Short Communication

A spatiotemporal analysis of the continent-wide contribution of agriculture in CO$_2$-eq production from 1990 to 2019 using the t-map package of R software

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ABSTRACT

Background and objective: Spatiotemporal maps are suitable tools to convey lots of information to the interested audience. The aim of this paper is to create continent-wide spatiotemporal maps regarding the role of agriculture on CO$_2$-eq production in the period between 1990 and 2019 using the t-map package of R software.

Materials and methods: Initial data were obtained from the Internet resources (the FAO, and ARCGIS websites), and after performing some adjustments and modifications i.e. deletion of unnecessary data and matching of the contents of the FAO and ARCGIS data files, as well as combining data files, final data were uploaded to the R software to convert to spatiotemporal maps using the t-map package.

Results and conclusion: The results showed that there was a decreasing trend of the share of agriculture in the total CO$_2$-eq production from 1990 to 2019, while at the same time, the amount of agriculture-induced CO$_2$-eq has increased very gradually. On the other hand, the amount of total CO$_2$-eq produced has increased considerably from 1990 to 2019; therefore, it can be concluded that the growth of CO$_2$-eq production in the other economic sectors is higher than that of agriculture. Thus, the first priority should be to curb the growth of CO$_2$-eq production in all economic sectors, especially non-agricultural ones.

1. Introduction

Data visualization is an important topic in the field of descriptive statistics. Lots of information can be conveyed to the audience if the raw data has been well visualized. On the other hand, utilizing modern data acquisition systems leads to the creation of large datasets that contain both spatial and time series data about the variable considered. Therefore, combining spatial and time series data in a spatiotemporal map is an interesting issue in data visualization. Open-source R software is a powerful computing platform for the analysis of statistical data. The t-map as well as the ggplot packages of R, which work based on the grammar of graphics procedure, are suitable software programs to visualize data effectively (Wickham, 2010; Tennekes, 2018). Before the development of R, GIS software was

used to present data in a spatiotemporal map (Cahyadi et al., 2022; Cardone & Di Martino, 2022). Since R is an open source, command line-based software and GIS is a commercial, click-based software, it is repeatedly said that R can motivate creativity in presenting data more than GIS.

The role of environmental pollutants in the phenomenon of global warming is inevitable (Huang et al., 2012). Scientists usually convert all types of pollutants to their CO_2 equivalent, known as CO_2-eq, in order to be able to compare the role of different sectors regarding the production of pollutants (Shin et al., 2017). Agricultural activities, among other human activities, share in the production of CO_2-eq (Balogh, 2020; Wang et al., 2020). Mimi and Jamous (2010) stated that due to dramatic population growth, industrialization, and urbanization, associated with extra pressure on the water, energy, and food sectors, accelerate the production of man-made Green House Gas (GHG) emissions. Consequently, future global warming would increase agricultural water demand while at the same time decreasing rainfall availability whichresults in water scarcity and adverse effects on food production. In another study in this field, Saray et al. (2022) utilized the Water-Energy-Food (WEF) Nexus approach to develop appropriate mitigation strategies for optimal cropping patterns and illustrate the interactions between water, energy, and food by focusing on CO_2 emissions. They showed that Water-Energy-Food Nexus Index (WEFNI) values could be used to optimize cropping patterns. To visualize the effect of agriculture on CO_2-eq production, the spatiotemporal map is considered to be a good choice.

This paper aims to create a continent-wide spatiotemporal map of the role of agriculture on CO_2-eq production in the period between 1990 and 2019 using the capabilities of the t-map package of R software. The idea of presenting an animated spatiotemporal map in a research paper is novel. Moreover, the use of a command line-based, open-sourceprogramming language i.e. R, instead of a commercial click-based software i.e. GIS, for developing a geographic map is new, too. The only limitation ofthis presentation is the shortage of spatiotemporal data, however due to the development of modern data acquisition systems, this limitation will fade away. The advantage of this map is that the role of each continent in each of the years considered regarding agriculture-induced CO_2-eq production can be presented in an animated format; therefore, considerable information can be conveyed to the map reader promptly. To sum up, there is a gap in the field of spatiotemporal map creation, especially in the literature onagriculture. This article tries to fill this gap using the capabilities of the R software for the case study of CO_2-eq production in the world's continents in the period between 1990 and 2019. Motivating environmentalists and agriculturalists to use this method to present their data in a spatiotemporal map is another aim followed in this paper.

2. Materials and methods

The spatiotemporal maps were created following the procedure described below:

a) Obtaining, primary preparation, and entering raw data into the R

The data sets of the contribution of continents in CO_2-eq production, as well as the share of agriculture in CO_2-eq production from 1990 to 2019, were downloaded from the FAO website[*]. The data was modified to remove its unnecessary data, as well as to change its row-wise time series data to column-wise data. The latter procedure was performed because the R software accepts Excel files having column-wise format. The conversion was simply carried out by copying the row-wise data and using the "transpose" command while pasting them. In other words, the final file (newcol.csv) was composed of five columns named: "CONTINENT", "YEAR", "Total_Emission_CO_2_eq_BillionTons", "Ag_Emission_share_percent", and "Ag_induced_CO_2_eq_BillionTons ". This file was uploaded to R using the R-code given in Appendix 1. It is worth mentioning that before utilizing the commands of a package, that package must be installed first (using R command: *install.packages("package name")*), then it must be called (using R command: *library(package name)*). Moreover, the working directory is a location in the computer memory that R has access to it and the files that should be uploaded to R must be located there. This

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[*] -https://www.fao.org/food-agriculture-statistics/data-release/environment/en/

location can be set using the command: *setwd("working directory path")*. The path of the current working directory can be seen using the command: *getwd()*. Therefore, the file named "newcol.csv" must be placed in the working directory before running the code.

The Geographic shapes of continents were obtained using a shape (.shp) file downloaded from the ArcGIS website[†]. This file was uploaded to R using the R-code given in Appendix 2. It is obvious that the file named "World_Continents.shp" must be placed in the working directory before running the code.

To combine geographic shape and dataset files, rows of the dataset file were sorted by the combined sorting method of first by "YEAR" and then by "CONTINENT" using the Sort & Filter button of the Excel software. The "CONTINENT" column of the geographic shape file was sorted accordingly.

b) Final preparation of data in R

The number of rows of the shape file was increased to reach the number of rows of the dataset file using the repetition of its contents 30 times by the R-code given in Appendix 3.

Finally, the two sorted and equal rowed files were combined using the R-code given in Appendix 4.

The final file (*final frame*) was the data frame that was used to create a spatiotemporal map.

c) Drawing spatiotemporal maps using the t-map package of R

To obtain the spatiotemporal maps required in this paper, the R-codes given in Appendix 5 were utilized.

The main input of the code given in Appendix 5 was the data frame developed above. Moreover, in order to obtain spatiotemporal maps, continents were colored according to the values of the columns: "Ag_Emission_share_percent",   "Total_Emission_CO2_eq_BillionTons",and "Ag_induced_CO2_eq_BillionTons". Using the R-codes given in Appendix 5, the maps will be updated according to the values of the "YEAR" column, in order to show the temporal variation of data.

3. Results and discussion

Fig. 1 shows the time series diagrams of CO2-eq produced globally and the portion of it that is induced by agricultural activities in the period between 1990 and 2019:
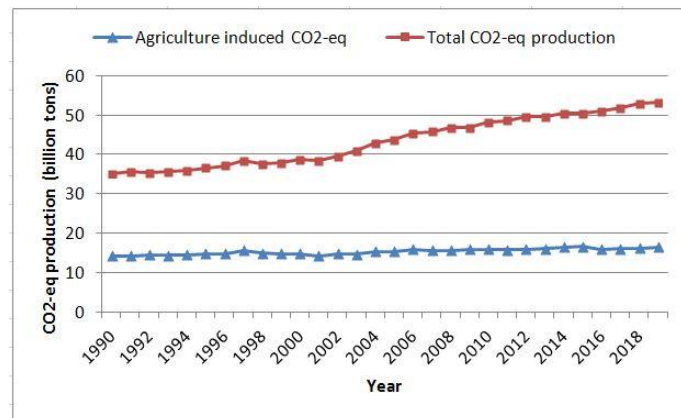

Fig. 1- Time series data of CO$_2$-eq produced in agriculture as well as total CO$_2$-eq production from 1990 to 2019

[†] - https://opendata.arcgis.com/api/v3/datasets/57c1ade4fa7c4e2384e6a23f2b3bd254_0/downloads/data?
format=shp&spatialRefId=4326&where=1%3D1

Furthermore, the major outputs of this paper are three image files (.gif) presenting the spatiotemporal variation of the contribution of continents and the share of agriculture in CO_2-eq production, as well as the spatiotemporal variation of agriculture-induced CO_2-eq production. The animated files have been attached as supplementary material to this paper; moreover, the spatial maps of the year 2019 were shown in Fig.s 2, 3, and 4:
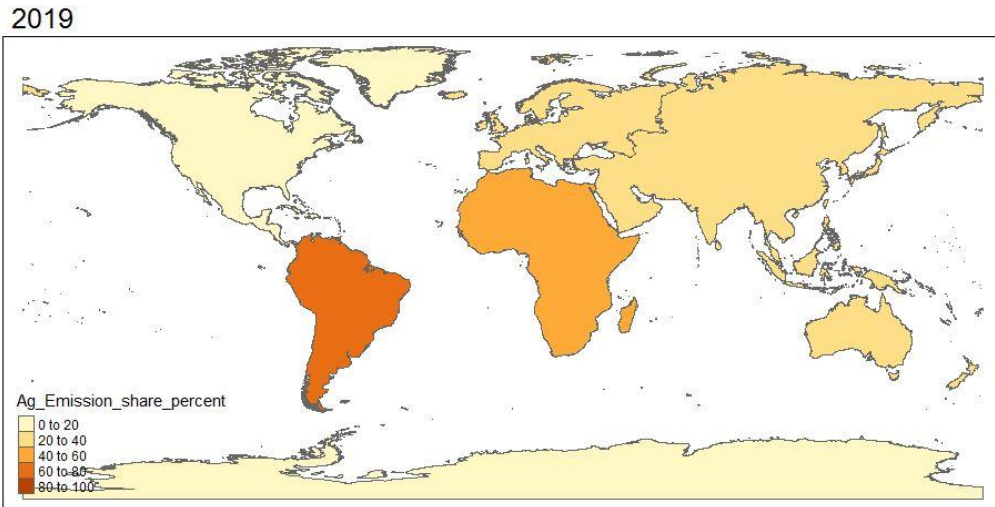

Fig. 2- Spatial variation of the share of agriculture in CO2-eq production in 2019 (The animated spatiotemporal map has been supplied as supplementary material)
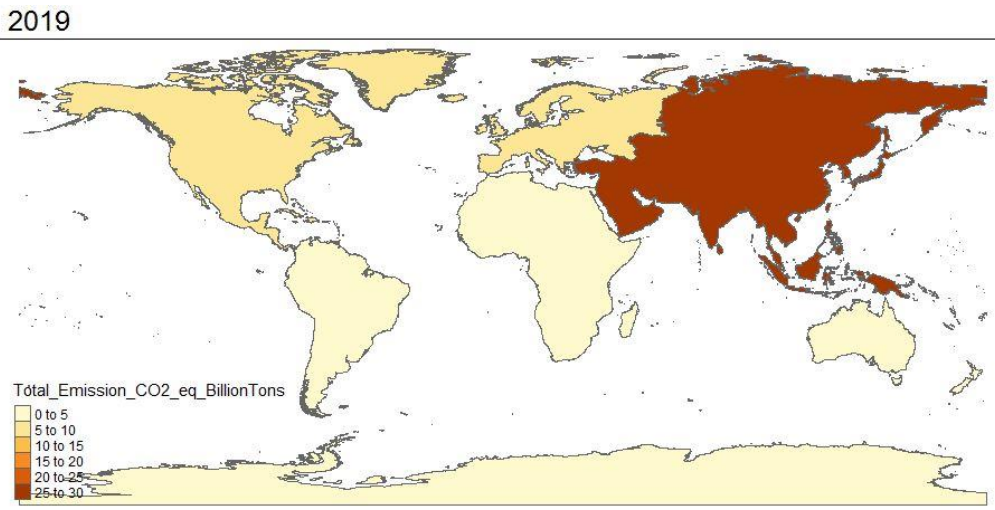

Fig. 3- Spatial variation of the contribution of continents in total CO_2-eq production in 2019 (The animated spatiotemporal map has been supplied as supplementary material)
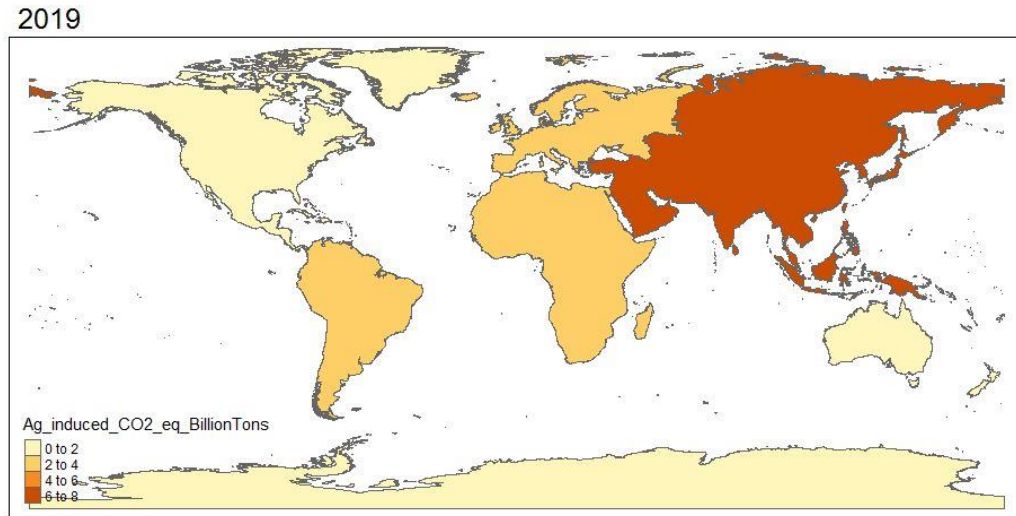
Fig. 4- Spatial variation of the contribution of continents in agriculture-induced CO$_2$-eq production in 2019 (The animated spatiotemporal map has been supplied as supplementary material)

The spatiotemporal map of the share of agriculture in CO$_2$-eq production shows that there is a decreasing trend of the share of agriculture in the total CO$_2$-eq produced from 1990 to 2019 (refer to the animated version of Fig. 2), while at the same time, the amount of agriculture-induced CO$_2$-eq has increased very gradually (Fig. 1). Grace et al. (2014) also reported that from 2000 to 2005 agriculture has been responsible for 7-14% of global CO$_2$ emissions. With a pessimistic approach, Sachs et al. (2010) showed that the food sector alone contributes about 35% of all greenhouse gas emissions through the processes of energy consumption, land-use change, methane release, and nitrous oxide emissions from fertile soils. Another point inferred from Fig. 2 is that the share of agriculture in CO$_2$-eq production of less-industrialized continents is higher than that of the industrialized ones; however, regarding Fig. 3, and its animated version, it is obvious that a very low portion of total global CO$_2$-eq is produced in less-industrialized continents. Moreover; the fluctuations of the amount of agriculture-induced CO$_2$-eq are specific to Asia and Europe, and other continents' fluctuations are almost zero (Refer to Fig. 4, and its animated version). This result is in agreement with the result of Verschuuren (2016), who reported that global emissions from agriculture have been rising yearly since 1990, although there are some differences between regions in this regard.

Another important point inferred from Fig. 3, and its animated version is the increasing trend of the role of Asia in CO$_2$-eq production. As shown, the temporal role of continents except Asia through the period of 1990 to 2019 is almost unchanged. The reason for this phenomenon may be the transfer of air pollutant industries from developed countries to Asian under-developed ones, because the labor wage in Asian countries is less than that of the developed countries, and this help to lower the production price of industrial goods. The concentration of more than half of the world's population in Asia can be another clue for this observation. Energy consumption habits of some oil-producing southwestern Asian countries can also contribute to the creation of this situation. Furthermore, Appiah et al. (2018) showed the existence of a positive correlation between agricultural production and the value of CO$_2$ emissions in the BRICS emerging economies. It should be noted that three out of five BRICS countries i.e. India, China, and 75% of Russia are located in Asia.

To summarize, spatiotemporal maps like these can help top decision-makers to correct their false decisions beforehand.

4. Conclusion

In this technical note, a methodology for the creation of spatiotemporal maps regarding the share of

agricultural activities performed in each of the world's continents in the production of CO_2-eq in the period between 1990 and 2019 using the capabilities of the R software was reported. Results were promising and spatial and temporal variability of CO_2-eq produced from agricultural activities as well as total CO_2-eq production in each of the world's continents were traced in the maps easily.

Due to the simplicity of the execution of procedures as well as the free availability of the R software, it seems that the software will obtain rapid popularity among environmentalists, as well as the specialists of other fields that require the analysis of spatial and time series data. It is strongly suggested that available spatiotemporal data are converted to spatiotemporal maps using the procedure discussed in this article in order to convey information to the interested audience in a visually attractive way. These maps can shed light on datasets containing large amounts of spatial and temporal data that are difficult to be managed without suitable conversion to an animated map.

Declarations

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Conflict of Interest /Competing interests (The author certifies that he has NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript).

Availability of Data and Material (Data are available when requested)

Consent to Publish (Author consents to publishing)

Authors Contributions (Not applicable, because this article has written by one author)

Code availability (Not applicable)

Appendix 1:

install.packages("sf")

install.packages("tmap")

install.packages("dplyr")

install.packages("gifski")

library(sf)

library(tmap)

setwd("C:/Users/...")   #Setting the address of the working directory
getwd()
newcol<-read.csv("newcol.csv")

Appendix 2:

continent<- st_read("World_Continents.shp")

Appendix 3:

library(dplyr)

modifyframe<-bind_rows(replicate(30, continent, simplify = FALSE))

Appendix 4:

finalframe<-cbind(modifyframe,newcol)

Appendix 5:

library(gifski)

agshare_anim<-tm_shape(finalframe)+tm_polygons(col="Ag_Emission_share_percent")+ tm_facets(along = "YEAR", free.coords = FALSE)

tmap_animation(agshare_anim, filename = "agshare _anim.gif", delay = 80)

total_anim<- tm_shape(finalframe)+tm_polygons(col="Total_Emission_CO2_eq_BillionTons")+tm_facets(along = "YEAR", free.coords = FALSE)

tmap_animation(total_anim, filename = "total _anim.gif", delay = 80)

agriculture_anim<tm_shape(finalframe)+tm_polygons(col="Ag_induced_CO2_eq_BillionTons) +tm_facets(along = "YEAR", free.coords = FALSE)

tmap _animation(agriculture_anim, filename = "agriculture _anim.gif", delay = 80)

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