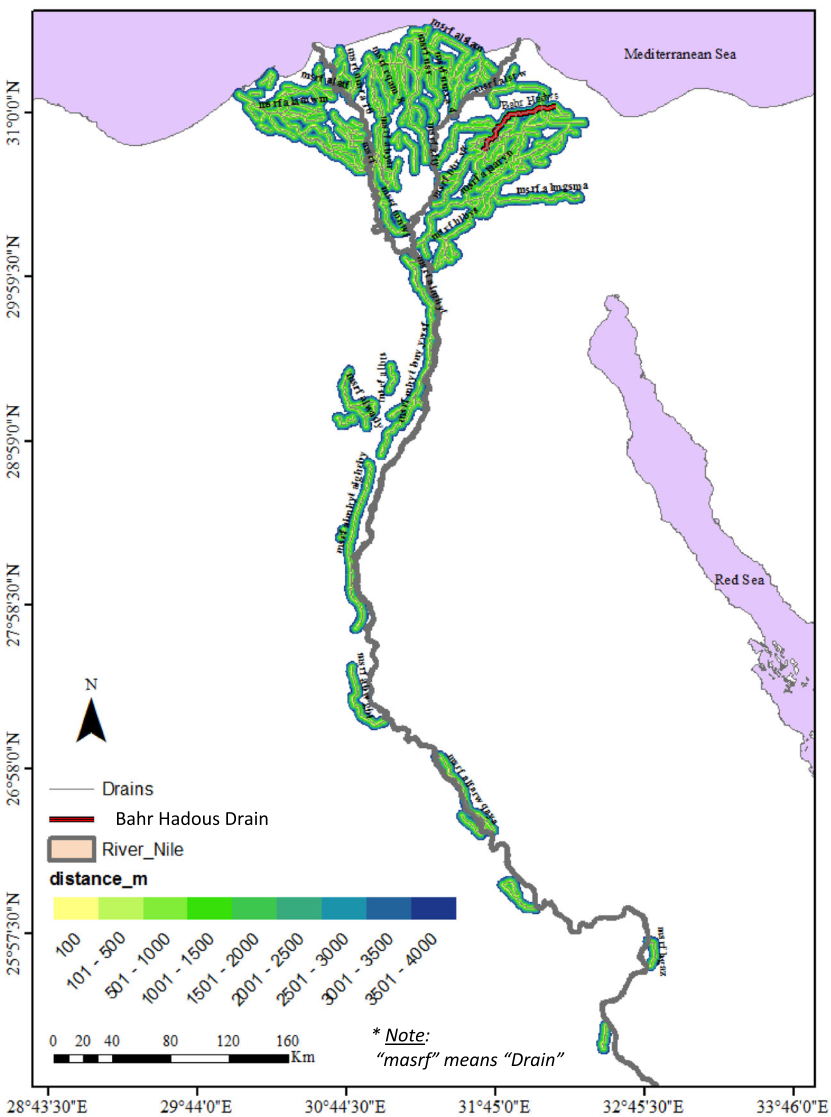
FIGURE 3 Estimated areas surrounding the agricultural drains in Egypt within 4 km distance: (a) average FT values during the period 1961–2000, (b) average FT values during the future period (2046–2065)

3.1 | Estimation of methane zones

Parts of the agricultural lands surrounding the agricultural drains were considered part of the drain system as they also emit CO_{2e} to the atmosphere. These areas could also interfere with other small nearby agricultural drains. The authors calculated the surface areas of these lands and aggregated them in zones starting from 100 m up to 4 km, as presented in Table I. Figure 3 shows the estimated areas surrounding the agricultural drainage network in Egypt that could be an additional source of CO_{2e} emissions. Accordingly, the total area causing CO_{2e} emission from the agricultural drainage network surface and its surrounding areas in Egypt (within 4 km distance) was about 22 700 km^2.

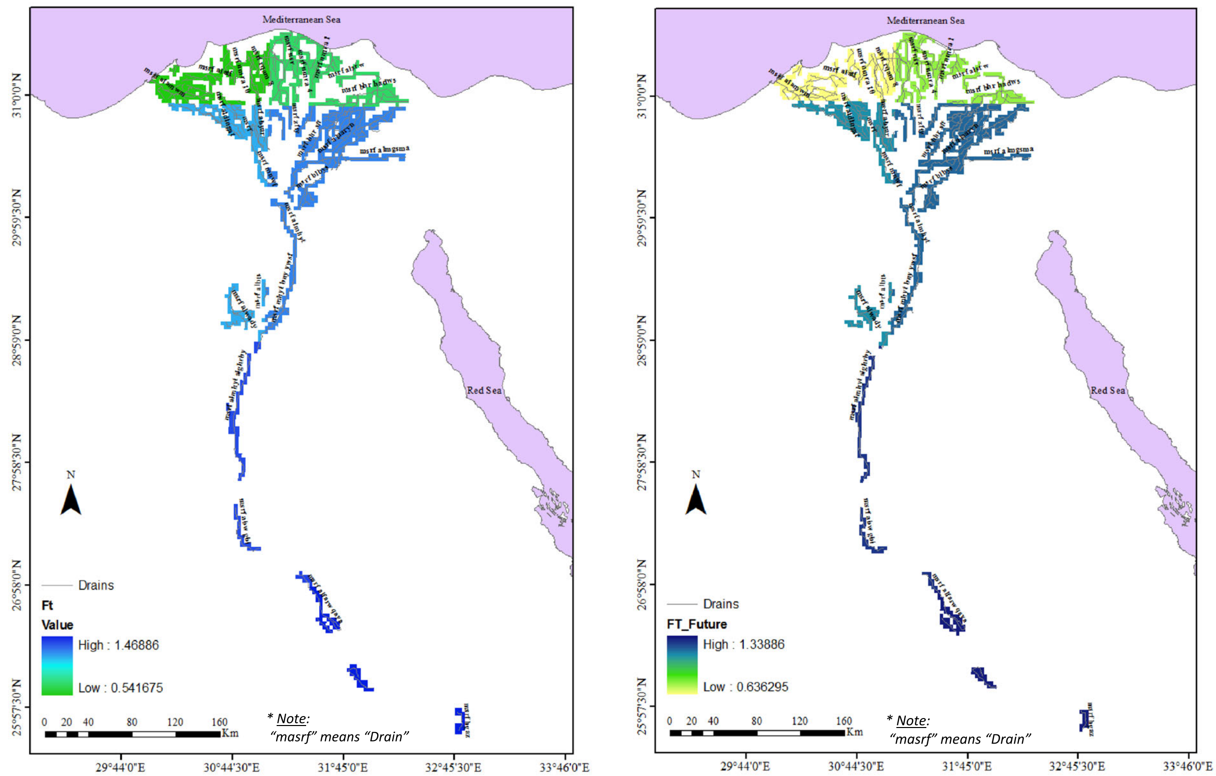
3.2 | Estimation of temperature factor (FT)

The temperature factor (FT) was defined and estimated by using Equation 2. Figure 4 presents the results of the GIS-CCME model. It was found that Upper Egypt had a higher FT, ranging from 1.34% during the period 2046–2065 to 1.47% during the period 1961–2000. The Nile Delta regions had lower FT ranging from 0.64% in 2046–2065 to 0.54% in 1961–2000. Maps of the FT of the two periods were compared as shown in Figure 5. The comparison revealed an increasing trend in methane emission during 2046–2065 in the Nile Delta by about 200%, and a decreasing trend in Upper Egypt by about 20%. The FT maps in Figures 4 and 5 demonstrate a



(c) ***Areas emit CO_{2e} surrounding the whole agricultural drainage network in Egypt***

FIGURE 3 (Continued)



(a) *Average FT values during the period (1961-2000)* **(b)** *Average FT values during the future period (2046-2065)*

FIGURE 4 Estimated FT variations in the main agricultural drainage network surface and its surrounding areas in Egypt

spatial overview of methane emission in equivalent CO_{2e} emissions under the expected future temperature variations.

3.3 | Estimation of annual average CO_{2e} emission load from the BHD surface and its surrounding areas for the period 2046–2065

Based on the annual average measured BOD values at each segment of the BHD, methane emission was estimated according to Equations 1 and 2. The FT was estimated from the GIS-CCME model for the two periods 1961–2000 and 2046–2065. Table II presents calculation of CO_{2e} emissions per year from the BHD and its surrounding areas based on the assumptions above. The annual average total CO_{2e} emission to the atmosphere (due to organic matter decomposition) from the BHD surface and its surrounding areas was estimated at about 3790 t eq. CO_{2e} yr^{1} during the period 2046–2065, Figure 6, which was less than 4.0 gigagram eq. CO_{2e} yr^{1}.

3.4 | Estimation of the annual average CO_{2e} emission load from the whole agricultural drainage network of Egypt for the period 2046–2065

As the length of the agricultural drainage network in Egypt is about 34 000 km (DRI, 2016), then total emission of CO_{2e} to the atmosphere (due to organic matter) from the whole agricultural drainage network in Egypt per year was estimated at about 2.0 million t eq. CO_{2e} yr^{1}. As CO_{2e} emission due to organic matter was assumed to represent 50% of all other drainage water pollutants, then the estimated annual average total emission of CO_{2e} (due to all drainage water pollutants) from the agricultural drainage network in Egypt to the atmosphere was about 4.0 million t eq. CO_{2e} yr ^{1} for the period 2046–2065. USAID's report (2016) stated that the total annual average emission of CO_{2e} from the agricultural sector in Egypt was about 29.0 million t eq. CO_{2e} yr ^{1}, meaning the estimated CO_{2e} emission load to the atmosphere from the 'additional source' which was the agricultural drainage network constituted about 13.8% of total emissions from the agricultural sector. It was also proved that

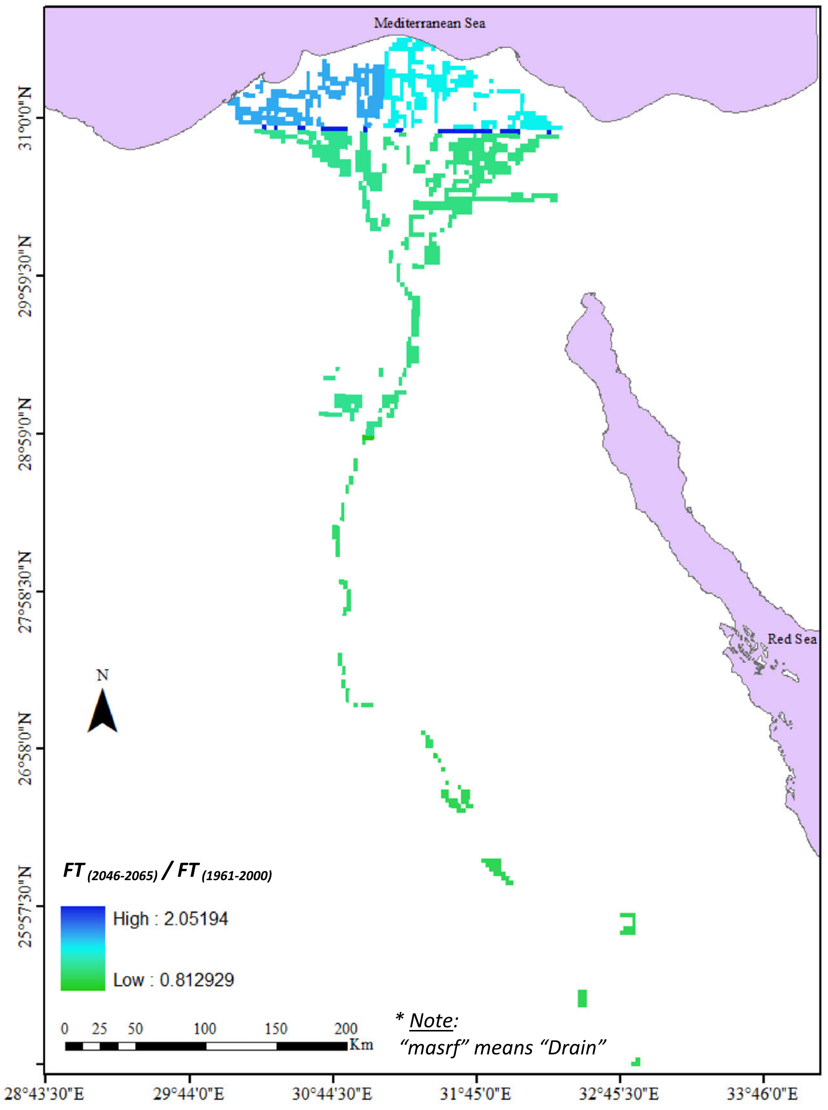


FIGURE 5 Comparison of FT variations in the main agricultural drainage network surface and its surrounding areas in Egypt—visualization of ratios {FT during the period 2046–2065 /FT during the period 1961–2000}: (a) estimated methane emission as CO_{2e} loads during the period 2046–2065 at each segment of BHD divided by FT, (b) estimated methane emission as CO_{2e} loads during the period 2046–2065 at each segment of BHD in eq. CO_{2e} t yr¹

estimated CO_{2e} emission load from the agricultural drainage network constitutes about 1.4% of the overall CO_{2e} emission load in Egypt, which was about 288 million t eq. CO_{2e} yr¹.

3.5 | Development of a indicative methane emission map for the agricultural drainage network of Egypt

By means of the GIS-CCME model used to estimate methane emission from the surface of the agricultural drainage network using FT variations in the future, the authors were able to compare the results with other relevant research and technical studies worldwide. The other relevant research and applications, as included in the 'Introduction' section, for example the estimation of CO_{2e} emissions from sewage water, wetlands, estuaries, coastal swamps, forested wetlands, rice fields, mangroves and salt marshes, concluded that FT variation was the most important factor in estimating the spatial variation of methane emissions.

In this context, this research paper developed a digital raster map of FT for the whole Egyptian agricultural drainage network for the period 2046–2065. This map can be used to indicatively estimate methane emission in equivalent CO_{2e} emissions from the surface of any agricultural drain segment in Egypt (Figure 7).

4 | CONCLUSION AND RECOMMENDATIONS

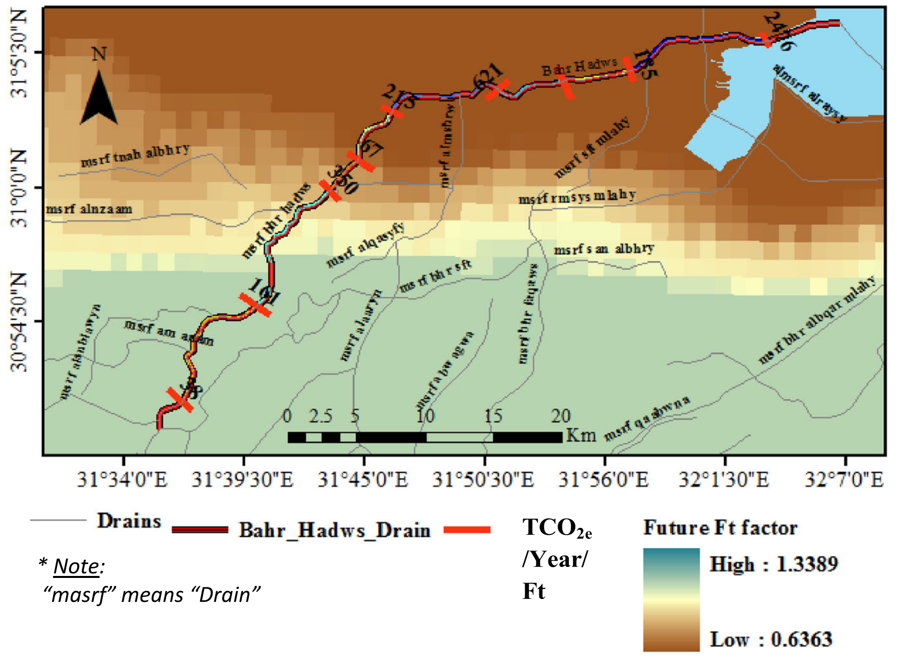
This research paper used available data and digital modelling tools from different authenticated sources to estimate methane emission from the agricultural drainage network surface to the atmosphere in Egypt, based on changes in temperature and organic matter

TABLE II Estimated annual average CO_{2e} emission loads from BHD surface and its surrounding areas per segment during the period 2046–2065

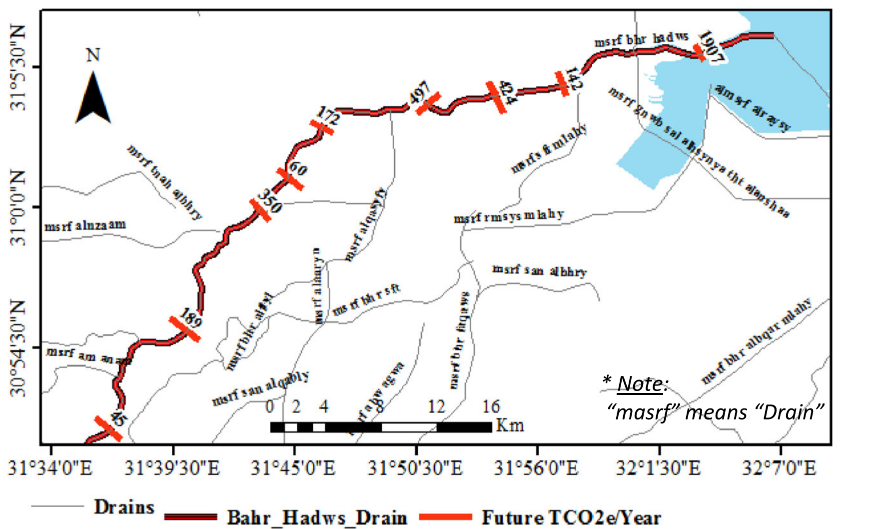
Segments (downstream to upstream) of BHD, as shown in figure 2		Drain length	Bed width	Water depth	Top width	Avg. BOD load	Volume	Avg. BOD load	Avg. BOD load	Avg. CO_{2e} load/FT	Avg. FT during 2046–2065	Annual Avg. CO_{2e} emission
		M	m	m	m	Mg/l	m^3/year	Kg/m^3	Kg/year	Eq. ton/year	Temp. Factor	Ton/year
Segment 1 of 9 L = 3 km	Before EH02	3000	17	1.5	20	133	83300	0.133	11100	38	1.18	45
Segment 2 of 9 L = 11 km	Before EH03	11000	26.5	1.8	30	86	559000	0.086	48100	161	1.18	195
Segment 3 of 9 L = 12 km	Before EH04	12000	31	2	35	128	792000	0.128	101000	350	1.00	350
Segment 4 of 9 L = 3 km	Before Dawar bridge	3000	36	2	40	85	228000	0.085	19400	67	0.90	60
Segment 5 of 9 L = 5 km	Before EH06	5000	45	2.5	50	105	594000	0.105	62300	215	0.80	172
Segment 6 of 9 L = 9 km	Before EH07	9000	54	3	60	117	1540000	0.117	180000	621	0.80	497
Segment 7 of 9 L = 5 km	Before EH10	5000	73	3.5	80	119	1340000	0.119	159000	550	0.77	423
Segment 8 of 9 L = 5 km	Before ElSalam ESL03	5000	92	4	100	28	1920000	0.028	53800	185	0.77	143
Segment 9 of 9 L = 11 km	After ElSalam ESL03	11000	140	5	150	90	7980000	0.09	718000	2480	0.77	1910
Annual average Total CO_{2e} emission from Bahr Hadous drain surface and its surrounding areas during the period (2046–2065) in eq. CO_2 tons/year												3,790

Notes
EH means Eastern Nile Delta Bahr Hadous Drain site
ESL means East Delta El-Salam Canal site

FIGURE 6 Estimated annual average methane emission as CO_{2e} loads from the BHD surface and its surrounding areas during the period 2046–2065



(a) ***Estimated Methane emission as*** CO_{2e} ***loads during the period (2046-2065) at each segments of BHD divided by FT***



(b) ***Estimated Methane emission as*** CO_{2e} ***loads during the period (2046-2065) at each segments of BHD in eq.*** CO_{2e} ***tons per year***

decomposition in the future. Methane emission was estimated from that 'additional' source as equivalent to CO_{2e} emission during the period 2046–2065. The study estimated the annual average total CO_{2e} emission from the Bahr Hadous drain (BHD) surface and its surrounding areas at about 3790 t CO_{2e}/yr^{1} during the period 2046–2065. This research paper estimated the ratio of 'the additional' annual average total emission of CO_{2e} from the agricultural drainage network surface to the total emission from the agricultural sector in Egypt as about 13.8% during the study period. This emission compared to the overall CO_{2e} emissions of Egypt was about 1.4%. Furthermore, this research paper developed the methane (equivalent CO_{2e}) indicative emission map from the agricultural drainage network of Egypt during the period 2046–2065, by means of which it is possible to estimate CO_{2e} emission loads at any segment on any agricultural drain in Egypt during the period 2046–2065. This research paper aims at drawing the attention of decision makers to the significant contribution of the 'agricultural drainage network' to overall methane emission as equivalent CO_{2e} emission in Egypt.

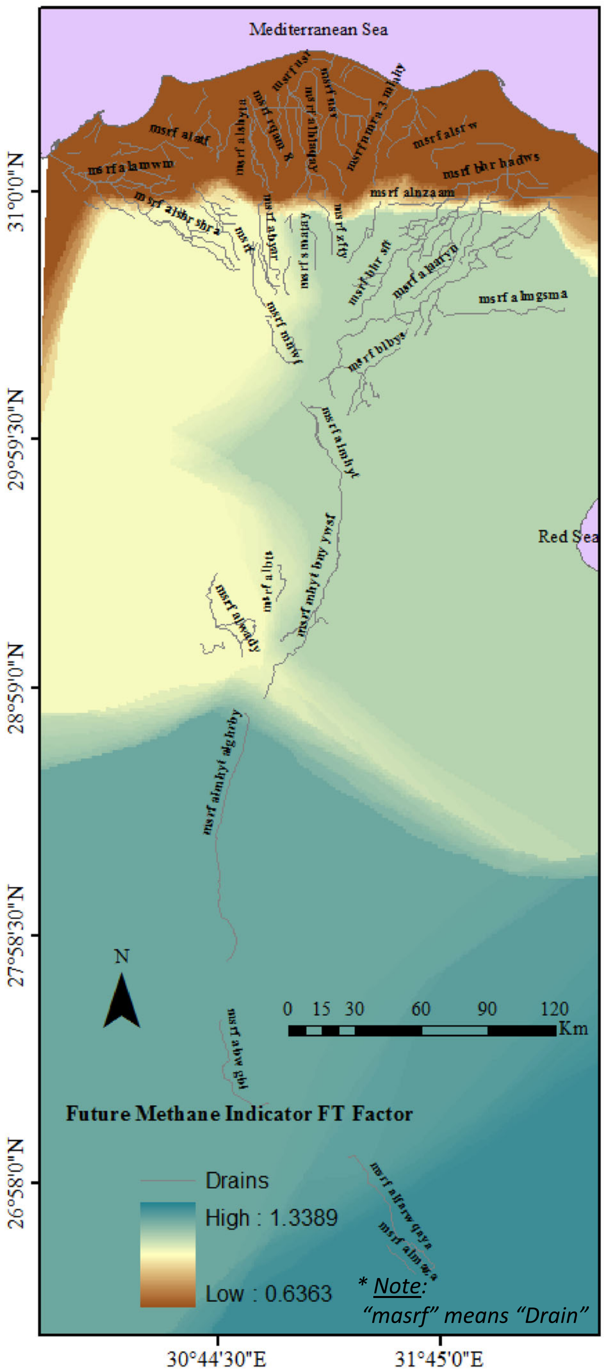


FIGURE 7 Estimated average annual methane indicative emission map from the main agricultural drainage network of Egypt during the period 2046–2065

The proven additional part of the CO_{2e} emission load from the surface of the agricultural drainage network in Egypt should be added to the overall annual CO_{2e} emission in Egypt and be mentioned in the IPCC's periodic Country Reports. The indicative methane emission map from the agricultural drainage network developed in this research paper could be used as guide for other countries having agriculture drainage networks with similar conditions to those prevailing in Egypt. It is recommended that this research paper should be followed up by more in-depth technical research studies to further investigate, analyse and estimate methane emission loads from agricultural drain surfaces.

Generation of renewable energy from the methane emission originating from agricultural drain surfaces and its surrounding areas using biogas reactors is a promising clean energy development for isolated and remote communities in rural areas in Egypt and worldwide. Furthermore, the dried sludge could be used as natural fertilizer (by-product) for agricultural lands. Therefore it is recommended to undertake further technical studies to examine the feasibility, suitability and environmental sustainability of generating renewable energy from biogas reactors under anaerobic conditions in areas surrounding agricultural drains.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the sincere efforts of the researchers and scientists of the National Water Research Centre, the Egyptian Public Authority for Drainage Projects of the Ministry of Water Resources and Irrigation of Egypt, and particularly the Drainage Research Institute, in identifying, collecting and making available the various types of data used from the various authenticated sources available. Profound appreciation is due to the chairpersons, directors and experts of the Ministry of Water Resources and Irrigation of Egypt, who offered sincere advice, enlightening remarks and critical reviews of this research paper.

REFERENCES

Akhilesh, V. (2014) *Is there any difference in expressing greenhouse gases as CH_4Kg/ha and CH4-C Kg/ha ?* Cochin University of Science and Technology Dec. https://www.researchgate.net/post/Is_there_is_any_difference_in_expressing_greenhouse_gases_as_CH4Kg_ha_and_CH4-C_Kg_ha/

Akumu, C.E., Pathirana, S., Baban, S. and Bucher, D. (2010) Modeling methane emission from wetlands in North-Eastern New South Wales, Australia using Landsat ETM+. *Journal of Remote Sensing*, 2, 1378–1399. https://doi.org/10.3390/rs2051378 https://www.mdpi.com/2072-4292/2/5/1378/

Climate Information Platform (CIP). (2015) Climate System Analysis Group, University of Cape Town, United Nations Institute for Training and Research. http://cip.csag.uct.ac.za/

Drainage Research Institute (DRI). (2016) *Year Book 2015–2016 entitled: Drainage Water Status in The Nile Delta, Technical Report No.* Egypt: Ministry of Water Resources and Irrigation, Cairo. p. 86.

Egyptian Environmental Affairs Agency of the Arab Republic of Egypt (EEAA). (1999) Initial National Communication on Climate Change. Report prepared for the United Nations Framework Convention on Climate Change (UNFCCC).

https://unfccc.int/sites/default/files/resource/Egypt%20INC.pdf/

Egyptian Environmental Affairs Agency of the Arab Republic of Egypt (EEAA). (2016) Third National Communication under the United Nations Framework Convention on Climate Change. Report prepared for the United Nations Framework Convention on Climate Change (UNFCCC). https://unfccc.int/files/national_reports/non-annex_i_parties/biennial_update_reports/application/pdf/tnc_report.pdf/

Hasan, E. (2013) Proposing mitigation strategies for reducing the impact of Rice cultivation on climate change in Egypt. *Journal of Water Science*, 27(54), 69–77. https://doi.org/10.1016/j.wsj.2013.12.007/

Intergovernmental Panel on Climate Change (IPCC). (2006) *Guidelines gas inventories*. Japan: Prepared by the National Greenhouse Gas Inventories Program for The Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf/

Intergovernmental Panel on Climate Change (IPCC). (2019) The IPCC Scenarios. https://worldoceanreview.com/en/wor-5/climate-change-threats-and-natural-hazards/climate-change-and-the-coasts/the-ipcc-scenarios/

Lee, C.N. (2011) *Removal efficiency and kinetic study of BOD and COD using aerobic and anaerobic digestion. A project report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor (Hons.) of Chemical Engineering, Faculty of Engineering and Science*, Universiti Tunku Abdul Rahman, Perak, Kampar District, Malaysia. https://Eprints.utar.edu.my/73/1/CL-2011-0707245-1.pdf/OR http://eprints.utar.edu.my/73/

Liu, Y. (1996) Modelling the emission of Nitrous Oxide (N_2O) and Methane (CH_4) from the terrestrial biosphere to the atmosphere, Report No. 10, MIT Joint Program on the Science and Policy of Global Change, Cambridge, MA, USA. https://globalchange.mit.edu/publication/14226/

Sun, M., Zhang, Y., Ma, J., Yuan, W., Li, X. and Cheng, X. (2017) Satellite data-based estimation of methane emissions from rice paddies in the Sanjiang plain in Northeast China. *PLoS ONE*, 12(6), e0176765. https://doi.org/10.1371/journal/ pone.0176765.

Swiss Climate. (2010) EcoCare realisiert Ihre MRV–Zertifikate, unabhängig von eingesetzten VPM-Tools und klassifizierungsgesellschaften, Monitoringkonzepte und emission berichte, Swiss Climate. https://climatechangeconnection.org/emissions/co2-equivalents/ (in German).

Thomas, C., Tennant, T. and Rolls, J. (2000) *The GHG indicator: UNEP guidelines for calculating greenhouse gas emissions for businesses and non-commercial organisations*. United Nations Environment Programme (UNEP). https://www.unepfi.org/publications/climate-change-publications/the-ghg-indicator-unep-guidelines-for-calculating-greenhouse-gas-emissions-for-businesses-and-non-commercial-organisations/

United Nations Environment Programme (UNEP). (2016) *The emissions gap report 2016*. Nairobi, Kenya. https://wedocs.unep.org/bitstream/handle/20.500.11822/10016/emission_gap_report_2016.pdf/, 10.18356/29587ada-en.

United Nations Environment Programme (UNEP). (2017) *UNEP's synthesis report on emissions gap*. Nairobi, Kenya. https://wedocs.unep.org/bitstream/handle/20.500.11822/22070/EGR_2017.pdf/

United Nations Framework Convention on Climate Change (UNFCCC). (1992) Document of United Nations Framework Convention on Climate Change, FCCC/INFORMAL/84 GE.05–62220 (E) 200705. https://unfccc.int/resource/docs/convkp/conveng.pdf/

United Nations Framework Convention on Climate Change (UNFCCC). (2015) Paris Agreement. https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement/

United States Agency for International Development (USAID). (2016) Greenhouse gas emissions in Egypt. https://www.climatelinks.org/s2016ites/default/files/asset/document/GHG%20Emissions%20Factsheet%20Egypt_v6_11_02-15_edits%20%281%29%20Steed%20June%202016_rev08-19-2016_Clean.pdf/, v6_11_02-15_edits (1) Steed June 2016_rev08-19-2016_Clean.

US Environmental Protection Agency (USEPA). (2007) *Inventory of U.S. greenhouse gas emission and sinks during (1990-2008)*. Washington DC, USA. https://www.epa.gov/sites/production/files/2015-12/documents/508_complete_ghg_1990_2008.pdf/

US Environmental Protection Agency (USEPA). (2019) *Overview of greenhouse gases*. Washington DC, USA. https://www.epa.gov/ghgemissions/overview-greenhouse-gases/

World Meteorological Organization (WMO). (2018) Greenhouse gas levels in atmosphere reach new record, Published 20 November 2018, Press Release Number: 22112018. https://public.wmo.int/en/media/press-release/greenhouse-gas-levels-atmosphere-reach-new-record

World Resources Institute (WRI). (2015) *Emissions including land-use change and forestry*. Washington DC, USA: Climate Data Explorer CAIT 2.0. https://www.wri.org/resources/websites/cait/

World Water Assessment Programme (WWAP). (2020) The United Nations World Water Development Report 2020, water and climate change, UNESCO 2020, ISBN 978–92–3-100371-4.

Zhan-Yun, M.A., Peng, F., Qing-Xia, G., Yan-Na, L.U., Jun-Rong, L. and Wen-Tao, L.I. (2015) Methane emissions and reduction potential in wastewater treatment in China. *Journal of Advances in Climate Change Research*, 6. 216–6. 224. https://www.sciencedirect.com/science/article/pii/S1674927815300071/

How to cite this article: Khairy W, Salem M, Saber G. Analytical study of carbon dioxide equivalent emission from agricultural drain surfaces — a case study from Egypt. *Irrig. and Drain*. 2021;1–13. https://doi.org/10.1002/ird.2565