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Greenhouse gas emissions and aerosol distribution in brick kiln zones of Punjab, Pakistan: an appraisal using spatial information technology

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Abstract

Greenhouse Gases (GHGs) and climate-altering air pollutants are damaging the ecosystem of earth. Hence, reducing gaseous emissions and air pollutants would help mitigate global warming and improve the low-carbon economy. Therefore, in this study, remote sensing datasets from the Goddard Earth Observing System, Atmospheric Infrared Sounder and Modern-Era Retrospective analysis for Research and Applications Version 2 are carried out to examine the seasonal trends of Carbon dioxide (CO2), Methane (CH4), Ozone (O3) and Aerosol Optical Depth (AOD) from 2016 to 2021 over brick kiln zones in Punjab, Pakistan. In this research, 2016 has been taken as the base year to compare the trends of GHGs and AOD in Punjab. Results of the study revealed that the highest concentration of AOD was exhibited in the winter seasons over Purple, Red and Orange Zones of brick kilns. Moreover, the highest extent of CO2, CH4 and AOD was observed in 2017. At the same time, O3 magnitude was evaluated as high during summer seasons which may be attributed to high temperature that leads to elevated formation of O3. Therefore, there is a dire need to undertake Nature Based Solutions (NBS) in the policymaking for the environmental development in Pakistan.

Keywords: Punjab-Pakistan, Nature Based Solutions (NBS), air pollution, brick kilns industry, ecosystem, air pollution, gaseous emissions, low carbon economy.

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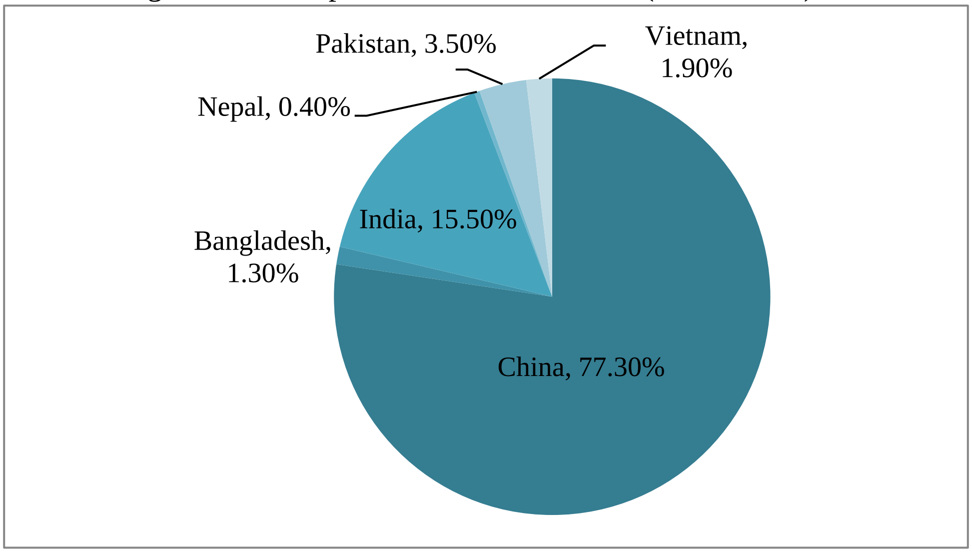
1. Introduction

Industrial expansion, economic development, population growth and migration of the population to urban areas have increased the demand and consumption of bricks (Gubic *et al.*, 2021; Chuma *et al.*, 2021). Brick industry is one of the traditional and ancient industries of the world and traces of evolution have been recorded 8300 years before Christ (BC) (Muzaffar, 2014; Uooj & Ahmad, 2017; Fiala *et al.*, 2019; Ghafoor *et al.*, 2022). Globally, the demand for bricks is growing to fulfil needs of the building materials for the housing sector (Mughal, 2019; Azhar & Qureshi, 2022). Parallel to this, South Asia is a major producer of bricks production due to fastest growing population and construction industry in China, India, Pakistan and Bangladesh (Seay *et al.*, 2021; Anwar *et al.*, 2021; Nawaz *et al.*, 2021; Asif *et al.*, 2021). In brick production, Pakistan has been ranked after India by contributing 3.50 % in economic development (Figure 1) through 20,000 brick kilns (Saeed, 2017; Ijaz *et al.*, 2020; Dasti, 2021).

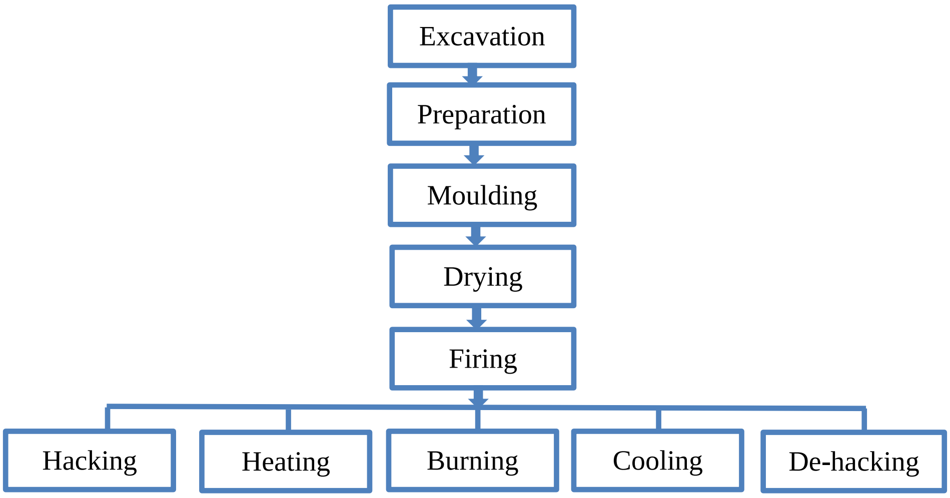
Figure 1: Bricks production in South Asia (Saeed, 2017)



Brick sector has a significant effect not only on the economy but also this sector is a source of Greenhouse Gases (GHGs) emissions as reported in China, India, Pakistan, Bangladesh and Nepal (Luby *et al.*, 2015; Chen *et al.*, 2017; Khan *et al.*, 2019; Saha *et al.*, 2021; Bhat & Gaga, 2022). The enormous air pollutants and gaseous emissions are discharged during different phases of brick manufacturing (Weyant *et al.*, 2014; Subhanullah *et al.*, 2022). Mainly, there are five stages of brick making where the firing phase is further subdivided into five steps (Skinder *et al.*, 2014; Aniyikaiye *et al.*, 2021) as presented in Figure 2. Whereas the highest mixture of GHGs is produced during the firing phase (Figure 3) of bricks baking process which is dependent on wood fuel and coal (Nepal *et al.*, 2019; Ali *et al.*, 2020; Joseph, 2021).

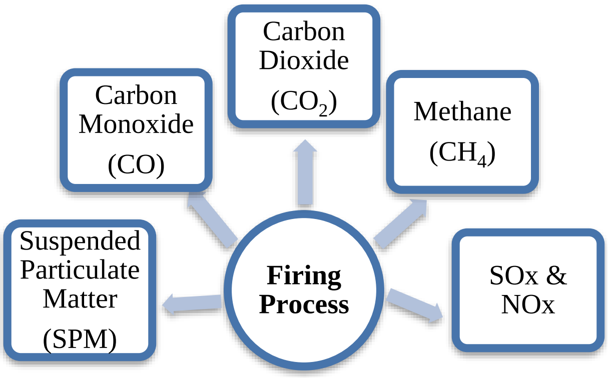
Basically, brick sector is a major consumer of wood fuel and coal. However, wood fuel is used to ignite the brick kilns. Preferred species of wood fuel are *Acacianilotia* (babul), *Dalbergiasissoo* (shisham) and *Zizyipusmauritiana* (ber) which are derived from provincial forests and obtained from the private sector and wood markets. Whereas, coal is obtained from District Chakwal, Khushab, Jhelum, Rawalpindi, Mianwali and other parts of the country. Consumption of wood fuel and use of lignite which is inferior quality coal are the major contributors in increasing the level of GHGs (Ullah *et al.*, 2018; Hossain *et al.*, 2019; Valdes *et al.*, 2020; Hamid *et al.*, 2022).

Figure 2: Bricks manufacturing phases



Moreover, stack emissions of brick kilns (Figure 3) such as carbon dioxide, carbon monoxide, sulfur dioxide, methane and Suspended Particulate Matter (SPM) emit during the firing phase and are among one of the causes of increasing air pollution and smog (Pramanik *et al.*, 2018; Pervaiz *et al.*, 2021b; Ali *et al.*, 2022).

Figure 3: Air emissions produced during firing process of brick making



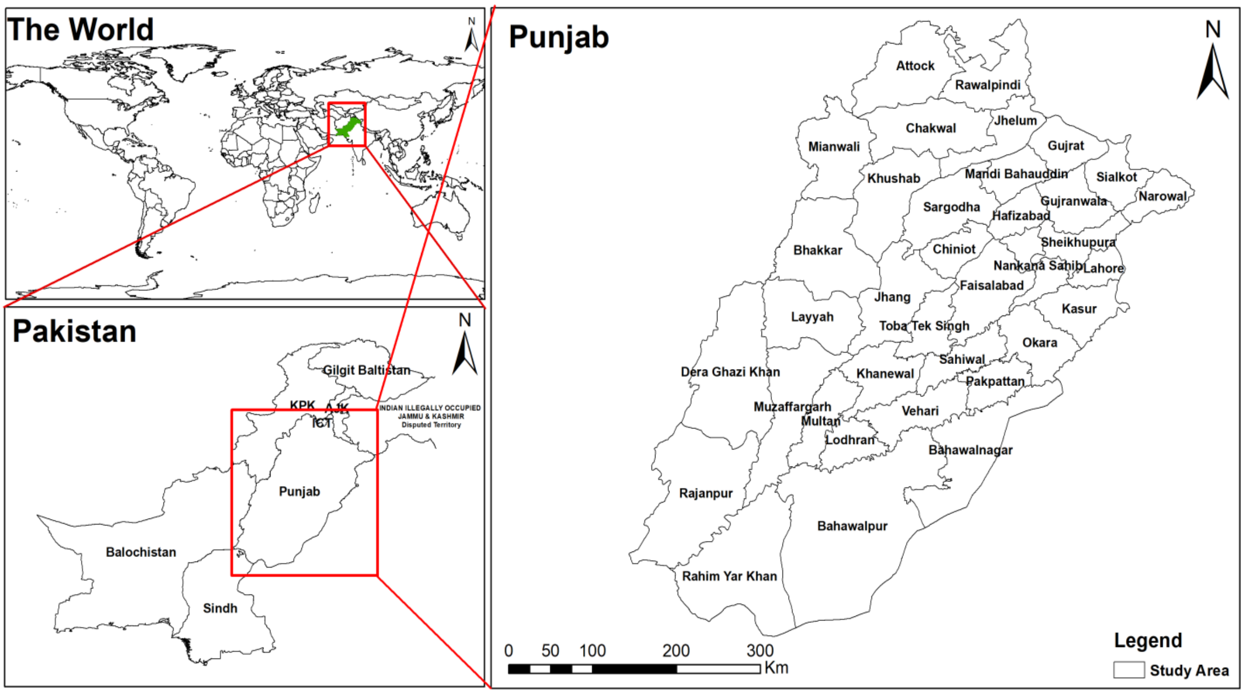
Therefore, the present research has been carried out to ascertain the air quality of Punjab, Pakistan by considering the above situation. The objectives of the present study are: (i) To provide a comprehensive view of brick kilns zones of Punjab, Pakistan, (ii) To investigate the trend and pattern of Greenhouse Gases (CO_2, CH_4, O_3) and Aerosol Optical Depth (AOD) during four seasons (winter, spring, summer, autumn) and (iii) To compare the trend of CO_2, CH_4 and O_3 and AOD of the years 2017, 2019 and 2021 with the base year 2016.

2. Research methodology

2.1. Site description

Punjab, province as shown in Figure 4 has been endowed with a significant and abundant wealth of natural resources and is well known for its prosperous river valley civilization (Islam *et al.*, 2022; Woo, 2023). The agricultural and industrial province is located at 27°42′ N to 34°02′ N latitudes and 69°81′ E to 75°23′ E longitudes and occupies an area of land around 205,344 km^2 (Khan & Khan, 2020; Hu *et al.*, 2021; Irfan *et al.*, 2022).

Figure 4: Map of the study site



2.2. Climate

Punjab has a sub-tropical climate characterized by four major seasons which are winter (December-February), spring (March-May) summer (June-August) and autumn (September-November) (Abbas *et al.*, 2017; Hussnain *et al.*, 2020; Javid *et al.*, 2020).

2.3. Data and methods

2.3.1. Satellite data

Monitoring emissions is one of the limitations of developing countries due to rudimentary infrastructure like Pakistan. Therefore, remote sensing tool has been used to analyze trends of CO_2, CH_4, O_3 and AOD (Wargan *et al.*, 2017; Ghosh *et al.*, 2019; Sun *et al.*, 2019; Cucho-Padin *et al.*, 2020; Razagui 2021) in winter, spring, summer and autumn seasons for the years 2016, 2017, 2019 and 2021 (Table-1). In addition, province specific information regarding brick kilns has been ascertained from Punjab Brick Kiln Census study (PBC, 2016).

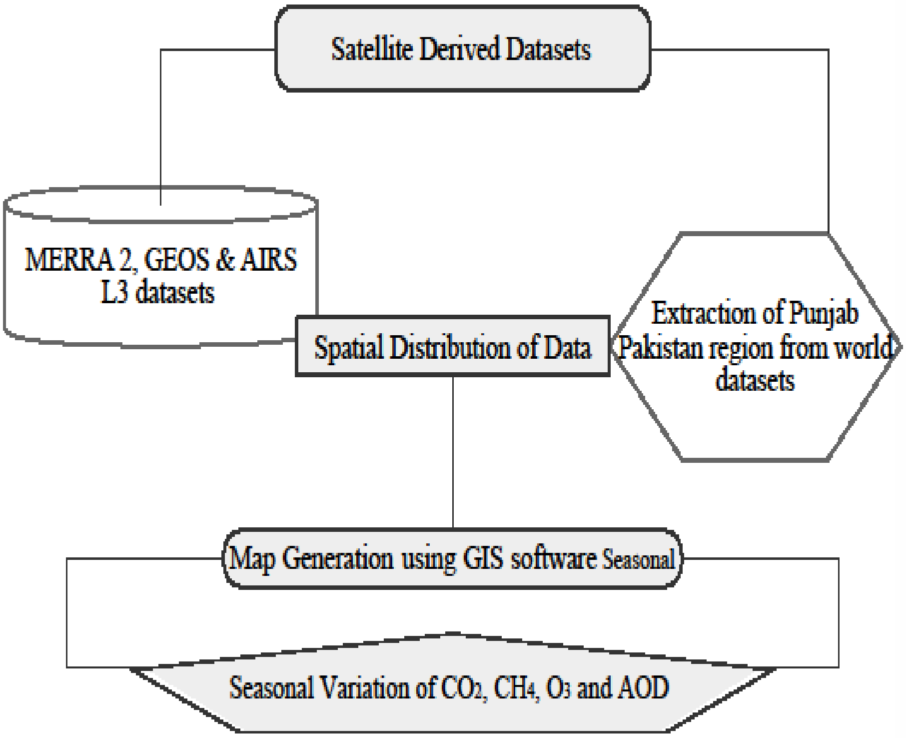
Table-1: Description of data

Data Set Name	Sensor	Spatial Resolution (km)	Data Acquisition Year	Seasons
CO_2	GEOS	0.5 x 0.625	2016, 2017, 2019 & 2021	winter, spring, summer & autumn
CH_4	AIRS	0.5 x 0.625	2016, 2017, 2019 & 2021	winter, spring, summer & autumn
O_3	MERRA 2	0.5 x 0.625	2016, 2017, 2019 & 2021	winter, spring, summer & autumn
AOD	MEERRA 2	0.5 x 0.625	2016, 2017, 2019 & 2021	winter, spring, summer & autumn

2.3.2. Geographic Information System (GIS)

In order to map the results (Figure 5), ArcGIS software was employed for data processing and analysis (Cetin, 2019; Tella & Balogun, 2021).

Figure 5: Schematic flowchart of the methodology



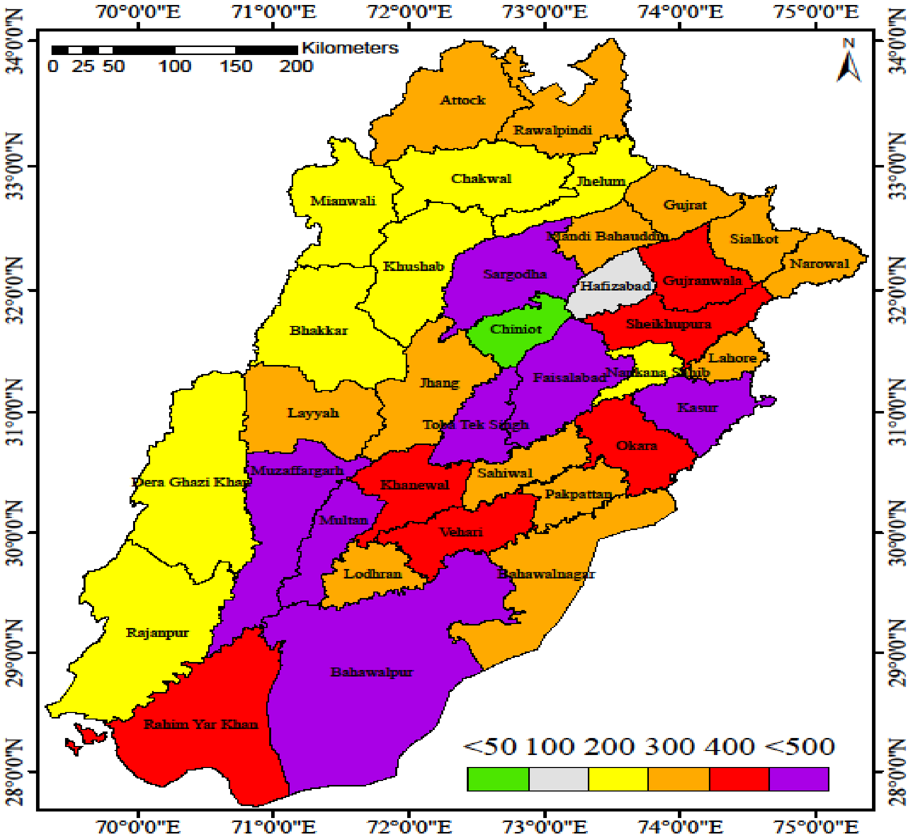
3. Results and discussion

3.1. Brick kilns zones in Punjab

Punjab is the largest hub in brick manufacturing having 10,347 brick kilns (David *et al.*, 2022). The brick manufacturing units are installed all over Punjab. While northern, southern and central regions of Punjab have the major zones of brick kilns (Figure 6). In the province, purple zones have the largest number of brick kilns based in District Bahawalpur, Kasur, Faisalabad, Muzaffagarh, Multan, Sargodha, and Toba Tek Singh. In the red zones, more than 400 brick kilns are set up in District Gujranwala, Khanewal, Okara, Rahim Yar Khan, Sheikhupura and Vehari. Orange zone consists of 13 dominant districts including Lahore which is also popular as the city of gardens (Pervaiz *et al.*, 2018). Whereas, less than 100 brick kilns are located in Hafizabad i.e., grey zone. While in the green zone, least number of brick units have been established in the District Chiniot (Pervaiz *et al*., 2021a).

In Punjab, brick kilns have been preferred to establish or install in the vicinity of agricultural land, rural peri-urban and urban areas due to the availability of raw materials and extensive labour resources (Iqbal, 2006; Shahzad & Ali, 2018; Khalid, 2019; Ahmad *et al.*, 2022). In spite of the significant contribution to the country's GDP the brick industry of Punjab has remained unrecognized and considered an informal industry (Iqbal, 2006; Sakhani *et al.*, 2021; Abbas *et al.*, 2022), due to two main reasons: (1) based on seasons which starts operation from October to March and winter is preferred by the manufacturer, and (2) most of the brick kilns prefer to be established on the leased land (De Lauri, 2017; Sarwar *et al.*, 2019; Ijaz *et al.*, 2020; Ahmad *et al.*, 2022).

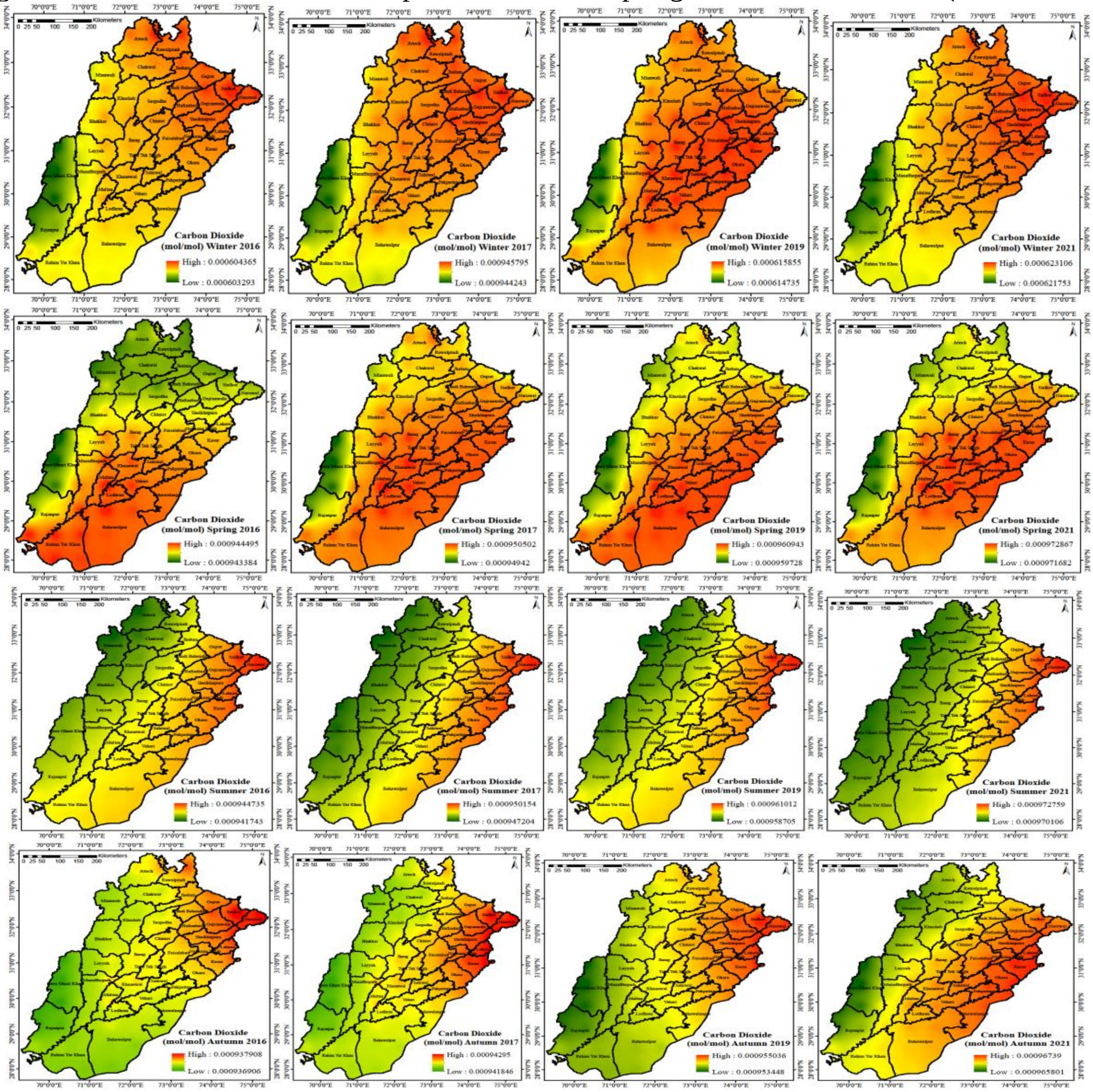
Figure 6: Brick kilns zones in Punjab



3.2. CO_2 trend and distribution pattern in Punjab

CO_2 is one of the greenhouse gases contributing to global warming (Liu *et al.*, 2018; Yoro & Daramola, 2020). Results of Figure 7 exhibited the trend and distribution pattern of CO_2 in Punjab's atmosphere from 2016 to 2021. Concomitantly, in the province the level of CO_2 emissions varies among different districts in winter, spring, summer and autumn seasons. Further, the seasonal pattern of CO_2 was found high from north to east and central belt of the province in the winter and autumn seasons which shifted to south-east in 2021. Comparing spatial results of the spring season, CO_2 had been found high in 2017 whereas this highest trend shifted towards south-east during 2019 and 2021. Nevertheless, purple, red and orange zones of the brick kilns have been evaluated with high magnitude of CO_2 in winter season as winter season is favourable and a known season for brick making (Pervaiz *et al.*, 2022). In addition, the highest trend of CO_2 concentration during the autumn season may be attributed to stubble burning in Punjab and low wind speed is a potential factor in increasing the extent of CO_2 in the atmosphere. A similar trend of CO_2 was observed by An *et al.* (2022) which supported the results of the present study. However, CO_2 concentration in the summer season has been shown at low level as summer is much rainier than the winter season and a similar finding has been reported in the earlier study of Saha *et al.* (2021).

Figure 7: CO_2 trend and distribution pattern in winter, spring, summer and autumn (2016 to 2021)

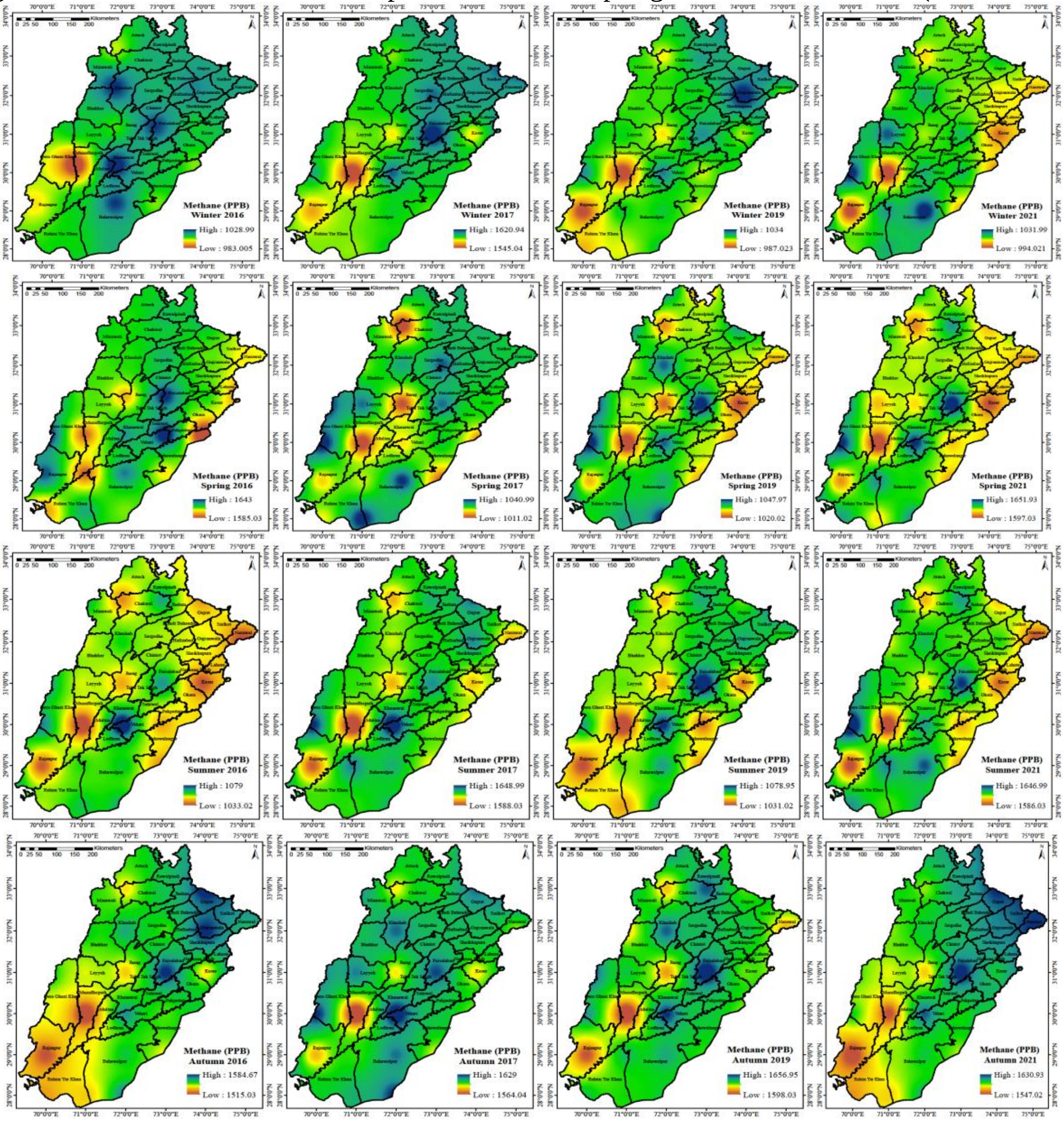


3.3. CH_4 trend and distribution pattern in Punjab

CH_4 emissions is a key challenge for Pakistan which is associated with combustion of fossil fuels, landfill wastes, livestock farming, rice cultivation, biomass burning (Mahmood *et al.*, 2016; Ilmas *et al.*, 2018)) and waste incineration. Hence, seasonal fluxes of methane (Singh *et al.*, 2000) vary all around Punjab during four seasons due to informal industry i.e., brick kilns. The spatial results of Figure 8 showed that level of CH_4 has been high in almost all brick kilns zones of Punjab in the winter and autumn seasons whereas the concentration of CH_4 was found at a low level in District Rajanpur where the least formal industries have been established. In the spring season, the trend of methane reduced from northern to eastern Punjab and recorded at a low range in 2021. Whereas the highest level of methane was exhibited in 2017. However, the comparative analysis of methane amongst four seasons shows that methane has been noticed at the lower level during the base year i.e., 2016 in the summer season which raised in

2017 and may be attributed to paddy fields as one of the sources to generate methane. Further, in the winter season, methane level increased in various districts during 2016, 2017 and 2019 due to combustion of fossil fuels and biomass burning. Similarly, the earlier study conducted by Mahmood *et al.* (2016), represented a high level of methane in the industrial areas.

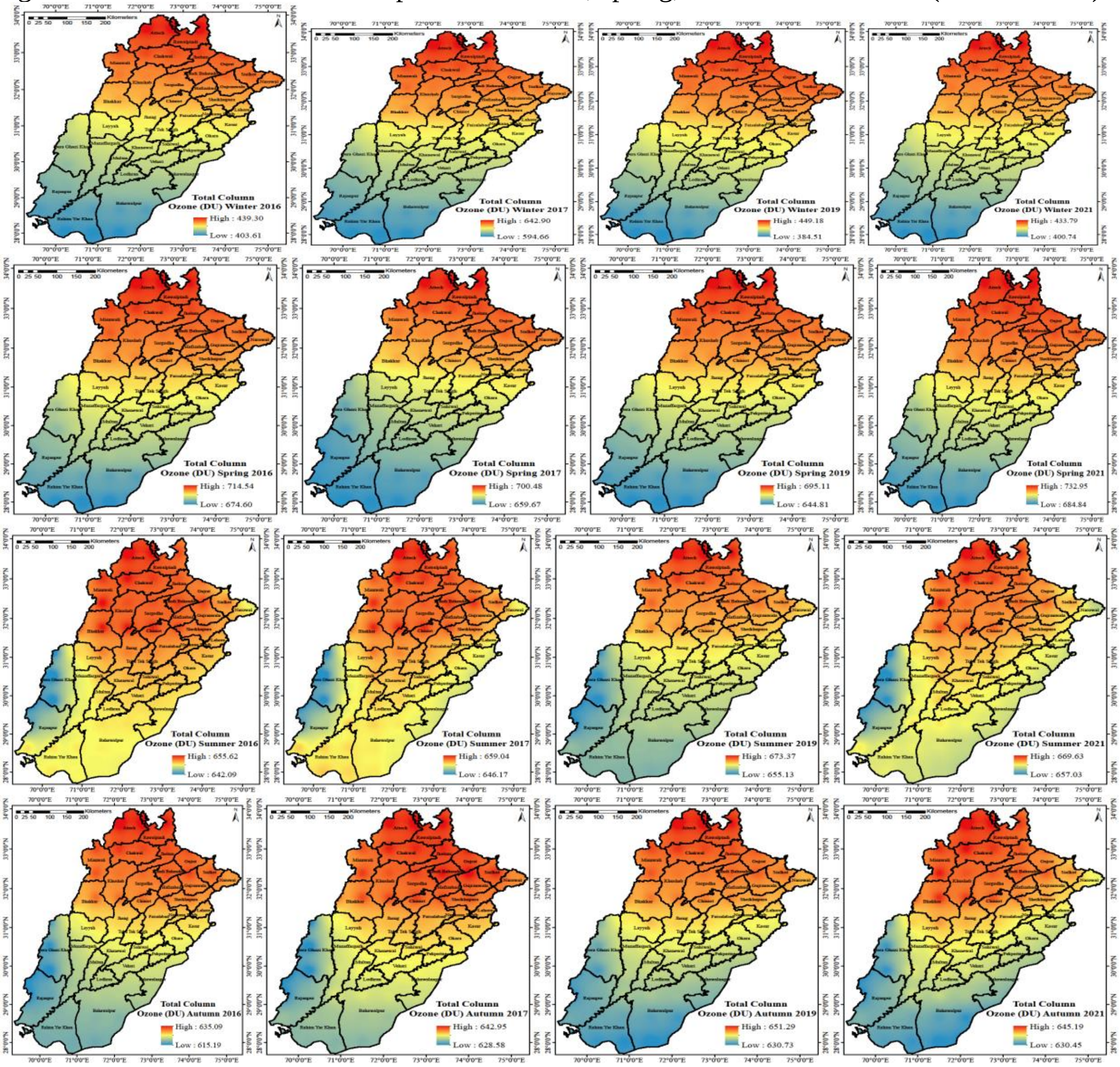
Figure 8: CH_4 trend and distribution pattern in winter, spring, summer and autumn (2016 to 2021)



3.4. O_3 trend and distribution pattern in Punjab

Seasonal variability of O_3 concentration (Yang *et al.*, 2019) has been visualized in the northern and north-eastern parts of Punjab during all seasons. The highest concentration of O_3 was examined over red, purple and orange zones of brick kilns. The extent of O_3 concentration was observed similar in the spring and autumn seasons. In the summer, O_3 concentration level was increased due to sunny days which elevated the magnitude of O_3 in 2017 and 2021 and similar results documented in the previous studies of Elampari *et al*. (2010), Li *et al.* (2020) and Munir and Khayyam (2022). On analyzing spatial results, it has been observed that in northern parts of Punjab, the intensity of O_3 level was high and supported findings of the study conducted by Pervaiz *et al*. (2022).

Figure 9: O_3 trend and distribution pattern in winter, spring, summer and autumn (2016 to 2021)

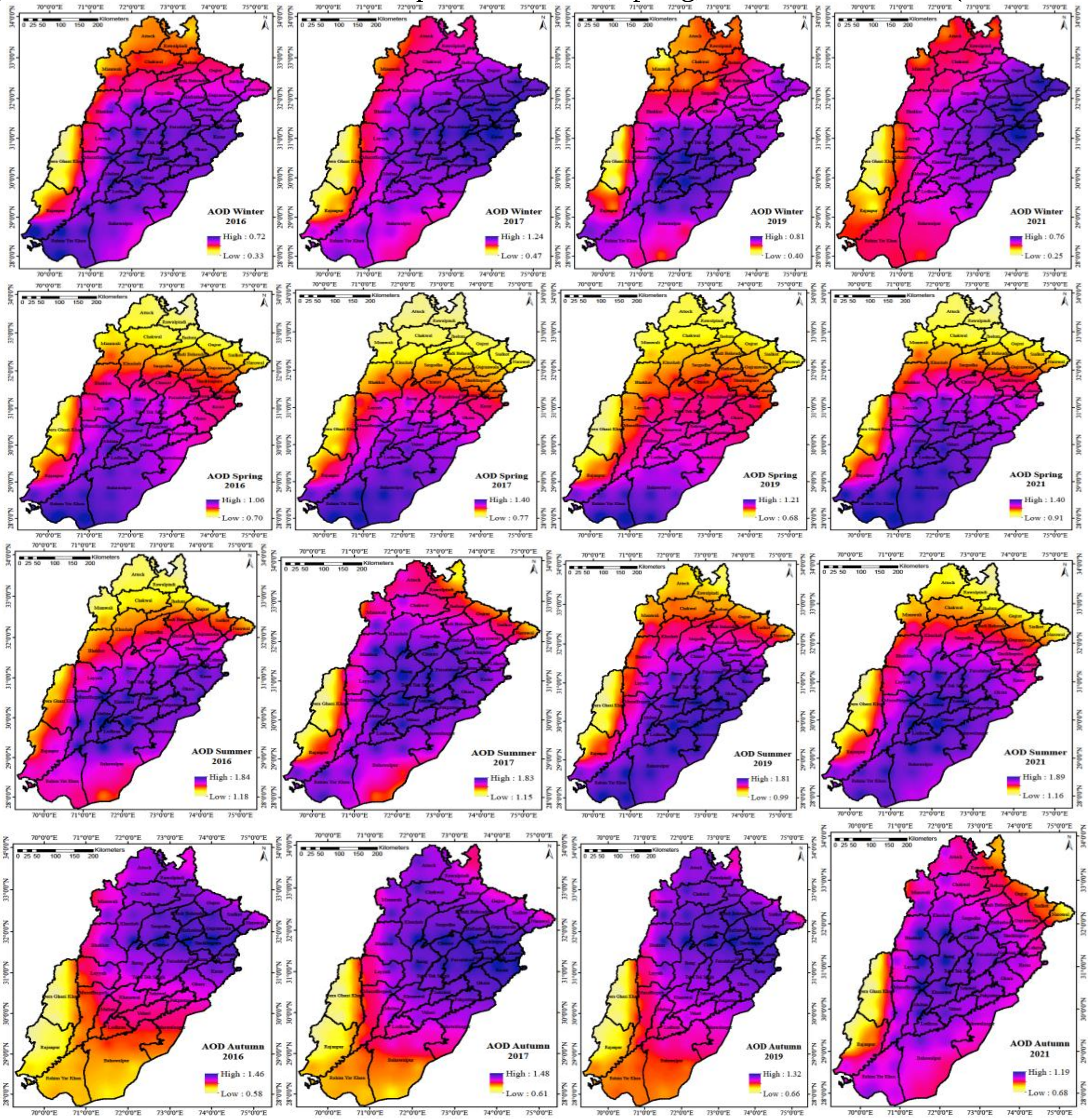


3.5. AOD trend and distribution pattern in Punjab

Figure 10 results exhibited the highest concentration of AOD in all brick kilns zones of Punjab. On the comparison of seasonal trends from 2016 to 2021, the highest concentration of AOD was recorded during winter seasons. Similarly, high magnitude of AOD was recorded in the northern, eastern and central parts of Punjab during autumn. In the spring, trend of AOD has been shifted from northern parts to eastern, central to southern parts of the province from 2016 to 2021. Similarly in summer, the extent of AOD increased due to bricks making season and substantial amount of agricultural land left uncultivated after harvesting of wheat crop during May and June. As a result, the level of AOD got escalated in the hot and windy summer season due to a huge number of fumes released in the air from stacks (Elampari *et al.*, 2010) and crop waste burning and similar results were reported in the study of Ali *et al.* (2014). Moreover, in the summer, peak values of AOD have also been attributed to the densely populated areas

(Tariq *et al.*, 2015) and purple, red, orange and yellow zones of brick kilns where highest numbers of brick furnaces have also been reported in the literature viz. Pervaiz *et al.* (2022). Further, during winter 2016 and in autumn 2021, the concentration of AOD raised due to shortage of rainfall and similar finding has also been investigated in the previous study of Biswas *et al.* (2008). Study of Tariq *et al.* (2021) also support that varied metrological conditions help to exceed the level of AOD.

Figure 10: AOD trend and distribution pattern in winter, spring, summer and autumn (2016 to 2021)



4. Conclusion and recommendations

The current research presented the spatial trends of CO_2, CH_4, O_3 and AOD in Punjab over brick kiln zones. By evaluating and comparing 2016-2021 data, it was noticed that highest concentration of CO_2 and CH_4 was observed in the winter seasons from 2016 to 2021 in Punjab. Further, O_3 was observed highest in the summer season and constant trends of O_3 were exhibited from 2016 to 2021 in the winter, spring and autumn. Whereas, AOD concentration was found high in the southern region of the province where aerosols are not only emitting from informal industry and anthropogenic sources but are also being transported from Thar Desert. Crop waste burning is one of the major contributing factors in increasing the value of AOD in Punjab during winter season. So, high values of GHGs and AOD are not only dependent on stack emissions of brick kilns but are also based on different industrial set ups, open waste burnings, populated residential areas and high traffic density roads. Hence, there is a dire need to adopt proactive approach to mitigate environmental challenges.

For the industrial areas to plant suitable trees such as *Azadirchta indica* (Neem), *Cassia fistula* (Indian Laburnum), *Ficus religiosa* (Pipal) and *Lagerstroemia indica* (Temple Tree) to overcome the rising CO_2 and AOD challenges and achieve economic and environmental benefits. Development of green belts around brick kilns zones is also one of the viable Nature Based Solution (NBS) to mitigate fugitive dust. In order to mitigate airborne pollutants, mechanical feeding of 10 mm size of pulverized coal in brick kilns may also facilitate better fuel combustion and release lesser air emissions. In addition, by adopting advanced cleaner technology i.e., vertical shaft brick kilns for brick making will help to improve the quality of the environment. Up-gradation of industrial processes to improve the combustion process, use of low sulphur content fuel, installation of air pollution control devices to mitigate emissions such as scrubbers and electrostatic precipitators before they emit into the air may also be helpful. In addition, nitrogen-based fertilizer should be discouraged in the cropping system and renewable energy should be promoted by providing subsidies to the consumers.

Declaration of conflict of interest

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