Научно-практический электронный журнал
Оригинальные исследования (ОРИС), *ISSN 2222-0402*
www.ores.su
original-research.ru

УДК 504.054

ХАРАКТЕРИСТИКА ВЫБРОСОВ МОНООКСИДА УГЛЕРОДА (CO), ДИОКСИДА СЕРЫ (SO2) И ОКСИДОВ АЗОТА (NOX) В ЭКВАТОРИАЛЬНЫХ СТРАНАХ ВОСТОЧНОЙ АФРИКИ

Бахаране Валериен
Аспирант Института экологии, Российский университет дружбы народов, Москва-Россия, Baharane@yandex.ru

Шаталов Андрей Борисович
Доцент кафедры экологической безопасности и управления качеством продукции Института экологии, Российский университет дружбы народов, Москва-Россия, ShatalovAB@yandex.ru

Тутисабимбабази Дьедоне
Специалист по мониторингу растений на участке, Управление по охране окружающей среды Руанды, Кигали-Руанда, tuyisabyedeus@gmail.com

Бименимана Селевериен
Ассистент преподавателя кафедры физики, Университет Руанды, Кигали-Руанда sbimenyimana03@gmail.com

Игве Эммануэль
Магистрант Института Экологии, Российский университет дружбы народов, Москва-Россия, emmaigwe05@gmail.com

Аннотация

Целью данного исследования было описание выбросов CO, NOx и SO2 в экваториальном регионе Восточной Африки. Используя автономную модель HEMCO, мы проанализировали источники выбросов на 2019 год. Наше исследование показало, что в выбросах NO, CO и SO2 доминируют сжигание биомассы и лесные пожары. Пространственная и временная изменчивость показала более высокие выбросы в сухие сезоны. Анализ на основе данных EDGAR за 26-летний период показал, что в антропогенных выбросах преобладают бытовые источники.

Ключевые слова: Восточная Африка, страны южнее Сахары, выбросы загрязняющих веществ в атмосферу, диоксид серы, угарный газ, оксиды азота

CHARACTERIZATION OF CARBON MONOXIDE (CO), SULFUR DIOXIDE (SO2), AND NITROGEN OXIDES (NO+NO2) EMISSIONS IN EQUATORIAL EAST AFRICAN COUNTRIES

Valérien Baharane
Postgraduate Student of the Institute of Ecology, Peoples’ Friendship University of Russia, Moscow-Russia, vbaharane@yandex.ru

Andrey B. Shatalov
Associate Professor of the Department of Environmental Safety and Product Quality Management of the Institute of Ecology, Peoples’ Friendship University of Russia, Moscow-Russia, ShatalovAB@yandex.ru

Dieudonné Tuyisabyimbabazi
Site Plant Monitoring Specialist, Rwanda Environment Management Authority, Kigali-Rwanda, tuyisabyedeus@gmail.com

Seleverien Bimenyimana
Assistant Lecturer of the Department of Physics, University of Rwanda, Kigali-Rwanda, sbimenyimana03@gmail.com

Emmanuel Igwe
Master's student, Institute of Ecology, Peoples' Friendship University of Russia, Moscow-Russia, emmaigwe05@gmail.com

ABSTRACT

This study aimed to describe the emissions of CO, NOx, and SO2 in the Equatorial East African region. Using HEMCO standalone model, we analysed the emissions sources for the year 2019. Our study found that emissions of NO, CO, and SO2 are dominated by biomass burning and forest fires. The spatiotemporal variability observed higher emissions during dry seasons. An analysis done on the EDGAR dataset for 26 years period, realized that household sources are dominating anthropogenic emissions.

Keywords: East Africa, sub-Saharan, air pollution emissions, sulfur dioxide, carbon monoxide, nitrogen oxides

Introduction

Air pollution is the leading environmental cause of premature death, particularly in African countries [1]. The deterioration of air quality in African cities arose from rapid urbanization and industrial development lacking the supporting infrastructures [2]. Besides, effective agreements and actions are absent between African scientists, non-government organizations, and politicians in the establishment of air quality standards and policies leading to the gap in adequate emission inventories and ineffective capacity for enforcement and enabling compliance with air pollution management policies, regulations, and standards. The unclean household energy sources contribute to the higher indoor air pollution observed in African countries. The leading sources of outdoor air pollution are but are not limited to, the big number of old diesel-powered vehicles, poor household waste management, and household biomass burning [3]. Slash-and-burn practices make Africa the leading region in terms of areas burned per year [4]. With energy demand rising by half since the year 2000, 75% of the African population still lacks access to electricity. Across the continent, fossil fuel leads the production of electricity, accounting for more than 80% of the total power supply [5]. To contribute to the description of potential emission sources in Africa, this study aims to assess the emission of air toxic air pollutants in nine equatorial East African countries focusing on carbon monoxide (CO), nitrogen oxides (NOx), and sulfur dioxide (SO2).

Material and methods

Study area

This study focused on the equatorial East African region. It covered nine countries including Burundi, the Central African Republic (CAR), the Democratic Republic of Congo (DRC), Ethiopia, Kenya, Rwanda, South Sudan (S. Sudan), Uganda, and the United Republic of Tanzania (Tanzania). The choice of these countries was done according to their location, not to any regional-based organization. All these counties experience bimodal rainfall regimes except South Sudan and the Central African Republic which experience a unimodal rainfall regime [6].

Emission estimation methods

We simulated emissions of gaseous pollutants, for the year 2019, using Harmonized Emissions Component (HEMCO) standalone model version 3.5.2. HEMCO is a software component for computing atmospheric emissions from diverse sources, regions, and species on a user-defined grid [7]. Inside the HEMCO algorithm, anthropogenic emission was computed from Diffuse and Inefficient Combustion Emissions in Africa (DICE–Africa) [8]. Anthropogenic emissions that are missing in DICE-Africa have been completed using the Emissions Database for Global Atmospheric Research (EDGARv4.3) [9]. Biomass burning emissions were acquired from Global Fire Emissions System (GFAS) [10]. Volcanic emissions were collected from the NASA Global Modeling and Assimilation Office (GMAO) [11]. Aircraft emissions were estimated from Aircraft Emissions Inventory Code (AEIC2019) [12]. Furthermore, ship emissions were acquired from the Community Emissions Data System (CEDS) inventory [13]. To assess the effectiveness of HEMCO, its results were compared with observations of CO and SO2 fluxes retrieved from Modern-Era Retrospective Analysis for Research and Applications, version 2 (MERRA-2) [14]. The contribution of different sectors to anthropogenic emissions was analyzed using the EDGAR dataset. The trend analysis was done using the Mann-Kendall trend test via the Python package for the non-parametric Mann-Kendall family of trend tests [15].

Results and discussion

Total emissions

Figure 1 presents the total emissions flux as simulated by HEMCO for SO2, CO, NO, and NO2. Since volcanic sources were dominating SO2 emissions, we switched them off to better illustrate other sources. Higher SO2, CO and NO emissions are coming from the south of the DRC, and in the Central African Republic countries. The locations of these sources are marked by intensive biomass and forest fires [16], especially during the dry seasons.

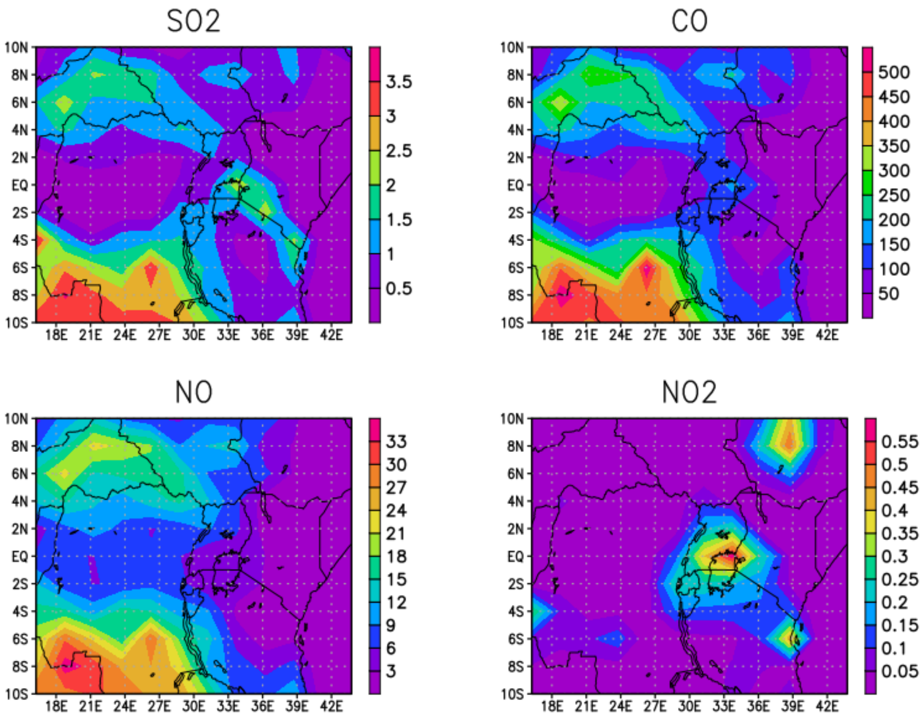

Figure 1. Spatial variation of air pollution emission flux (g/m2/year) in Equatorial East African countries in 2019 as estimated using the HEMCO Model.

The NO2 emissions are maximum in the southeast of Uganda and the central part of Ethiopia. However, an observation can be made on the fact that HEMCO excludes NO2 emissions from burning. Table 1 summarized the emissions from the most influential sectors and the total emission for each pollutant as estimated by the HEMCO model. Biomass burning is the main source of CO and NO, while volcanic sources dominate SO2 emissions. The higher values of SO2 from the volcanic sources are influenced by the Nyiragongo volcano which is one of the largest gas emitters located in the northeast of the DRC [17].

To illustrate the change in anthropogenic emissions within 26 years (2013-2022), we used the EDGAR database and examined the emissions by country and then by sector as presented in Figure 2 and Figure 3. During that period, CO, NOx, SO2, and PM2.5 respectively increased by 55.6%, 170%, 153%, and 79.6% with an annual increase rate of 1.71%, 4.07%, 3.79%, and 2.37% for each respective pollutant, (Figure 2). To avoid overlapping between sectors no comparison should be done between the data presented in Table 1 with the EDGAR emissions presented in Figure 2.

Table 1. Pollutant emissions from the most influential sectors for the year 2019 (Gigagram of species).

	Aircraft	Anthropogenic	Biomass burning	Lightning	Ship	Managed Soil	Volcanic	Total
CO	7.48	5,009.06	76,003.17	-	0.41	-	-	95,973.95
SO2	2.10	92.30	513.98	-	11.22	-	1,289.64	2,033.38
NOx	17.57	30.92	4,118.84	1,420.17	6.94	1,003.32	-	6,879.90

Table 2. Results of Mann-Kendell trend test done on pollutant emissions of 26 years period.

	CO			SO2			NOx			PM2.5		
Country	**p***	**τ**	**s**	**p***	**τ**	**s**	**p***	**τ**	**s**	**p***	**τ**	**s**
Burundi	**0.06**	**0.27**	**87**	**0.10**	**0.23**	**75**	**0.00**	**0.61**	**199**	**0.03**	**0.30**	**97**
CAR	**0.01**	**0.37**	**120**	**0.00**	**0.69**	**225**	**0.00**	**0.95**	**307**	**0.33**	**0.14**	**45**
DRC	**0.16**	**0.20**	**65**	**0.00**	**0.77**	**249**	**0.00**	**0.94**	**305**	**0.00**	**0.95**	**309**
Ethiopia	**0.00**	**1.00**	**325**	**0.00**	**0.98**	**319**	**0.00**	**0.98**	**319**	**0.00**	**1.00**	**325**
Kenya	**0.00**	**1.00**	**325**	**0.00**	**0.76**	**247**	**0.00**	**0.90**	**293**	**0.00**	**0.99**	**323**

Rwanda	0.69	-0.06	-19	0.00	0.50	163	0.00	0.75	245	0.02	0.34	111
S. Sudan	0.86	-0.03	-9	0.00	0.80	261	0.00	0.94	305	0.00	0.84	273
Tanzania	0.00	0.84	273	0.00	0.67	223	0.00	0.85	277	0.00	1.00	325
Uganda	0.00	0.95	307	0.00	0.99	321	0.00	0.99	323	0.00	0.96	311

*p: p-value < 0.05 indicates the rejection of the null hypothesis of no trend and thus, reveals the existence of the trend.

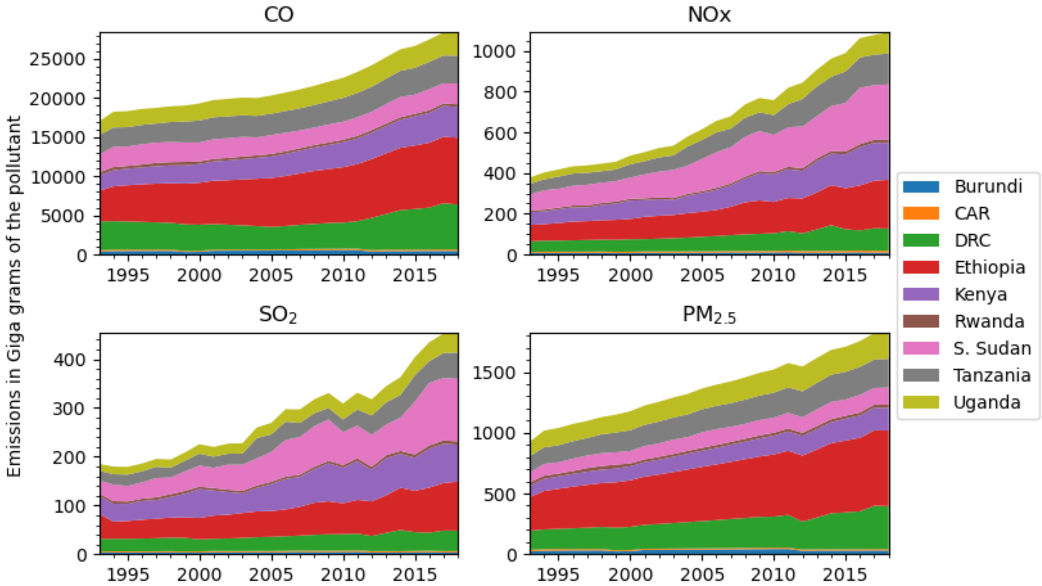

Figure 2. Anthropogenic emission trends by country from 1993 to 2018.

The country profile revealed that Ethiopia is the most emitter in the region, and the Republic of South Sudan was marked by an increase in SO2 and NOx emissions all over the study period. The increase in emissions flux coming from Ethiopia is justified by its also leading place in economic growth in the region [18]. The increase in air pollutant emissions in the Republic of South Sudan may be attributed to the widespread practice of bush fire for household and agricultural purposes plus the extent of forest fires during the dry season. In general, all studied emissions increased, as confirmed by the Mann-Kendall trend test (Table 2), except for CO for which the test did not confirm an increasing trend for Burundi, Rwanda, South Sudan, and the Democratic Republic of Congo countries. There was not a confirmed trend also for SO2 in Burundi and PM2.5 in the Central African Republic. Residential sources dominated the CO emissions with a 26-yearly average of 65.0% followed by Solid Fuel with 22.2%. The NOx emissions are mainly coming from road transportation (26.2%), residential sources (23.9%), emissions from managed soil (15.4%), manufacturing industry and construction (15.0%), and activities aiming for electricity and heat production (10.6%). Residential, heat and electrical generation, and manufacturing industry sources are the main SO2 sources with averages of 38.1%, 27.6%, and 26.5%, respectively. The PM2.5 emissions are dominated by residential sources with a 26-yearly average of 79.9% followed by solid fuel (7.1%). Biomass burning which is the source of these chemical species still the main source of energy for heating and food preparation in the region [3], this justifies the dominance of the residential and solid fuel in the emitted pollutant from the region.

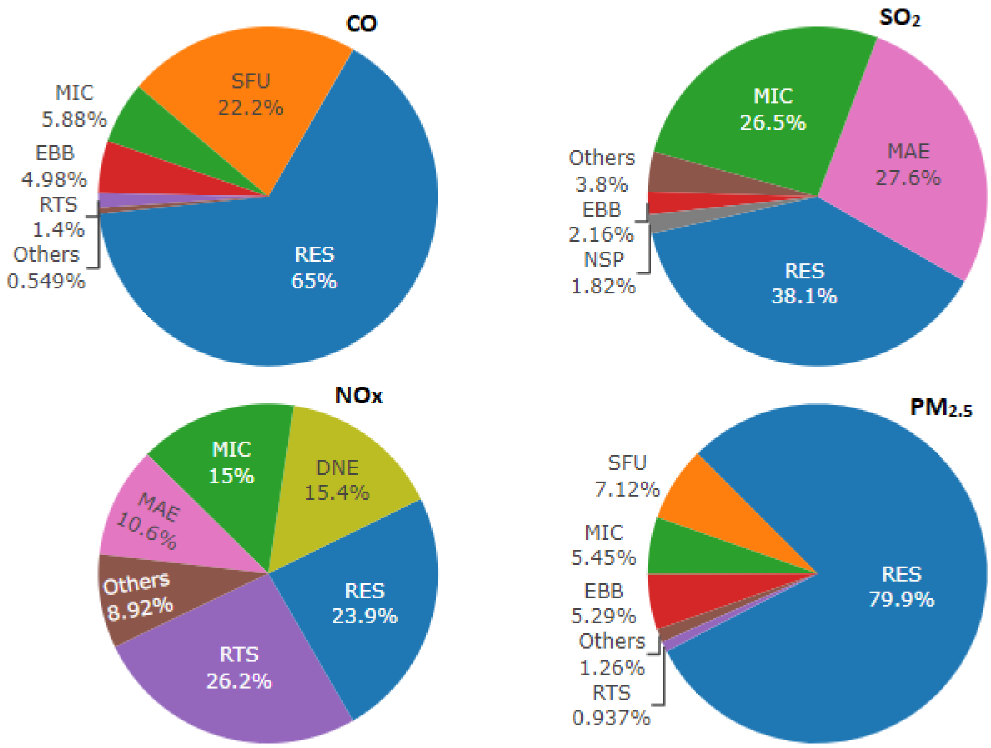

Figure 3. Averaged 26 years of air pollutant emissions' sector contribution. with DNE: Direct N2O Emissions from managed soils; EBB: Emissions from biomass burning; MAE: Main Activity Electricity and Heat Production; MIC: Manufacturing Industries and Construction; MMA: Manure Management; NSP: Non-Specified; RES: Residential and other sectors; RTS: Road Transportation no resuspension; SFU: Solid Fuels.

The seasonal variability of emissions for each pollutant is given in Figure 4. It is clear that during the period of December-January-February (DJF), emissions of all analyzed gases are concentrated in the northern part of the equator (CAR and S. Sudan) while during the period of June-July-August (JJA), higher emissions are coming from the southern part of the equator (Angola, Zambia, and the southern part of DRC). The seasonal variability of all gases, except for NO2, is highly linked with the dryness and wetness of the region [19] as the wet seasons result in less pollution due to washout, and dry seasons induce more pollution. In the region, the higher rainfall intensity is centred at the equator during March-April-May (MAM) to shift to the North part of the equatorial region during the JJA and then to the southern part during the DJF. The observed patterns agree with the research conducted by Williams et al., (2012) on the impact of the uncertainties in African biomass burning emission estimates [20]. The source of higher seasonal pollution is in confirmation with the values presented in Table 1, where biomass burning is dominating in all studies species. The study conducted by Ramo et al., (2021) [21] on the African burned area maps more fire coming in the same regions.

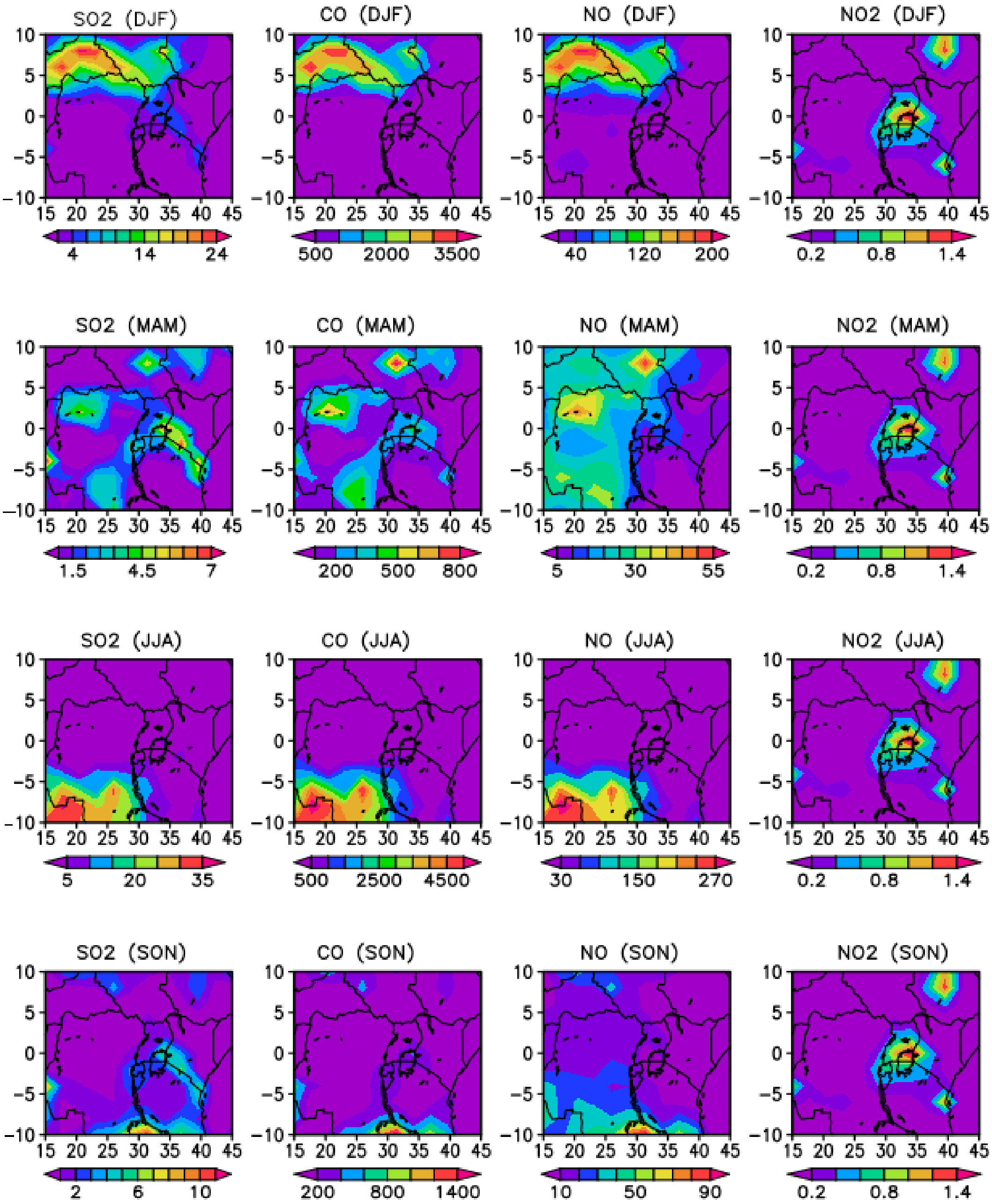

Figure 4. Averaged-seasonal emissions flux (×10-12 kg/m2/s) of SO2, CO, NO and NO2 for the year 2019 as estimated by the HEMCO model.

Model comparisons

We compared emissions calculated by HEMCO with emissions retrieved from the GIOVANNI data repository. Emissions downloaded using the GIOVANNI repository are time-averaged monthly mean reanalysis from MERRA-2. The comparison maps are given in Figure 6. We re-gridded MERRA-2 products to HEMCO resolution to better compare the two datasets. The mapped emissions exclude SO2 from volcanic sources for each ensemble member. The calculation and the observations captured the same patterns with a disaccord in emissions flux in some parts of the regions. The disagreement may be explained by the quasi-permanence cloudiness over the equatorial belt, which makes unreliable the satellite observations [22], and influences the calculation made by models. Pearson's coefficient of correlation between HEMCO estimates and MERRA-2 products was found to be 0.873 and 0.814 for CO and SO2, respectively.

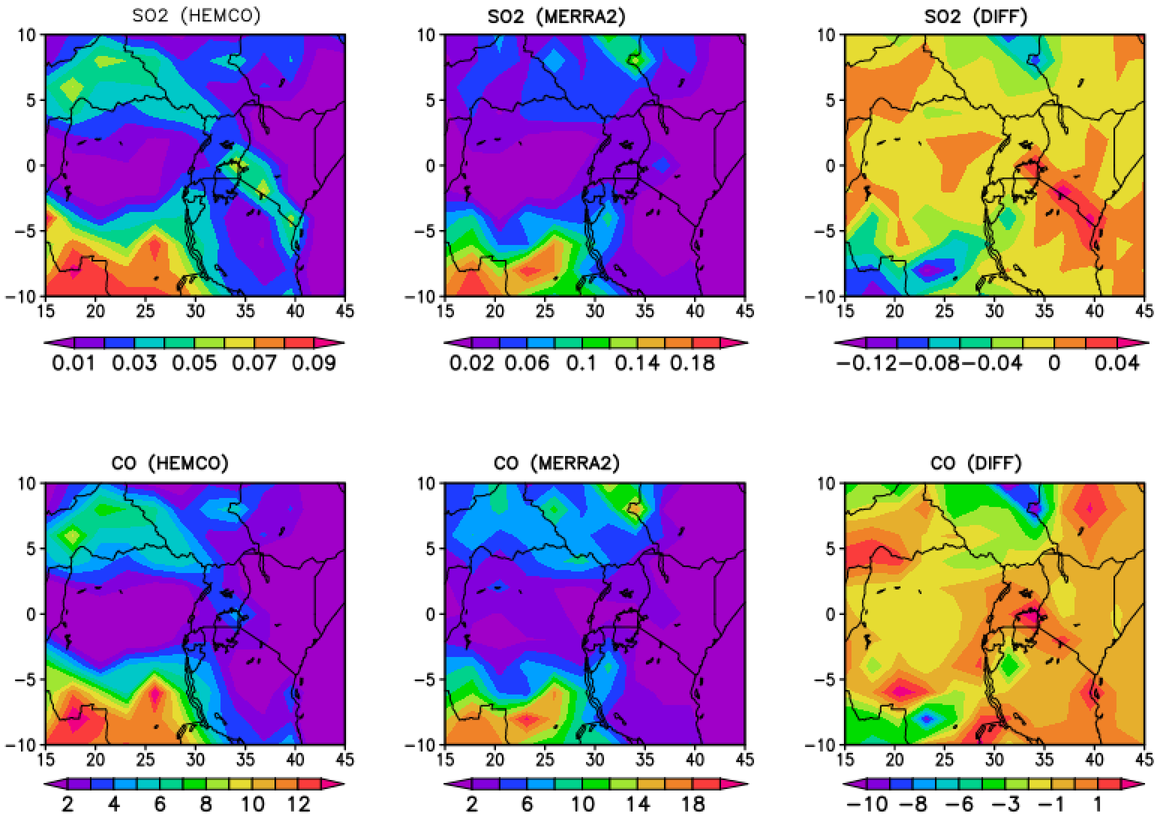

Figure 6. Comparison of emissions flux (×10-10 kg/m2/s) estimated using the HEMCO model and MERRA-2 for the year 2019.

Conclusions

The characterization of air pollutant emissions is the first step to fighting air pollution incidences. This study aimed to describe the emissions of CO, NOx, and SO2 in the Equatorial East African region. Results from HEMCO calculations showed that higher emissions in the study regions are coming from biomass and forest fires in both parts of the equatorial belt. A 26-year analysis of anthropogenic sources revealed that principal sources are residential sources, solid fuel, road transport, electricity, heat production, and managed soil. Results proved that the seasonal variability of the emissions in the region follows the permutation of the seasons, with higher emissions during the dry seasons than in the wet seasons. The findings of this study may help in the reduction of air pollutants in the study region.

Authors' contribution: VB conceptualized and wrote the original draft, SAB supervised the study, and DT, SB and IE perused and improved the readability of the report.

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