Journal of Air Pollution and Health (Spring 2022); 7(2): 143-156

Original Article

Available online at http://japh.tums.ac.ir

Time variability of cumulative carbon dioxide concentration for adequacy assessment of greenspace: A case study in Surabaya, Indonesia

Sarwoko Mangkoedihardjo**, *Irwan Bagyo Santoso

Department of Environmental Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

ARTICLE INFORMATION

Article Chronology:
Received 03 March 2022
Revised 09 May 2022
Accepted 17 May 2022
Published 29 June 2022

Keywords:
Carbon dioxide (CO_2); Ambient air; Concentration mapping; Time variability; Greenspaces

CORRESPONDING AUTHOR:

prosarwoko@gmail.com
Tel: (+61) 5948886
Fax: (+61) 5928387

ABSTRACT

Introduction: The upward movement of Carbon dioxide (CO_2) mass into the air and downwards towards the earth's surface, especially vegetative areas, affected the variability of CO_2 concentration in the ambient air. In this pattern, this study aimed to determine the net cumulative value of CO_2 concentration (Net_CO_2-Con) in an urban area to assess the adequacy of greenspace.

Materials and methods: This research method uses CO_2 concentration observations within 24 h in 137 observation locations covering an area of 350 km^2 in Surabaya city. The sampling location was set at a height of 2 m above the local ground. The CO_2 concentration observations were carried out in the dry season and the rainy season for a total of 640 air samples.

Results: The results of this study obtained Net_CO_2-Con values for ambient CO_2 concentrations in a daily pattern. Starting at night there was a flow of CO_2 flux into the air, which reached its peak in the morning, in about 90% of the city area. This event was evidence of a lack of CO_2 absorption due to the lack of extensive vegetative areas. On a bright day the CO_2 flux flows towards the land, which indicated the presence of vegetation absorption in addition to soil absorption. The seasonal time variability of CO_2 flux density had the same pattern for the daily time variability.

Conclusion: Mapping for CO_2 flux could be an approach to determine the adequacy of greenspace. Areas of upward movement of CO_2 flux density were priority areas for greenspace intensification.

Introduction

The growth and development of human life and its activities are one of the factors that increase the concentration of Carbon dioxide (CO_2) in the air apart from the environment [1–3]. The increase in CO_2 does not continuously accumulate in concentration, but can be controlled through the mechanism of the vegetation process [4, 5]. Thus, there is a relationship between humans and vegetation, especially humans and their activities produce CO_2 and vegetation uses this gas for growth. The results show that when there is sunlight, the CO_2 flux density moves downwards, indicating the mass of CO_2 transferred from the ambient air to the vegetation area. When there is no sunlight, the CO_2 flux density moves upward, indicating the mass transfer of CO_2 from the

Please cite this article as: Mangkoedihardjo S, Santoso IB. Time variability of cumulative carbon dioxide concentration for adequacy assessment of greenspace: A case study in Surabaya, Indonesia Journal of Air Pollution and Health.2022;7(2): 143-156.

Copyright © 2022 Tehran University of Medical Sciences. Published by Tehran University of Medical Sciences.
This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International license (https://creativecommons.org/licenses/by-nc/4.0/). Noncommercial uses of the work are permitted, provided the original work is properly cited.

land's surface to the surrounding air. In the daily time variability of CO_2, the flux to the air is controlled by the flux into the vegetation system. The relationship between CO_2 flux and the vegetation fraction of a number of major cities in the world has been described by previous studies [6–10]. The researchers found that cities with a high vegetation fraction will have minimal CO_2 flux density from land to ambient air.

However, the aforementioned research results still require deepening of knowledge, especially in relation to the parameter that represents the cumulative CO_2 emission-absorption process on a time scale. This parameter is the net cumulative CO_2 concentration, as a result of the flux equilibrium between air and land at any given time. The time scale that is important for knowing CO_2 flux is daily, according to the time variability of the respiration-photosynthesis process. Likewise, the seasonal time scale is important to know the effect of environmental conditions on different seasons, for the tropics, especially the location of this research is the dry and rainy seasons.

Therefore, this study aimed to obtain the net cumulative value of CO_2 concentration (Net_ CO_2-Con) in ambient air in the time variability of day-night and dry-rainy seasons. Furthermore, these results are mapped on a city scale, which can be used to determine priority for greenspace adequacy in an area. The results of this study have added benefits to the assessment method and intensification of the adequacy of greenspaces in general.

Materials and methods

Materials

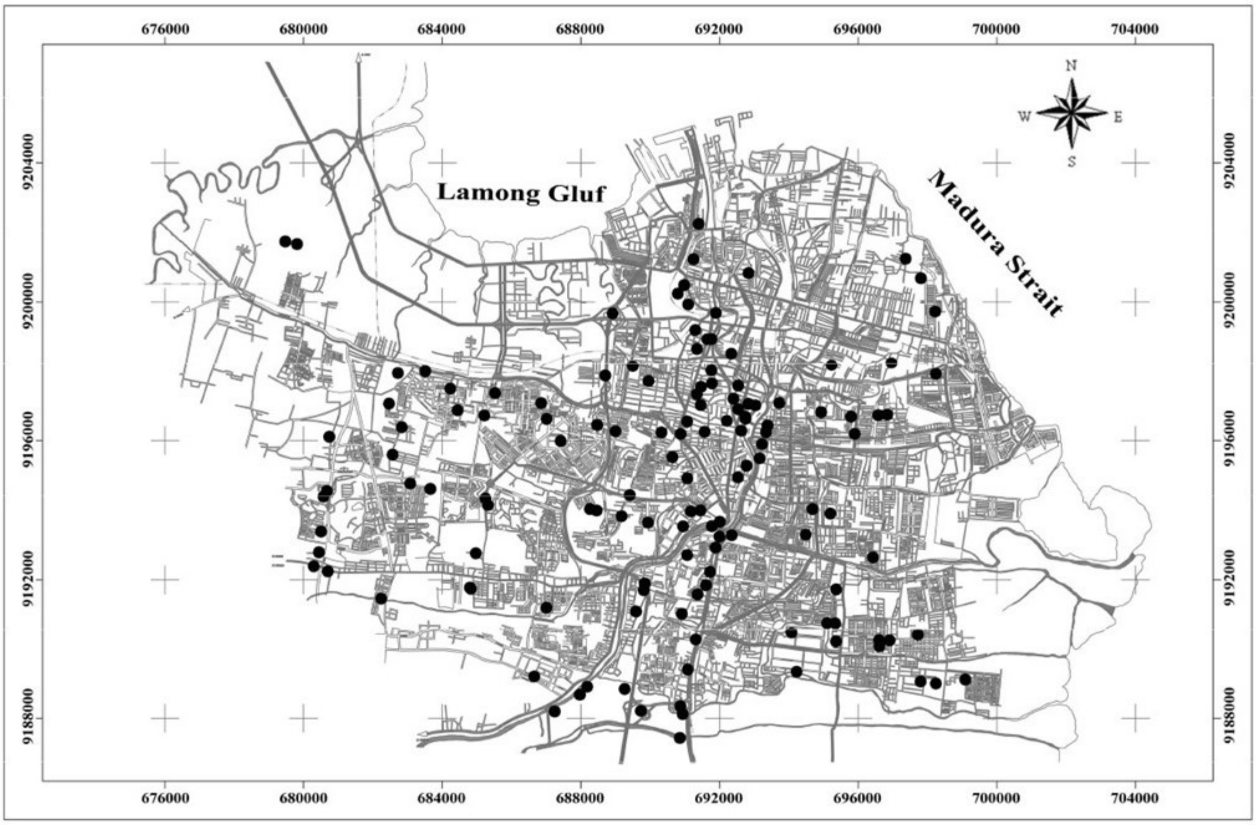
Observation materials include: 1) High resolution image map, minimum resolution of 1 m for the shooting time before and after the observation time. 2) Topographic maps were obtained from the Surabaya City Government. 3) Wind data regarding direction and speed, and humidity of the air from the Juanda and Perak Surabaya meteorological stations. 4) The Lutron brand of CO_2 concentration measuring instrument (InfraRed Detector) is connected to a USB RS232 cable with a data logger. 5) Data logger for Toshiba notebook PCs. 6) Lutron brand air temperature measuring instrument, which is an integral part of measuring CO_2 concentration. 7) Lutron brand solar radiation measuring instrument. 8) Global Positioning Systems - Hand hell of the Garmin 76Csx series. 9) PCI Geomatica Ver 9.0 for image data processing such as orthorectification and land cover classification.

The CO_2 measuring instrument with an infrared detector is calibrated prior to its use for field measurements. Measurement of the average CO_2 for an interval of 1 min is obtained from the average results of 10 measurements, each of which takes 6 s. Calibration is carried out at night in one location for 20 d. Performed at midnight because at midnight the air is stable [11, 12] and minimal meteorological disturbances. The location of the calibration is in the yard of the house in dense settlements with shrubs and no shrubs. Equipment calibration data is processed into analytical quality control curves, which have a precision characteristic of a standard deviation of 3.1 ppm and an accuracy range of 6 ppm.

Number of sample locations

The city of Surabaya is designated as a research study area with the following considerations: 1) The physical characteristics of the city of Surabaya are vary, covering hills (west Surabaya area), coast (east Surabaya region) and plains (central Surabaya region); 2) The city of Surabaya has a various source of CO_2 activities, such as transportation, industry, trade, education, settlements, and polluted rivers.

Sampling locations were determined based on probability sampling. All samples or units of observation in their area have the same opportunity to be sampled. Therefore, location determination can use simple random sampling. The city of Surabaya has an area of about 350 km^2 and 1 unit of observation area of about 2.0-2.5 km^2 [11], therefore 137 observation location were needed. With a number of observation location, the placement is distributed with the following variability considerations: 1) Topographic and land use characteristics. Land use variability includes vegetative and non-vegetative areas, residential areas, commercial areas, industrial areas, transportation areas, and water body areas. 2) Meteorological characteristics relate to wind direction and speed, cumulative density of solar radiation, average air temperature. Vector analysis was used to determine wind direction and speed at the sampling site [13] based on data available at meteorological stations. The distribution of all locations of observation is shown in Fig. 1.



Surabaya city boundary map

Fig. 1. Observation location in the city of Surabaya

At each observation location, air samples were taken with an altitude of 1.5-2 m from the local land surface [12, 14, 15], because the majority of human activity was at that height. In addition, at a height of 2 m it has a minimum roughness layer, a minimum meteorological effect, and a dominant CO_2 absorption and emission.

Observation time

For this research to continue without interruption, but still be able to cover 2 different seasons, the observation time was arranged as follows. In the seasonal time variability scale, the research was carried out in the rainy season (January-February) and the dry season (April-May). Observation time is taken 1 time per week on the busiest day of population activity (for the city of Surabaya, it is Tuesday).

On a daily variability scale, measurements were made with an interval of 6 h at night (22:00 pm), morning (04:00 am), noon (10:00 am), and afternoon (16:00 pm) western Indonesian time. The measurement time was scanning for 6 seconds and repeated 10 times, for a total of 1 min. Thus, the CO_2 concentration at that time was the average of the result of the scanning loop. Then, the CO_2 concentration data was interpolated to obtain CO_2 series data per minute within 24 h.

With the organization of the observation time, this study collected and analysed a total of 640 air samples.

Software

Analysis of observation results specifically uses licensed software, PCI Geomatica Ver 9.0, which was used to process satellite image data. Next, geometric correction of 3D orthorectification was carried out and produced a referenced image of position and elevation. This was followed by a delineation of land use or cover in each unit of analysis (or, unit of observation area). The CO_2 concentration measurement data for each unit of observation area becomes the basis for making CO_2 isoconcentrations for the entire city area.

For statistical Analysis of Variance (ANOVA) SPSS version 24 was used, which was free to download. The results of inter-seasonal and daily observations showed significant differences in environmental independent variables.

Results and discussion

Environmental conditions

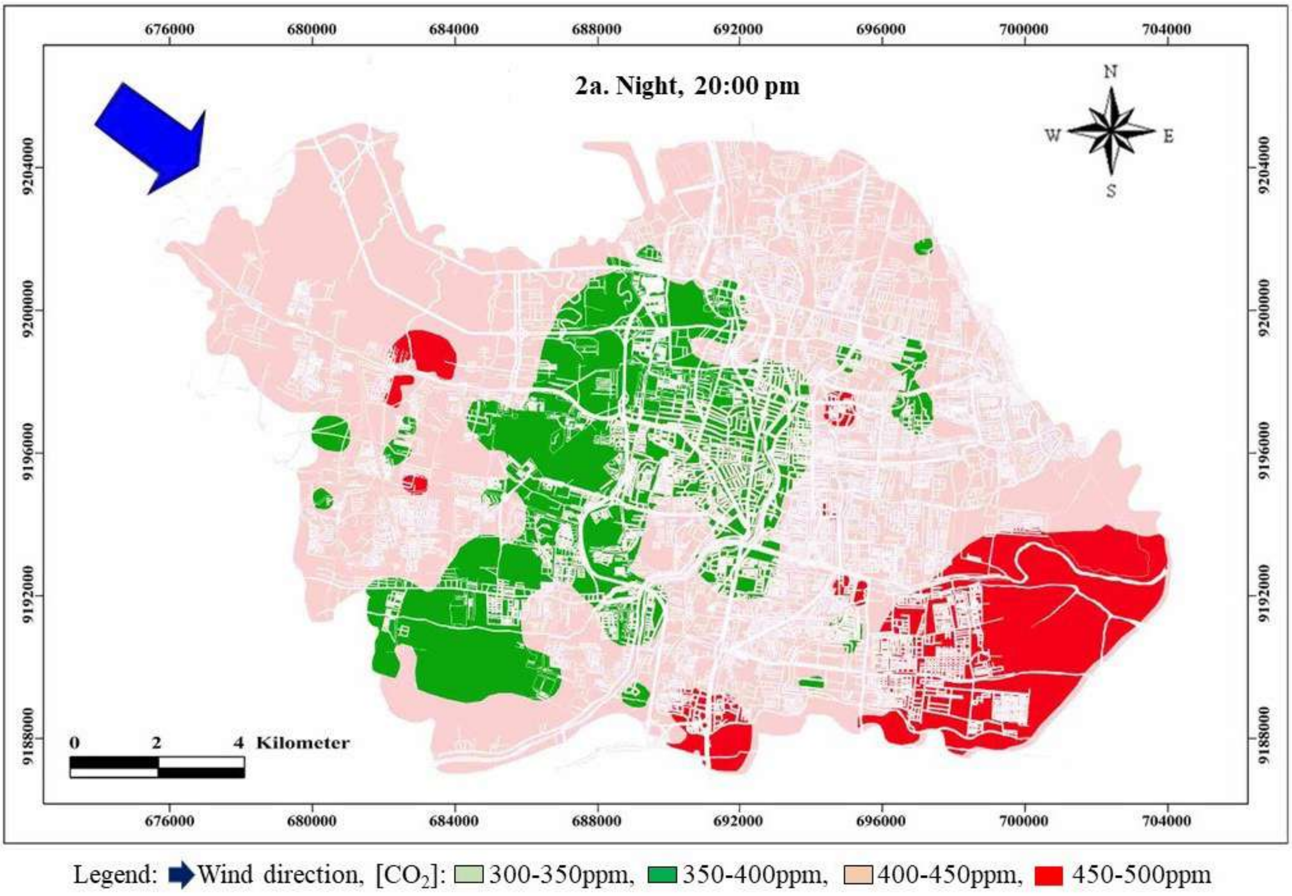
During the observation time, quantitative data were obtained about the environmental conditions of the city of Surabaya which supported this research in the dry and rainy seasons (Table 1). More specifically, in the dry season the wind direction moves from northwest to southeast. Meanwhile, during the rainy season the wind moves from the northeast to the west and southwest. In addition, along the north-east borders the sea, which has the potential to contribute CO_2 [16–18] to the land area of the city.

Daily carbon dioxide concentrations in the dry season

The net cumulative CO_2 concentration (Net_CO_2-Con) at night, morning, noon and afternoon in the dry season are presented in Fig. 2a-d. The red colour shows the CO_2 flux into the air and the green colour flows to the land including vegetation. The thicker the colours, the greater the density of CO_2 flux.

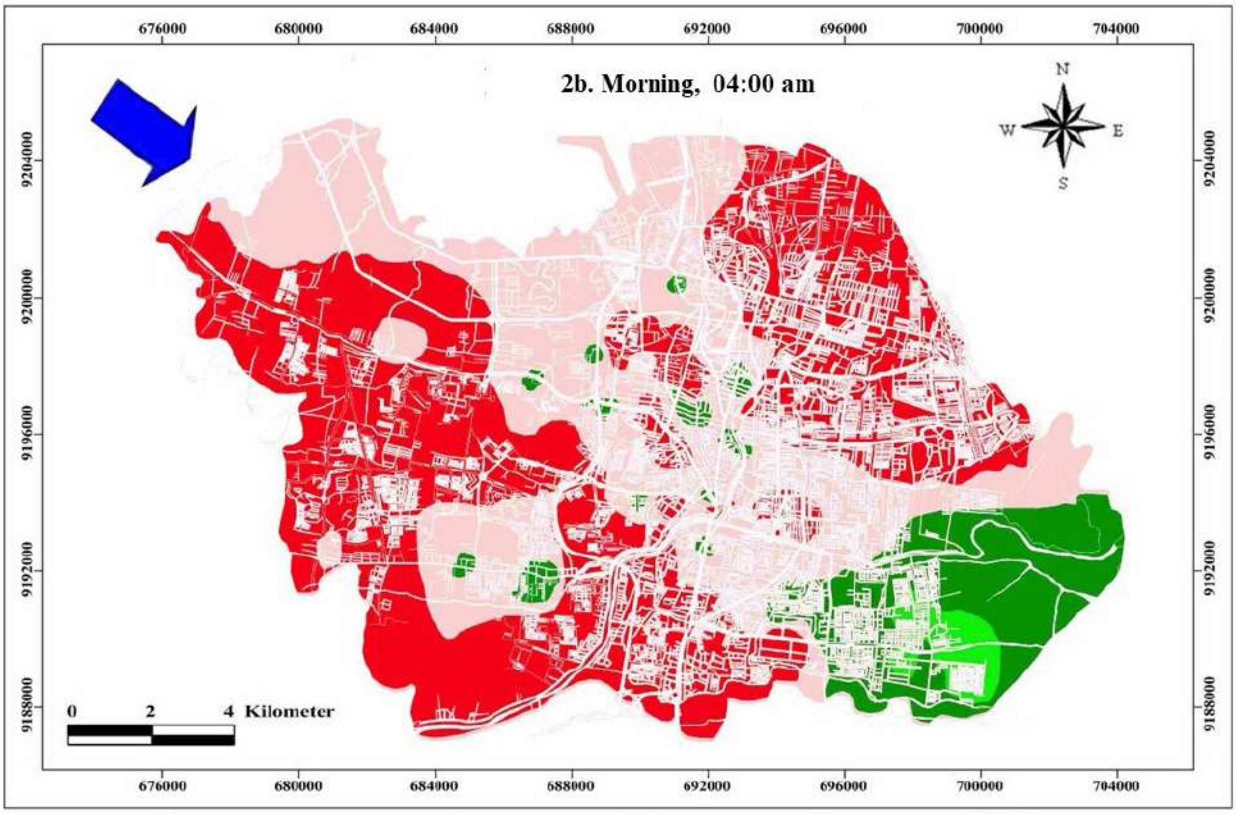
Table 1. Supporting data on environmental conditions

No	Variable and parameter	Unit	Minimum	Average	Maximum
1	Meteorology:				
	Cumulative solar energy	10uWatt/cm^2	15,840	91,634	453,000
	Temperature	ºC	28.8	30.5	35.4
	Wind velocity	m/s	0.42	1.86	4.60
	Wind direction	º	23	180	308
2	Land elevation	m MSL	2.93	-	29.1
3	Land use:				
	Non-vegetative land	%	-	74.5	-
	Vegetative land	%	-	23.2	-
	Water bodies and swamps	%	-	2.3	-



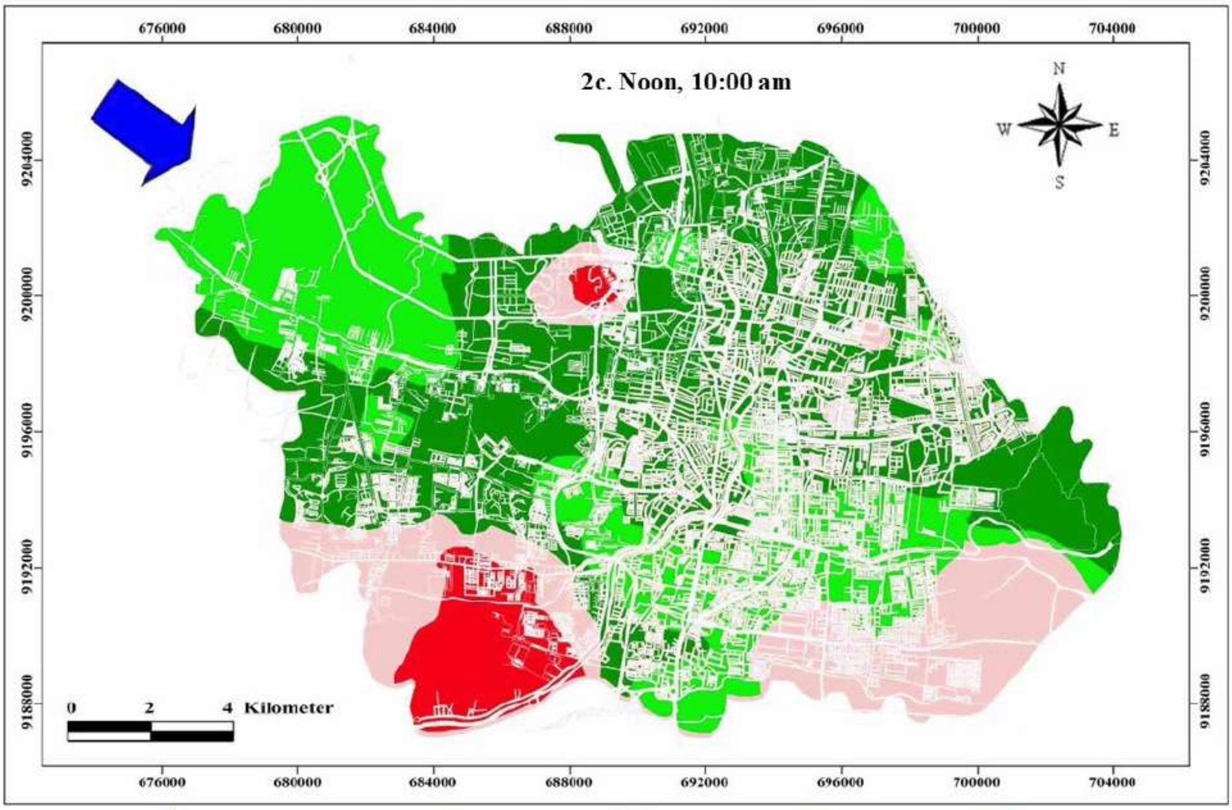
(a)

Fig. 2. Daily time variability of the net cumulative CO_2 concentration in the dry season in the city of Surabaya



Legend: Wind direction, [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

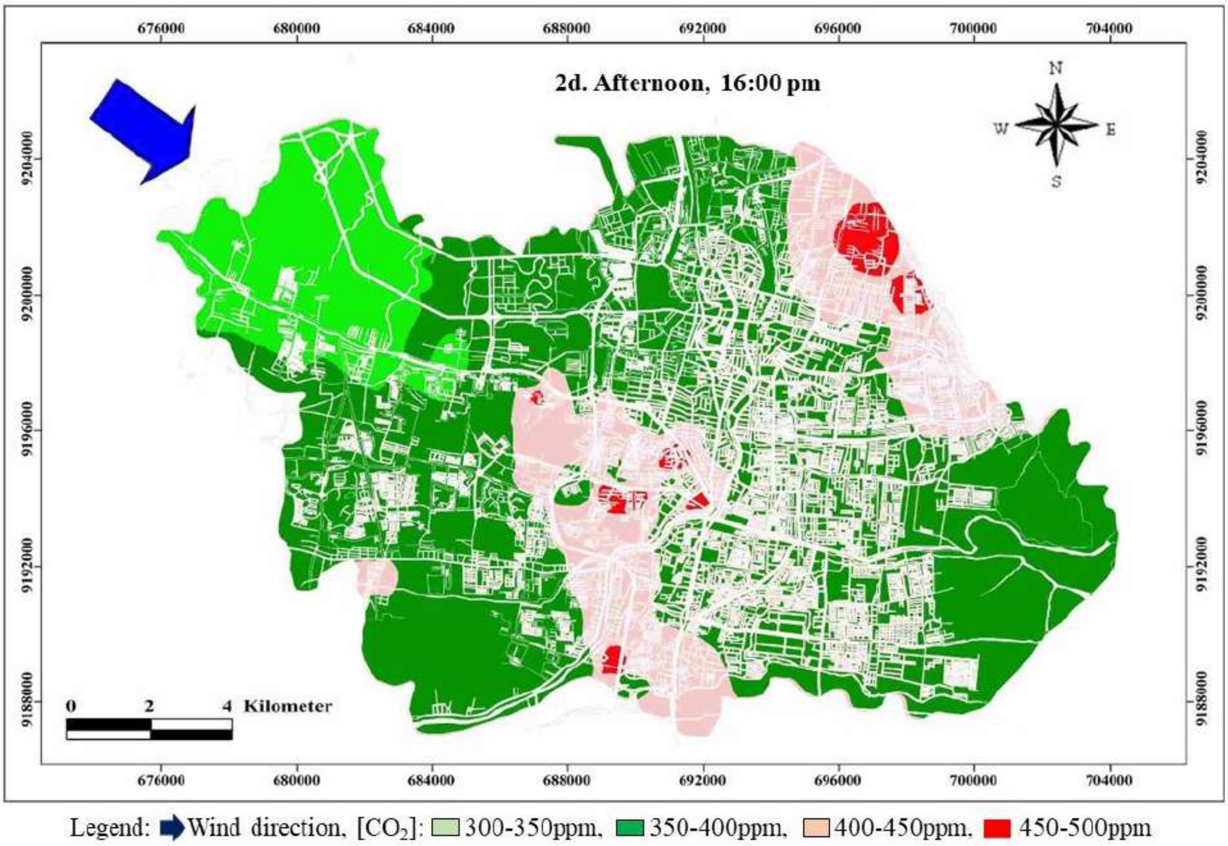
(b)



Legend: Wind direction, [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

(c)

Fig. 2. Daily time variability of the net cumulative CO_2 concentration in the dry season in the city of Surabaya



(d)

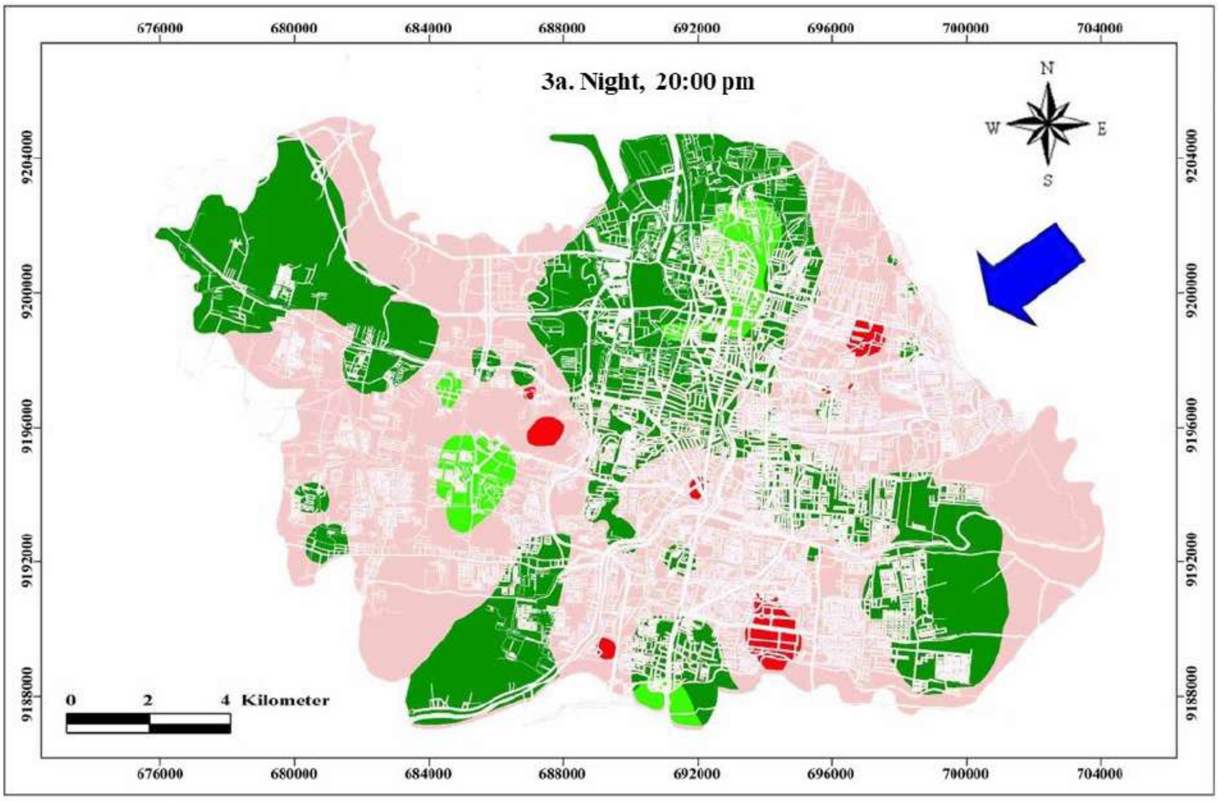
Fig. 2. Daily time variability of the net cumulative CO_2 concentration in the dry season in the city of Surabaya

The facts have shown that starting at night there is a flow of CO_2 fluxes into the air, which peaks in the morning, in about 90% of the city area. This event is evidence of the absence of CO_2 absorption by vegetation, and even vegetation respiration increases the CO_2 concentration in the air. Furthermore, in the afternoon to afternoon, the CO_2 flux flows clearly towards the land, in this case the absorption of vegetation to carry out the photosynthesis process with additional CO_2 absorption in the soil system. Meanwhile, the difference in CO_2 flux density (colour thickness) may be due to dynamic factors such as transportation and commercial activities in the city of Surabaya.

Daily carbon dioxide concentrations in the rainy season

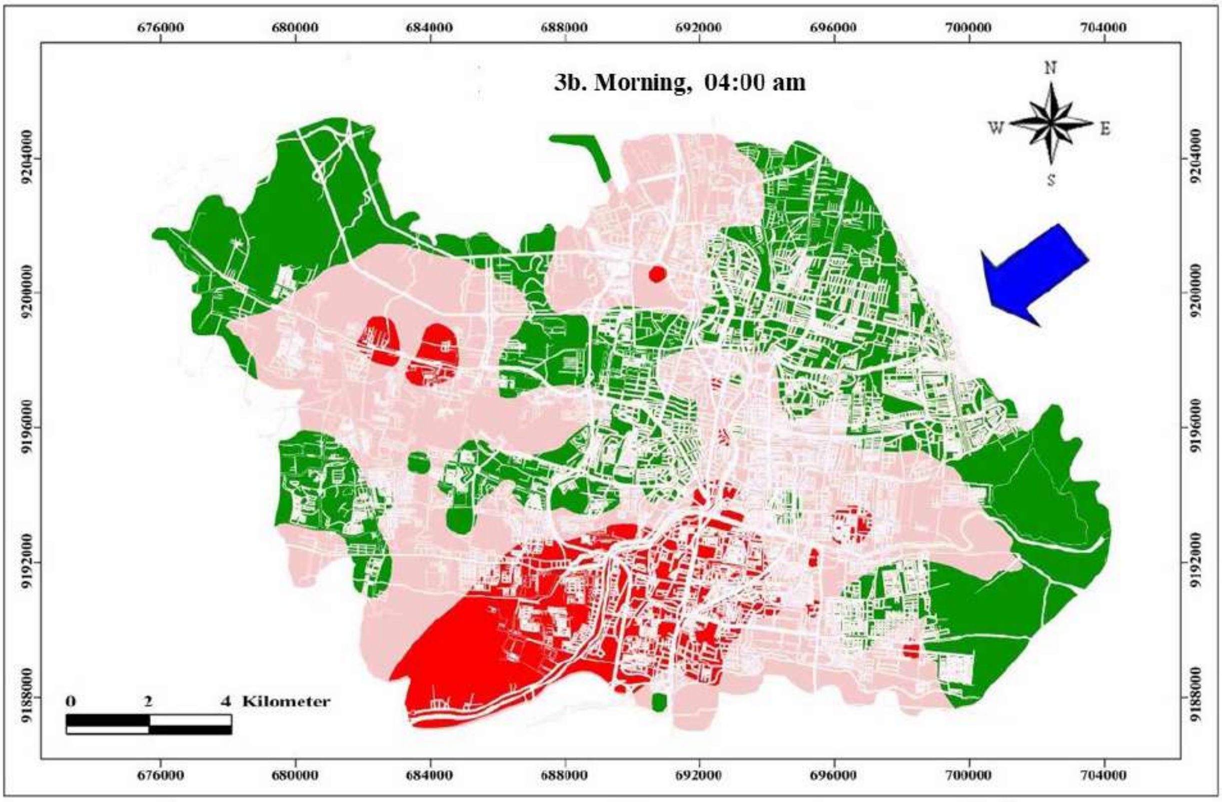
The net cumulative CO_2 concentration (Net_ CO_2-Con) at night, morning, noon and afternoon in the rainy season are presented in Fig. 3a-d. The red colour shows the CO_2 flux into the air and the green colour flows to the land including vegetation. The thicker the colours, the greater the density of CO_2 flux.

The facts show that for 24 h, the flow of CO_2 flux into the air (red colour) is approximately the same as the flow of CO_2 flux to the land (green colour). There is no significant difference around the city that experiences



Legend: Wind direction, [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

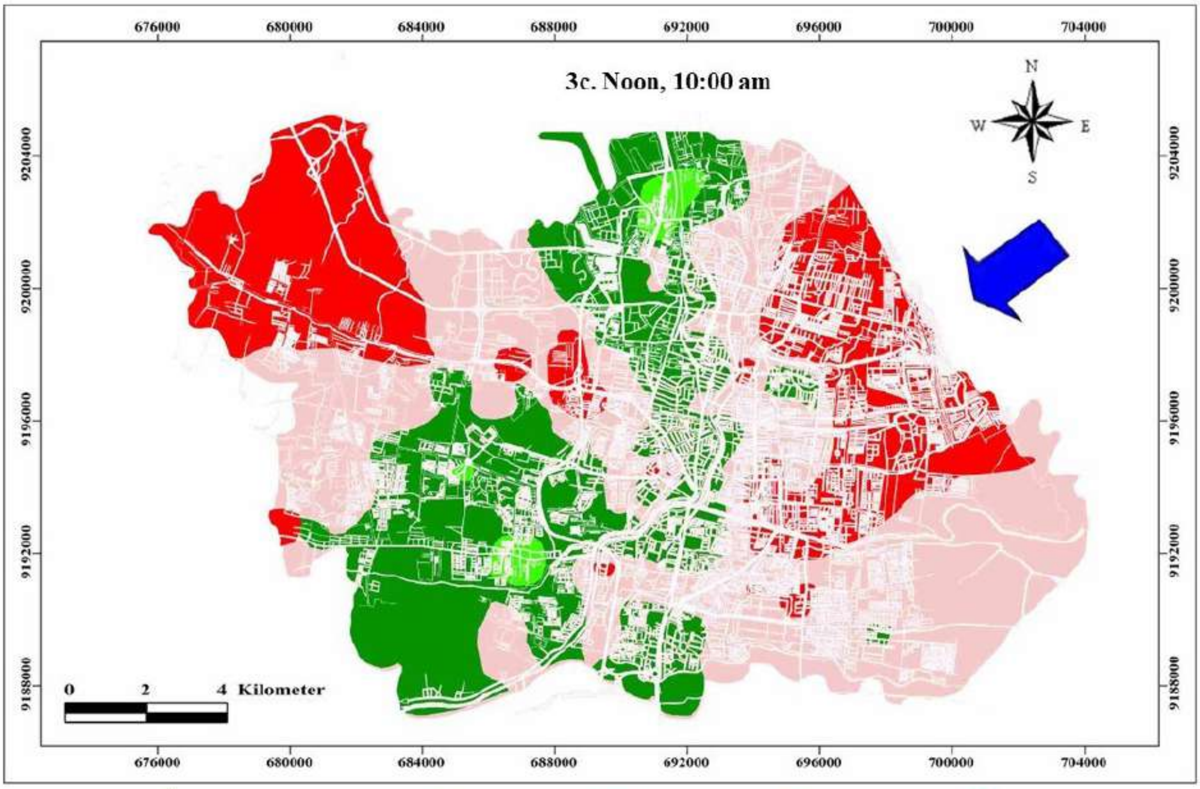
(a)



Legend: Wind direction, [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

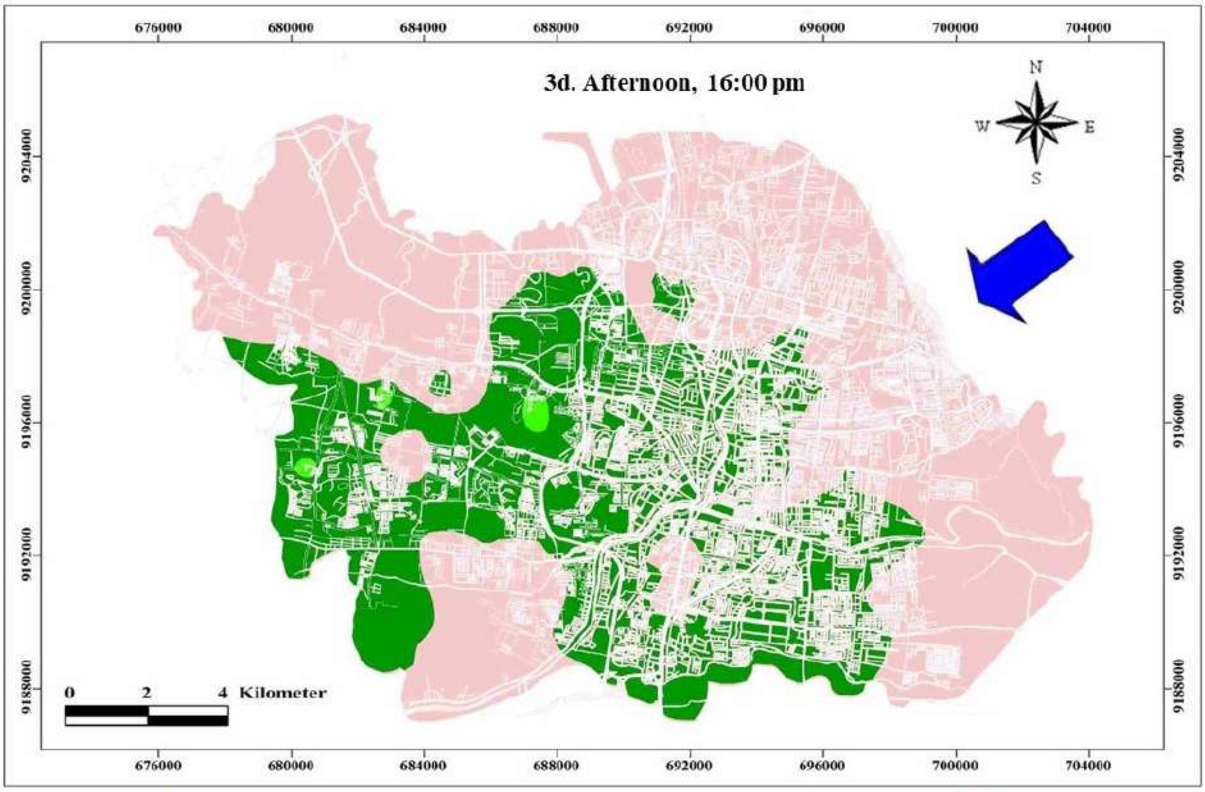
(b)

Fig. 3. Daily time variability of the net cumulative CO_2 concentration in the rainy season in the city of Surabaya



Legend: Wind direction, [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

(c)



Legend: Wind direction, [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

(d)

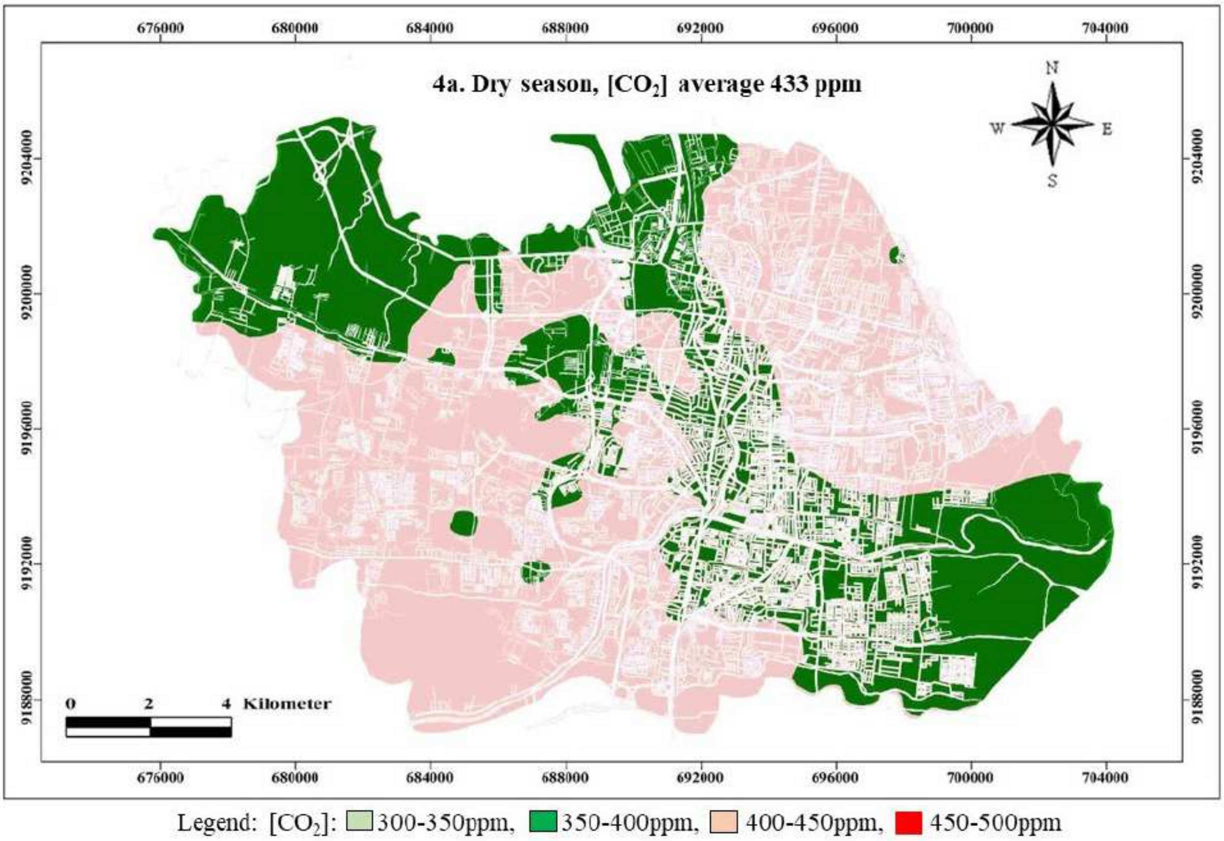
Fig. 3. Daily time variability of the net cumulative CO_2 concentration in the rainy season in the city of Surabaya

the flow of CO_2 flux. This incident may occur due to two things. The first is due to the cloud cover of sunlight, thereby reducing the chance of the photosynthesis process by vegetation. The second is probably due to the transport of oceanic CO_2 [16–18] to the land following the wind direction.

Along the north-east coast of the city, at night, the flow of CO_2 fluxes is into the air. In the morning, these places show the flow of CO_2 flux towards the land. And, even continuing from noon to afternoon there was an increase in the density of the CO_2 flux into the air. For the rest of the area, the CO_2 flux appears consistent with dry season conditions (Fig. 2) but at a lower density.

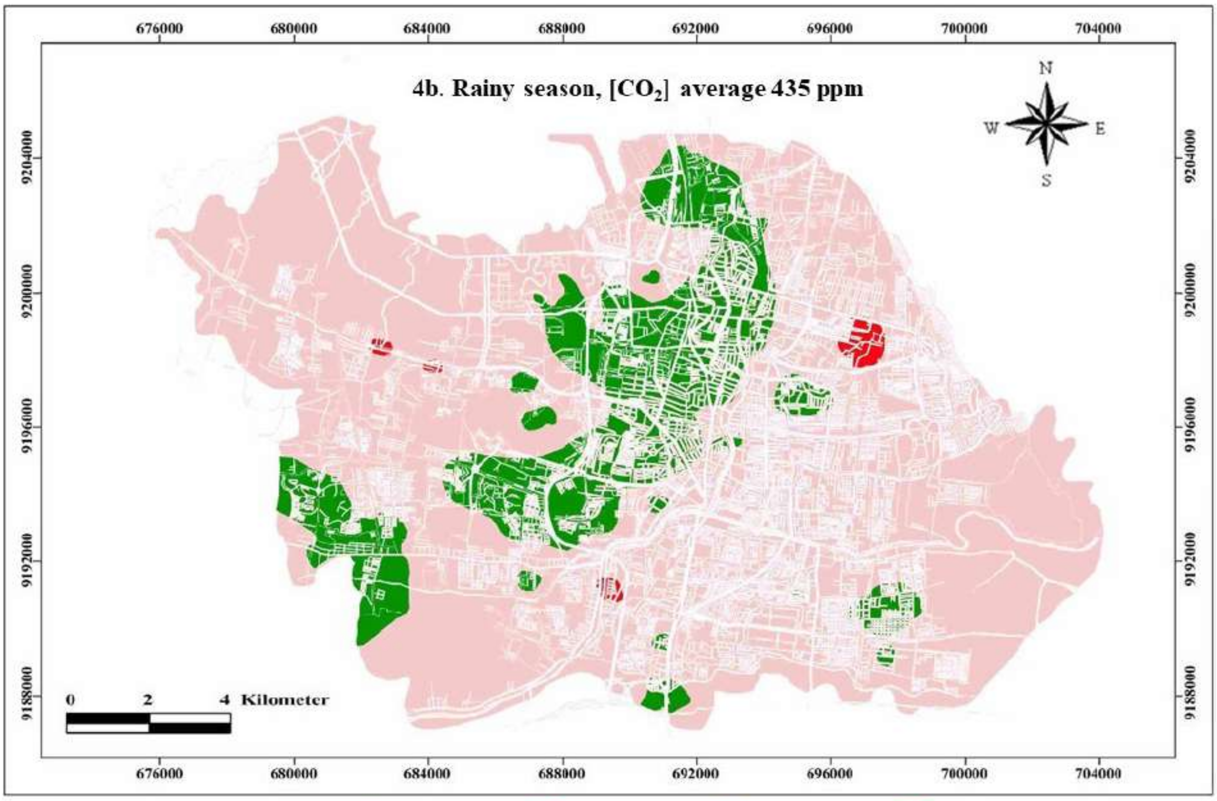
Seasonal carbon dioxide concentrations

Seasonally observed CO_2 concentrations have obtained the average value and the CO_2 flux density can be mapped in Fig. 4a and b. The facts obtained are that the average CO_2 concentration in different seasons is not different, which is around 433-435 ppm. The mean concentration is close to the normal ambient air CO_2 quality [19–21].



(a)

Fig. 4. Seasonal time variability of the average CO_2 concentration in the city of Surabaya



Legend: [CO_2]: 300-350ppm, 350-400ppm, 400-450ppm, 450-500ppm

(b)

Fig. 4. Seasonal time variability of the average CO_2 concentration in the city of Surabaya

Seasonally, it appears that the area of CO_2 flux to land in the dry season is wider than in the rainy season. On the other hand, the area of CO_2 flux into the air during the rainy season is wider than the dry season. Seasonal time variability has the same pattern for daily time variability. This reinforces the reasons for the incident due to two things. It is due to the cloud cover of sunlight, thereby reducing the chance of the photosynthesis process by vegetation, and the transport of oceanic CO_2 [16–18] to the land following the wind direction.

Assessment of greenspace adequacy

By obtaining the average CO_2 concentration in ambient air throughout the year that is close to the normal ambient air quality (Fig. 4), it does not mean that the current presence of greenspace is sufficient. In accordance with the function of greenspace based on the results of this study is to downward flow CO_2 flux to the land, therefore, the adequacy of greenspace needs to be assessed based on the distribution of CO_2 flux areas.

The upward flow of CO_2 flux into the air from night to morning is a normal natural occurrence, as all living things emit CO_2. Therefore, the distribution of the area characterized by the flux flow from night to morning (Fig. 2) is not a determining factor for the intensification of greenspace. This applies to all times, both daily and seasonal time variability.

The essential function of green open space is to form conditions, which can flow CO_2 flux to the land's surface. It is because vegetation absorbs CO_2 to carry out the photosynthesis process. To fulfil this essential function, it is necessary to consider the distribution of areas, where the upward flow of CO_2 flux to the air requires intensification of greenspace.

For the city of Surabaya, the distribution of areas requiring intensification of greenspace is the afternoon-afternoon period during the rainy season (Fig. 3) and is strengthened by seasonal CO_2 flux conditions (Fig. 4). The intensification of greenspace covers at least the entire suburb of the city. The area of intensification of greenspace is in line with the approach to the distribution of greenspace based on the studies of previous researchers [22–25].

This intensification of greenspace can be implemented through expanding the existing area and/or using plant species that are capable of absorbing a lot of CO_2, as well as by applying biodiversity for efficient and effective results [26, 27]. Another advantage of the intensification of green open spaces around the city is to capture the flow of CO_2 fluxes from outside the area. Particularly, the application of greenspace along the north-east city boundary is to absorb CO_2 originating from ocean emissions.

Conclusion

Observation of CO_2 concentration by daily and seasonal time variability can produce a net cumulative CO_2 concentration (Net_CO_2-Con). This result can explain the flow of CO_2 flux to the air and to the land. Mapping CO_2 flux can be the basis for an approach to determine the intensification of the adequacy of greenspace. The basis for this approach facilitates the intensification of the distribution of greenspace areas within a city area.

Financial supports

This work was financed by Institut Teknologi Sepuluh Nopember, Surabaya.

Competing interests

The authors declare no potential conflict of interest affecting this work.

Authors' contributions

SM: conception, design, acquisition of data, analysis and interpretation of data, drafting the manuscript, and revising it; IBS: as did SM' contribution, focusing on field works and mapping.

Acknowledgements

The authors gratefully acknowledge financial support from the Institut Teknologi Sepuluh Nopember for this work, under project scheme of the Publication Writing and Intellectual Property Rights Incentive Program (PPHKI) 2021 (in Bahasa Indonesia: "PPHKI: Keputusan Rektor Institut Teknologi Sepuluh Nopember Nomor T/2029/IT2/HK.00.01/2021 Tanggal 20 Mei 2021 Tentang Penugasan Penulisan Publikasi dan Hak Kekayaan Intelektual Batch 1").

Ethical considerations

Ethical issues (including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/

or submission, redundancy, etc.) have been completely observed by the authors.

References

1. Mohmmed A, Li Z, Olushola Arowolo A, Su H, Deng X, Najmuddin O, et al. Driving factors of CO_2 emissions and nexus with economic growth, development and human health in the Top Ten emitting countries. Resources, Conservation and Recycling. 2019 Sep 1;148:157–69.

2. Liu HZ, Feng JW, Järvi L, Vesala T. Four-year (2006–2009) eddy covariance measurements of CO_2 flux over an urban area in Beijing. Atmospheric Chemistry and Physics. 2012 Sep 3;12(17):7881–92.

3. Kordowski K, Kuttler W. Carbon dioxide fluxes over an urban park area. Atmospheric Environment. 2010;23(44):2722–30.

4. Acosta M, Juszczak R, Chojnicki B, Pavelka M, Havránková K, Lesny J, et al. CO_2 Fluxes from Different Vegetation Communities on a Peatland Ecosystem. Wetlands. 2017 Jun 1;37(3):423–35.

5. Leroy F, Gogo S, Guimbaud C, Bernard-Jannin L, Hu Z, Laggoun-Défarge F. Vegetation composition controls temperature sensitivity of CO_2 and CH4 emissions and DOC concentration in peatlands. Soil Biology and Biochemistry. 2017 Apr;107:164–7.

6. Fu P, Xie Y, Moore CE, Myint SW, Bernacchi CJ. A Comparative Analysis of Anthropogenic CO_2 Emissions at City Level Using OCO-2 Observations: A Global Perspective. Earth's Future. 2019;7(9):1058–70.

7. Costa END da, Souza MFL de, Marrocos PCL, Lobão D, Silva DML da. Soil organic matter and CO_2 fluxes in small tropical watersheds under forest and cacao agroforestry. PLOS ONE. 2018 Jul 16;13(7):e0200550.

8. Mabuchi K, Takagi H, Maksyutov S. Relationships between CO_2 Flux Estimated by Inverse Analysis and Land Surface Elements in South America and Africa. Journal of the Meteorological Society of Japan Ser II. 2016;94(5):415–30.

9. Muñoz-Rojas M, Lewandrowski W, Erickson TE, Dixon KW, Merritt DJ. Soil respiration dynamics in fire affected semi-arid ecosystems: Effects of vegetation type and environmental factors. Sci Total Environ. 2016 Dec 1;572:1385–94.

10. Balzarolo M, Vescovo L, Hammerle A, Gianelle D, Papale D, Tomelleri E, et al. On the relationship between ecosystem-scale hyperspectral reflectance and CO_2 exchange in European mountain grasslands. Biogeosciences. 2015 May 28;12(10):3089–108.

11. Santoso IB, Mangkoedihardjo S. Mapping Cumulative Carbon Dioxide Concentrations at Two meters Above the Ground for Greenspace Assessment in Surabaya. Middle East Journal of Scientific Research. 2013;18(3):288-92.

12. Büns C, Kuttler W. Path-integrated measurements of carbon dioxide in the urban canopy layer. Atmospheric environment. 2012;46:237–47.

13. Pongpiachan S, Surapipit V, Ketratanakul A, Wuttijak N, Pongnoppa A. Risk analysis by emission source strengths and wind directions of trace gases at Map Ta Phut Industrial Estate, Rayong province, Thailand. WIT Transactions on Information and Communication Technologies. 2010 Aug 26;43:PI-337.

14. Olumayede EG. Atmospheric Volatile Organic Compounds and Ozone Creation

Potential in an Urban Center of Southern Nigeria. International Journal of Atmospheric Sciences. 2014 Aug 21;2014:e764948.

15. Hayashi K, Matsuda K, Ono K, Tokida T, Hasegawa T. Amelioration of the reactive nitrogen flux calculation by a day/night separation in weekly mean air concentration measurements. Atmospheric Environment. 2013;79:462–71.

16. Sea MA, Garcias-Bonet N, Saderne V, Duarte CM. Carbon dioxide and methane fluxes at the air–sea interface of Red Sea mangroves. Biogeosciences. 2018 Sep 4;15(17):5365–75.

17. Khan MHR. Influence of salt marsh ecosystem on the concentration and emission of CO_2 from the Wadden sea coast soil of northern Germany. Bangladesh Journal of Scientific Research. 2016;29(2):101–9.

18. Gago J, Gilcoto M, Pérez FF, Ríos AF. Short-term variability of fco2 in seawater and air–sea CO_2 fluxes in a coastal upwelling system (Ría de Vigo, NW Spain). Marine Chemistry. 2003 Feb 1;80(4):247–64.

19. Kimball BA, Paul J Pinter J, lamorte RL, Leavitt SW, Hunsaker DJ, Wall GW, et al. Data from the Arizona FACE (Free-Air CO_2 Enrichment) Experiments on Wheat at Ample and Limiting Levels of Water and Nitrogen. Open Data Journal for Agricultural Research. 2017 Jun 13;3:29–38.

20. Zou Z, Liu F, Chen C, Fernando WGD. Effect of Elevated CO_2 Concentration on the Disease Severity of Compatible and Incompatible Interactions of Brassica napus–Leptosphaeria maculans Pathosystem. Plants. 2019 Nov;8(11):484.

21. Köhler IH, Huber SC, Bernacchi CJ, Baxter IR. Increased temperatures may safeguard the nutritional quality of crops under future elevated CO_2 concentrations. The Plant Journal. 2019;97(5):872–86.

22. Samudro H. Landscape intervention design strategy with application of Islamic ornamentation at Trunojoyo Park Malang, Jawa Timur, Indonesia. Journal of Islamic Architecture. 2020 Jun 9;6(1):41–7.

23. Li F, Guo S, Li D, Li X, Li J, Xie S. A multi-criteria spatial approach for mapping urban ecosystem services demand. Ecological Indicators. 2020 May 1;112:106119.

24. Lind L, Hasselquist EM, Laudon H. Towards ecologically functional riparian zones: A meta-analysis to develop guidelines for protecting ecosystem functions and biodiversity in agricultural landscapes. Journal of Environmental Management. 2019 Nov 1;249:109391.

25. Díaz-Pascacio E, Ortega-Argueta A, Castillo-Uzcanga MM, Ramírez-Marcial N. Influence of land use on the condition of the riparian zone along an urban-rural gradient in the Sabinal River, Mexico. Botanical Sciences. 2018 Jun 19;96(2):180–99.

26. Gawronski SW, Gawronska H, Lomnicki S, Sæbo A, Vangronsveld J. Chapter Eight - Plants in Air Phytoremediation. In: Cuypers A, Vangronsveld J, editors. Advances in Botanical Research [Internet]. Academic Press; 2017 [cited 2022 Mar 2]. P. 319–46. (Phytoremediation; vol. 83). Available from: https://www.sciencedirect.com/science/article/pii/S0065229616301276

27. Samudro G, Mangkoedihardjo S. Mixed plant operations for phytoremediation in polluted environments – A critical review. Journal of Phytology. 2020 Dec 16;99–103.