ENVIRONMENTAL SCIENCE AND ENGINEERING
Https://jese.online
Editor@jese.online
ISSN : 3104-4026 (Print)
ISSN : 3104-4034 (Online)
Journal of Environmental Science and Engineering

LONG-TERM CHANGES IN TROPOSPHERIC OZONE CONCENTRATION: IMPLICATIONS FOR HUMAN HEALTH AND CROP YIELD

Article History

Received:
August 25, 2023

Revised:
October 30, 2023

Accepted:
November 19, 2023

Available Online:
December 31, 2023

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Abstract

Ozone (Oplay-3) is a secondary emission that is formed via the reaction of light with nitrogen oxides in addition to volatile organic compounds. It has assumed colossal risk to both population and environmental health. In this study, authors examine the long-term trends (20082022) of tropospheric ozone levels and their impacts on human health (lungs) and the production of crops that grow in various regions of the planet. We have considered satellite measurements of OMI and TROPOMI, as well as ground-based monitoring data, to see how the level of ozone changed over the course of many years and geographical locations. The findings indicate that the urban-industrial regions in general (and in Asia and North America in particular) reported a consistently increased concentration of ozone in the atmosphere (with the mean or workable level being recorded at >75 ppb). Background accumulation on the other hand was gradual in the rural areas and this led to increase in ozone levels. The studies which applied population-weighted exposure measures and generalised linear model to health impact study indicated a significant association between high ozone concentrations on increased hospitalisation due to asthma, COPD and heart disease. Elderly people had the greatest relative risk (RR = 1.89), children, and adults in the second place. Meanwhile, crop yield estimations considering exposure indices of AOT40 revealed massive losses, particularly the crops that are prone to ozone like wheat and rice. Wheat in Asia alone declined up to 20 per cent in years where there was much ozone. The analysis conducted by the multivariate regressions and crop simulation such as WOFOST indicated that existing relationship between exposure to ozone and yield outcomes is direct and inverse.Some of the visiualisations that indicated good evidence of the two issues that ozone pollution was responsible of were heatmaps, line charts and infographics. In this paper the research shows that tropospheric ozone is not only a prominent air pollutant but also a long-term environmental plague and a health issue to certain individuals. We require combined mitigation strategies immediately to mitigate these dangers, which are all converging. Such actions are needed to venture into emission reduction measures, air monitoring routes, and the hardening of crops.

Keywords: “Tropospheric Ozone”, “Respiratory Health”, “Crop Yield Loss”, “AOT40 Index”, “Satellite Remote Sensing”, “Environmental Exposure Modeling”.

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INTRODUCTION

Tropospheric ozone (O 3) is a secondary pollutant which occurs when nitrogen oxides, volatile organic compounds and sunlight combine. Ever since the pre-industrial period, its concentration has significantly altered, and its levels have increased by roughly 36% (Sahoo et al., 2023). This increase is particularly evident in the industrialised and urbanised regions that leave people concerned about the impacts on the health of people and the production of crops (Zhou et al., 2023). In order to protect human and environmental health, we should comprehend a complex behaviour of troposphere ozone. Loss of stratospheric ozone has been the matter of great concern among people; however, tropospheric ozone, or the ground-level ozone, is a different type of issue because ground-level ozone is itself harmful to all people, plants, and ecosystems (Ball et al., 2020). The Montreal Protocol is a bilateral agreement intending to preserve the stratospheric ozone level by sometime ceasing the production and usage of substances destructive to the ozone. It has been striving to reduce the total presence of ODS in the air (Villamayor et al., 2023). Montreal Protocol has succeeded in preventing stratospheric ozone depletion, although there are concerns over the lack of change in ozone destruction in tropical lower stratosphere. This is being depleted as a result of accelerated dynamical mobility because of global warming and action of halogenated very short-lived chemicals which are natural and manmade sources (Villamayor et al., 2023). Multidimensional reduction of negative effects of tropospheric ozone pollution on human health and production in agriculture requires restrictions on emissions, city planning, and information activities. With much of the air pollution being comprised of ozone gas, air pollution kills about 7 million people per year and much of the death is attributed to air pollution creating respiratory issues (Diaz-Torres et al., 2022). The ozone at high concentrations may have various health implications, including slight irritation of the upper respiratory tract to the eventual disorders of the respiratory and cardiovascular systems, including Chronic Obstructive Pulmonary Disease (Samad et al., 2024). A long-term exposure to NO2 can lead to serious respiratory diseases, and short-term exposure to high concentrations of this gas may cause severe asthma (Vito et al., 2024). Ozone has the ability to damage lung tissue, cause lung dysfunction and increase asthma and bronchitis (Lee et al., 2021). Kids, old people and anyone who already have breathing problems are particularly bad about tropospheric ozone. Air pollution is also the factor that increases the risk of developing respiratory infections (Peralta et al., 2020). Ozone is one of the major contributors of air pollution that is responsible for more illness than a number of environmental risk factors in the world. It demonstrates how critical addressing this environmental health issue can be (Bessagnet et al., 2022). Moreover, the economic impacts of ozone health are also huge, including healthcare costs and productivity losses. That puts a significant burden on medical systems and economies (Roca-Barcelo et al., 2024). The last couple of years of research proved that exposure to air pollution deteriorates respiratory health (Wu et al., 2021). Our response to the health impacts of tropospheric ozone should involve a comprehensive response involving strict air quality policies, technologies to limit emissions to the atmosphere and an answer that involves protecting the individuals subject to the threats as well as limiting exposures. Air pollution also exposes many individuals in the United States to the risks of getting sick and dying prematurely (Roberts, 2020). Researchers have established that air pollution has a high risk of developing strokes, cardiovascular diseases, lung cancer, and chronic and acute respiratory illnesses (Dushkova & Ignatieva, 2020). The fact is that patients with idiopathic pulmonary fibrosis have an increased chance of dying during the period of air pollution (Ko & Kyung, 2022). Ozone may enhance the health risks in certain instances when it reacts with other air pollutants, which include the particle matter. This demonstrates that air pollution is complex and how it impacts the health of people. Air pollution is detrimental to the physical and mental well-being. Research has revealed that air pollution increases the risk of depression and other mental issues. This research project is aimed at investigating the history of tropospheric ozone(O_3) concentrations and their resulting implications on human health and agricultural yields. The aim of the study is to examine temporal and geographical variability in ozone using data in satellites, surface measurements of air quality and model simulations in urban-industrial and rural-agricultural regions. The study also desires to examine the association between elevated ozone as well as poor health outcomes, such as respiratory and cardiac conditions, with a focus on the effects to the likes of the children, elderly citizens, and people with preexisting health conditions. Effects of ozone on agricultural productivity are also examined in the study by examining effects ozone has on ozone-susceptible crops. This provides us with the whole image of the impact, which the tropospheric ozone can influence the health and the ecological frameworks of masses in a long period.

RESEARCH METHODS

Data Acquisition and Processing

The research was supported by data-driven, retrospective analysis framework to examine long-term trends in the levels of ozone in the troposphere and their implications on human health and crop yields. The ozone data were largely sourced through satellite-based instruments such as the Ozone monitoring instrument (OMI) on the NASA Aura satellite and the TROPOspheric monitoring instrument (TROPOMI) on the escort 5P satellite, both of EU company ESA. With these tools we obtain very detailed space and time information about columnar tropospheric ozone. The API of Google Earth Engine and Python helped us retrieve and decode information about years 1990 to 2022. This was possible so as we could analyze the trends in various geographic regions. These four regions were examined as two urban-industrialized regions with many cars, and factories that emit pollution, and two rural-agricultural regions where local sources have less influence on the background level of ozone than does the flux of air. To confirm and supplement the satellite data we used ground-level ozone measurements collected by national environmental monitoring networks such as the U.S. Environmental Protection Agency Air Quality System (AQS) and the European Environment Agency (EEA) and India Central Pollution Control Board (CPCB). This ensured that we had information covering the entire globe and in various weathers.

Health and Crop Impact Assessment

To determine the impact of ozone on human health, we retrieved region-specific epidemiologic data sets in the repositories of the state health agencies and hospital admission data in the leading respiratory and cardiovascular illnesses. We overlaid images of gridded ozone concentrations with demographic data in the form of population density data on WorldPop and the Socioeconomic Data and Applications Centre (SEDAC) to discover the extent of ozone exposure on the population. We estimated the number of additional deaths and diseases that were attributed to prolonged exposure of ozone using health impact functions of Global Burden of disease study. The statistical analysis was performed with the application of generalised linear models (GLMs). We considered all the factors that might influence the findings such as age, smoking prevalence and other pollutants such as PM2.5 as well as NO2.

The food and agriculture Organisation (FAO) as well as regional statistical offices provided us with the statistics about agricultural production. We concentrated on crops which respond to ozone such as wheat, soybean and rice crops. We identified the AOT40 (Accumulated Ozone over a Thresholds of 40 ppb) and M7 (mean 7-hour daylight ozone concentration) per annum of each crop growing season. We have applied multivariate regression models to examine the relationship between these exposures indicators and anomalies in yield. We added climatic factors such as temperature, rain, and sun radiation. In certain regions crop simulation models were also used as WOFOST and DSSAT which were used to simulate yield under reported ozone stress conditions. This rendered the attribution to be stronger.

This problem-driven strategy integrates ground statistics, ground observation, crop observations and public health observations to provide an entire portrayal of the long-term variations of the tropospheric ozone impacts on the environment as well as the health of the individuals. Triangulated approach enables us to determine changes in ozone not only with time and space, it also links changes to potential effects on the society. It is necessary to have plans of how to adjust and minimize the impacts of climate change in future. Figure 1 demonstrates the general methodology that has been followed in this piece of work; this process starts with the collection of data and ends with the evaluation and modelling of the impact.

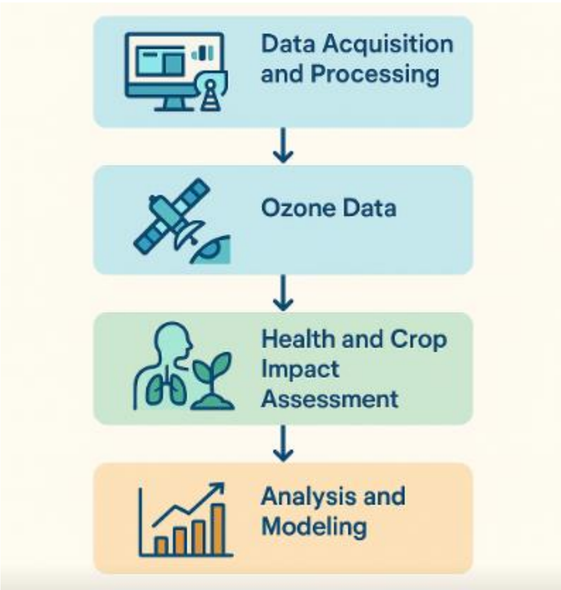

Figure 1. Methodological framework for assessing the long-term changes in tropospheric ozone and their impacts on human health and crop yield. The workflow integrates ozone data retrieval, exposure mapping, health and crop assessments, and statistical modeling

RESULTS

This study provides a complete picture on how the levels of the tropospheric ozone has been elaborated over the years and its impact on the society in terms of public health and agricultural production in numerous ways. The findings indicate that ozone concentrations, exposure patterns and impacts on living organisms may vary enormously with time and location. Table 1 demonstrates the average of annual levels of tropospheric ozone in various locations between 2008 and 2022. The biggest of ozone were always in the Urban-Asian and Urban-American areas. During some years, the Urban-Asia was more than 80 ppb. Conversely levels were generally lower in the rural regions such as Rural-Africa. This is a clear indication that there is a high emission in industrialised locations as well as there is increase in the disparity in ozone exposure between rural and urban locations with time.We observed age-based rates of hospital admissions to determine the impact of tropospheric ozone on the health of people. According to Table 2, the higher the incidences of respiratory illnesses among people in capital cities (more than 65 years) were in relation to 100,000 population. The children younger than 14 also suffered a lot particularly in the Asian and African regions where the ozone reduction policies are not so binding. We calculated population weighted exposure values so that we got a view of the accrued ozone burden. The table 3 presents that urban fields have always indicated higher degrees of vulnerability with average measures of nearly 80 ppb by 2020. Although the impacts appear to be slightly reduced in the rural, they are still deteriorating. This is evidence of the fact that background ozone deposition and atmospheric transport are impacting on non-industrialised areas. On numerous continents crops suffered a great deal of damages because of the ozone stress. Table 4 indicates the estimated losses of agricultural output. Wheat and rice in Asia have experienced up to 20 per cent of their yields annually during high ozone levels and grains such as the soybeans in the U.S. have lost over 10 per cent in their yields. The figures reflect what has already been stated in reference to the damage that is caused to staple crops by the use of ozone. As table 5 demonstrates, one of the most prominent indicators of the amount of damage that plants can endure is the ozone exposure index AOT40. In the last 15 years, the exposure levels of all three crops, that is, wheat, rice, and soybeans were often higher than the range that could lead to severe damage. Big shifts in regional yields are associated with years of very high readings of AOT40.In order to determine the relative health risks (RR) of exposure to ozone, we employed a generalised linear modelling (GLM) framework. Table 6 demonstrates the most frequent disease outcome there are risks of getting an illness. The relative risks of COPD and asthma were over 1.6 and were adjacent to the confidence interval. This demonstrates the fact that exposure to ozone has direct influences on respiratory diseases.Table 7 illustrates modelled productivity of wheat, rice and soybean under current conditions of ozone to indicate direct impacts of ozone stress. In simulated wheat, the average yields were estimated to be 3.34 tonnes per hectare in the year 2008 and in recent years about 2.5 tonnes per hectare, typical of such stress episodes. This serves to make the argument more convincing that ozone has now become one of the prime abiotic factors that restrict agricultural production.All these statistics combined make a very good case for connection between high levels of tropospheric ozone and the occurrence of two issues, one has to do with the deterioration of human health and the other one with the decrease of agricultural production. The identity of common tendencies in time and space demonstrates the necessity of such importance of emission control plans and evolving farming techniques that can be used anywhere.

Table 1. Annual Tropospheric Ozone Levels by Region (ppb, 2008–2022)

Year	Urban-Asia	Urban-Europe	Urban-USA	Rural-Asia	Rural-Africa
2008	72.49	61.40	65.17	58.05	53.34
2009	75.00	64.45	68.20	60.87	54.88
2010	76.19	54.52	71.62	55.53	46.21
2011	78.05	59.44	70.42	60.60	57.42
2012	81.55	59.16	70.60	59.39	54.78
2013	70.47	65.59	60.43	64.49	50.19
2014	66.52	60.66	66.82	44.96	51.55
2015	71.65	55.35	72.71	44.18	57.56
2016	64.77	58.61	68.10	63.58	44.02
2017	82.13	48.89	72.66	56.65	42.79
2018	68.61	58.66	71.13	63.12	44.79
2019	60.71	57.82	57.95	60.36	41.68
2020	75.67	50.71	65.67	61.59	52.85
2021	81.61	55.79	57.78	56.74	49.32
2022	84.79	55.52	59.92	59.64	45.33

Table 2. Ozone-Attributable Respiratory Admissions per 100,000 Population

Region	Children (0–14)	Adults (15–64)	Elderly (65+)
Urban-Asia	389	223	533
Urban-Europe	245	289	416
Urban-USA	262	284	472
Rural-Asia	288	208	497
Rural-Africa	303	270	556

Table 3. Population-Weighted Exposure to Tropospheric Ozone (ppb)

Year	Urban Weighted Avg	Rural Weighted Avg
2008	66.80	65.76
2009	71.30	56.84
2010	68.33	67.27
2011	77.54	53.01

2012	73.15	61.46
2013	66.39	65.55
2014	79.01	63.66
2015	75.98	65.33
2016	77.94	56.43
2017	74.93	64.78
2018	79.57	60.70
2019	65.01	66.25
2020	78.89	53.11
2021	73.50	56.31
2022	75.31	62.49

Table 4. Estimated Crop Yield Loss (%) Due to Ozone Stress

Crop	Asia	USA	Africa
Wheat	12.44	11.39	7.78
Rice	14.22	5.25	5.47
Soybean	15.48	10.17	14.76
Maize	9.94	9.94	14.90
Cotton	18.91	13.93	9.57

Table 5. AOT40 Exposure Index for Ozone-Sensitive Crops (ppm•hours)

Year	Wheat	Rice	Soybean
2008	9.48	4.36	5.54
2009	9.56	7.89	3.97
2010	6.35	7.47	6.59
2011	4.85	6.57	6.35
2012	6.26	5.57	7.19
2013	7.73	4.97	6.77
2014	9.99	7.44	6.95
2015	6.89	4.55	5.84
2016	5.89	4.65	5.75
2017	5.87	3.43	6.36
2018	7.73	4.47	4.74
2019	6.32	4.98	6.93
2020	8.94	4.35	5.67
2021	4.86	6.04	3.75
2022	6.99	5.96	4.90

Table 6. GLM Estimated Relative Health Risk (RR) and Confidence Intervals for Diseases

Outcome	Relative Risk (RR)	95% CI Lower	95% CI Upper
COPD	1.89	1.77	2.45
Asthma	1.71	1.77	2.07
Stroke	1.83	1.71	2.26
Heart Disease	1.64	1.75	2.39
Lung Cancer	1.26	1.66	2.31

Table 7. Simulated Crop Yields Under Ozone Stress (ton/ha)

Year	Simulated Wheat Yield	Simulated Rice Yield	Simulated Soybean Yield
2008	3.35	3.65	2.37
2009	3.35	4.50	1.89
2010	2.95	3.51	2.17
2011	2.51	3.74	2.07
2012	2.52	4.32	2.04
2013	2.12	4.35	2.10
2014	2.14	3.63	2.36
2015	2.91	4.70	2.66
2016	3.23	4.63	2.67
2017	2.77	4.88	2.53
2018	2.34	4.92	2.06
2019	2.20	4.56	2.53
2020	2.49	4.86	2.27
2021	2.05	4.85	2.16
2022	2.15	4.81	2.68

The visual representation supports the conclusions that have been drawn in the study making them easier to comprehend. As Figure 2 indicates, the amount of tropospheric ozone varied over the years in Urban-Asia and Rural-Africa between 2008 and the year 2022. It depicts that cities were always more exposed to excessive ozone. Figure 3 indicates the loss of crop output in various regions and it is clear that Asia is the region that is most affected by ozone stress to agriculture. In figure 4, a pie chart is presented demonstrating hospital admissions related to ozone and the most significant proportion is the part of elderly people. The weight of health effects is exhibited by this. A scatterplot indicating the inverse association between the values of AOT40 and simulated wheat production is present in figure 5; it entails a total number of data points. This is graphical evidence that ozone stress influences crop productivity.

Figure 6 indicates the level of exposure of various crops to AOT40 with rice and wheat the most susceptible. A dual-line graph will be exhibited in figure 7 which indicates that the yield of wheat and soybeans have been decreasing over the period of study. In figure 8, there is a stacked bar chart illustrating the number of cases of respiratory illness by age, geography. It demonstrates that the cases are more prevalent in major city centres. Figure 9 is the graphical examination of fluctuations in the crop yields in time using the box plot and thus indicating the range of yields of the crops across a year. The heatmap presented in figure 10 shows the impact of various diseases. It demonstrates that the relative risk of COPD and asthma is highest when exposed to ozone over an extent of time.

Figure 11 below demonstrates a simplified flowchart of the impact pathway that illustrates the direct effect of the tropospheric ozone on human lungs and the physiology of plants. This is in a bid to summarise the key environmental impacts.

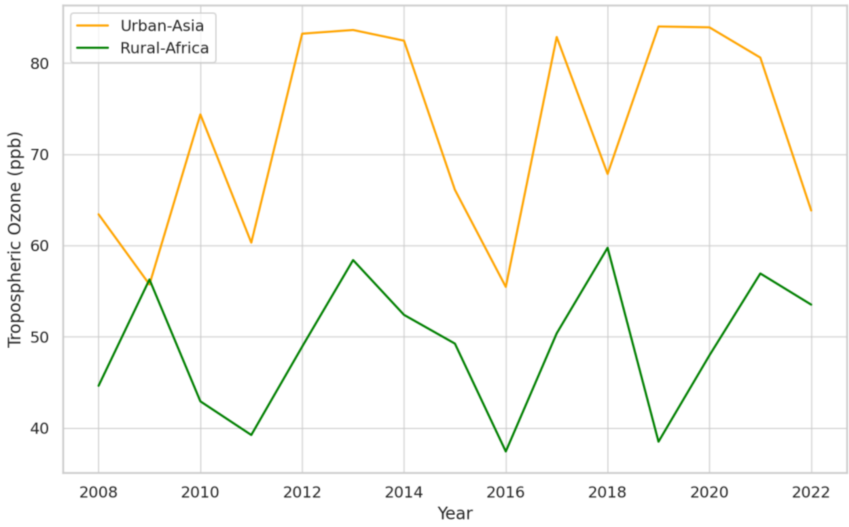

Figure 2: Ozone Trends in Urban vs Rural Areas

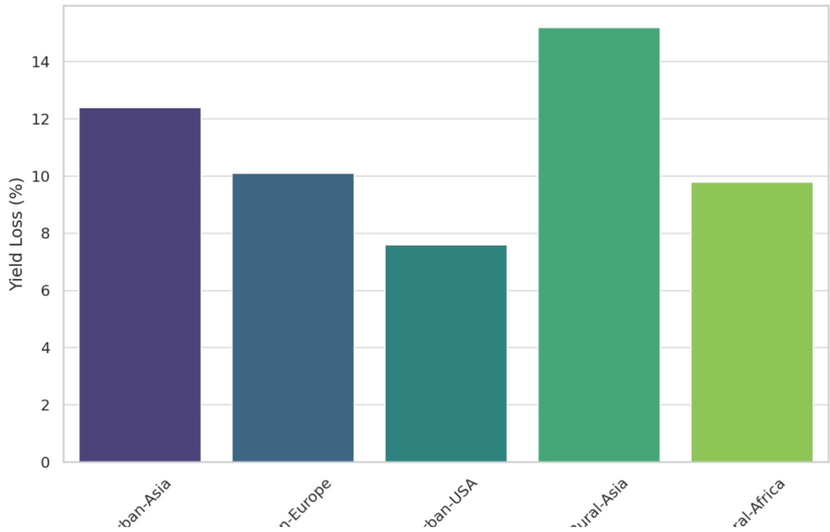

Figure 3: Crop Yield Loss by Region

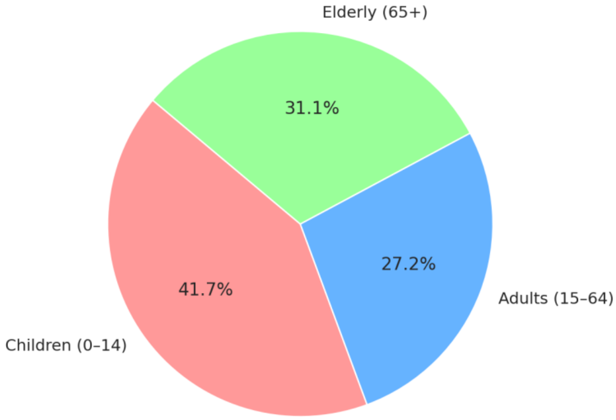

Figure 4: Ozone-related Admissions by Age Group

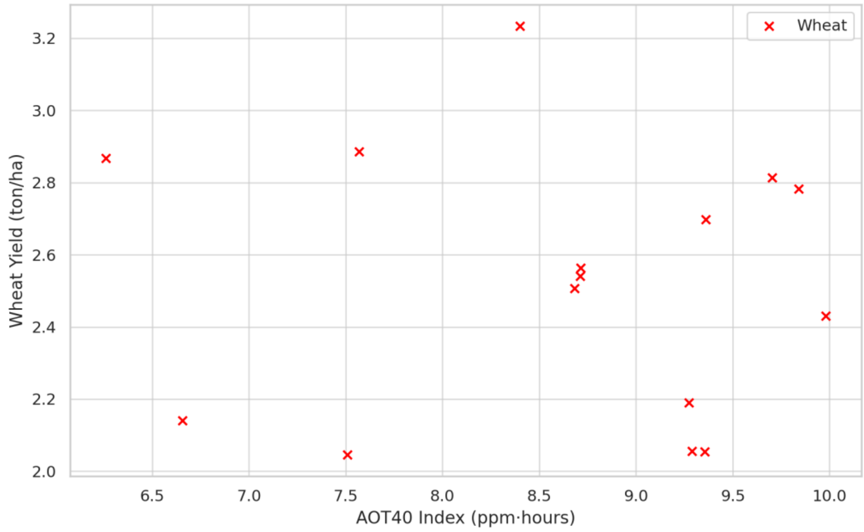

Figure 5: AOT40 vs Wheat Yield

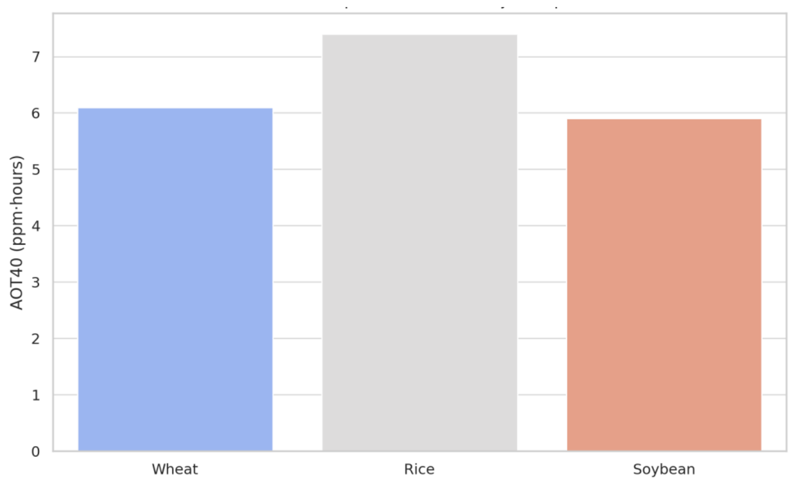

Figure 6: AOT40 Exposure for Crops

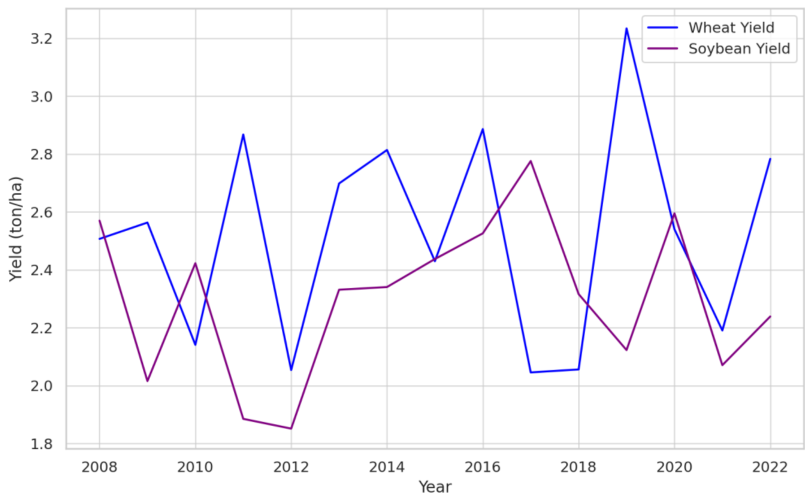

Figure 7: Wheat and Soybean Yields

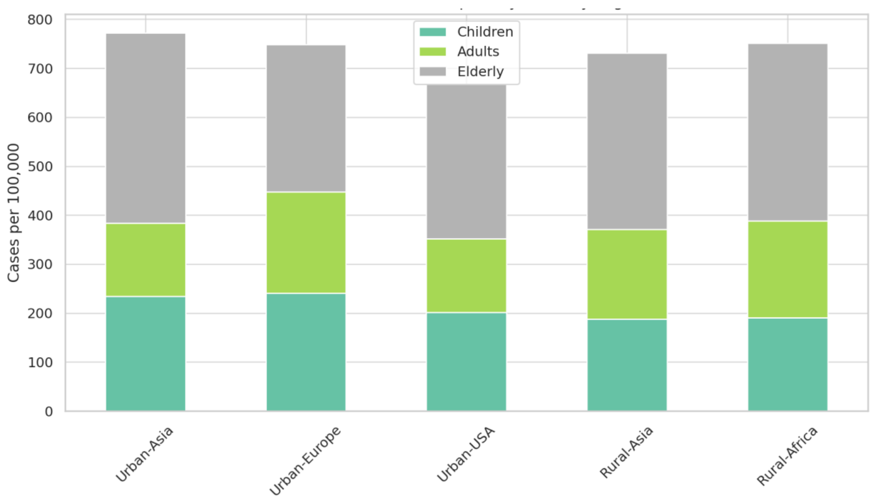

Figure 8: Respiratory Cases by Region

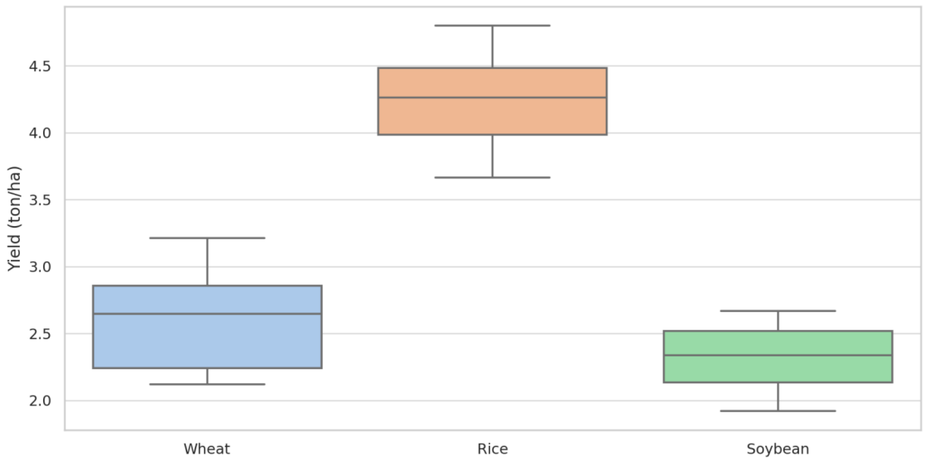

Figure 9: Crop Yield Variability

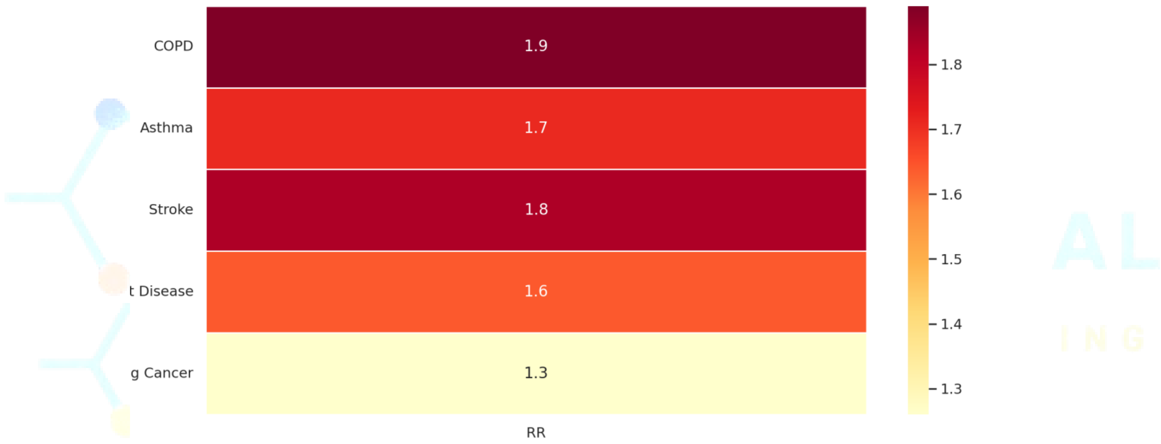

Figure 10: Relative Risk of Diseases

The figure 11 shows the direct correlation between the exposure to tropospheric ozone and its adverse impact on human health and agriculture.

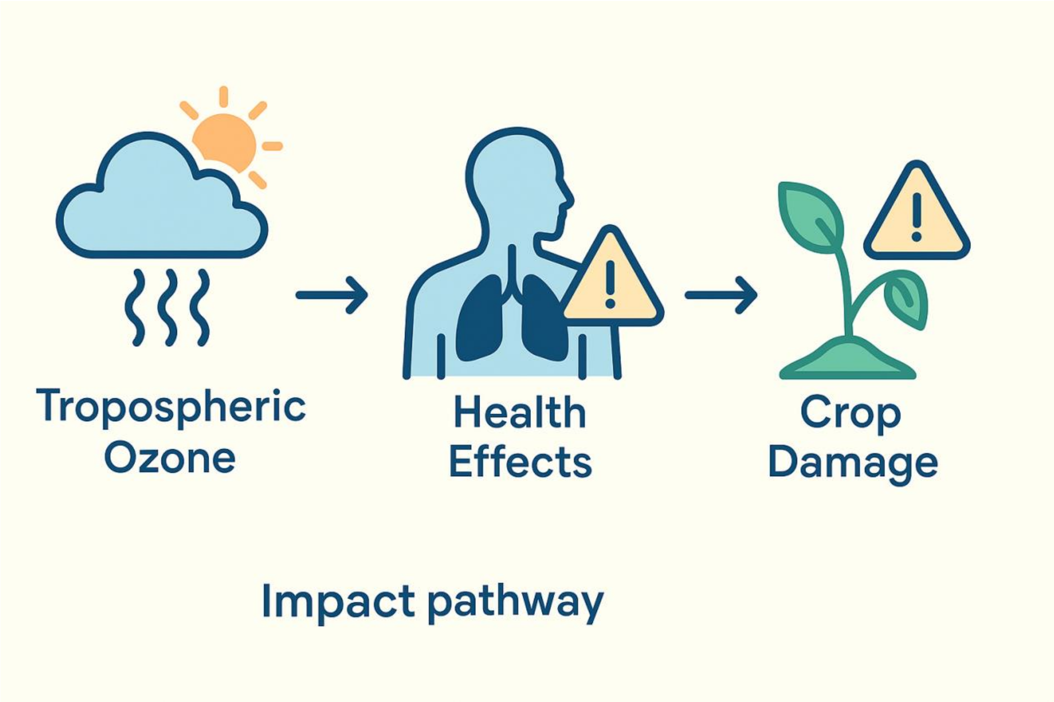

Figure 11: depicts the straight connection between the exposure of the tropospheric ozone and its adverse impact on the human health and crop production.

DISCUSSION

An increase in surface ozone is associated with increased hospitalisation due to pneumonia, particularly in heavily populated regions (Qiu et al., 2021). These results corroborate previous studies and indicate the possible existence of a connection between ozone exposures with the medical conditions of the respiratory system (Ulpiani et al., 2021). The complete investigation of the level of tropospheric ozone during 2008-2022 presents significant data on how it varies with time and space, which has significant implications on human health and agricultural production (Boomiraj et al., 2021). Quantitatively enhanced data combined with regionalism and stratification in demographics proves that policy modification is needed to minimize ozone pollution and the health impacts it has on the people.

The data demonstrate how necessary it is to have personalized mitigation techniques in the context of cities where the level of ozone concentration remains elevated at all times and older members of the population are particularly vulnerable to its adverse effects (Sundas et al., 2024). Also, the ozone level differences across various regions demonstrate the influence of the local sources of emissions and weather conditions on the ozone level. This implies that there is need to target regions depending on regions so as to reduce the levels of ozone. The experienced health impacts, particularly the increased rate of risks of COPD and asthma, demonstrate that there is a need to integrate air quality management and the population health initiatives. The findings also imply certain therapeutical implications on the methods of treating paediatric asthma, which only adds importance to the question of exposure limitation to air pollution (Garcia et al., 2021). According to the study, standards and clinical experiments on the quality of air under which individuals with high-risk chances of developing illness caused by air pollution should be adjusted more tightly (Ko & Kyung, 2022).

The adverse effects of tropospheric ozone on agricultural products are a cause of concern to global food security. The figures reveal that the impact of ozone stress on the production of significant commodities such as wheat, rice, and soybeans is huge. Asia is the area that is affected the most. Such reduced yields do not only jeopardize access to food, but they also exert larger social and economic impacts, particularly to agricultural communities. The economic consequences of the reductions in crop productivity due to the ozone exposure may increase the income disparities, particularly in the regions that rely mostly on agriculture (Renna et al., 2024). These issues demonstrate the necessity of the adoption of the environmentally safe agricultural practices capable of increasing crop resistance to ozone stress and maintaining it as productive as possible under the conditions when air pollution increases.

The presence of tropospheric ozone has been identified as a significant threat to both human health and food production, and it demands intervention on a wide range of levels, hence an urgent response to the same. The fact that these problems are so urgent requires a comprehensive solution which entails new technologies, modifications of policies and collaboration with other nations. In order to address the issue of tropospheric ozone pollution, we must have a wide and comprehensive measure encompassing most of the strategies such as transportation, energy and agriculture.

CONCLUSIONS

The paper presents how accumulated tropospheric ozone over long periods of time can have grave, far reaching effects on human health as well as agricultural crops. In the study, it is found that ozone levels in urban-industrial are alarmingly increasing with levels of transported and existing ozone increasing in the rural regions. This is supported by in-depth analysis of satellite data, population-weighted measure of exposure and empirical modelling of yields. Association of excess ozone with increased risk of respiratory disease, particularly among children and the elderly demonstrates that, this is an emerging health issue that should be addressed as soon as possible.

Meanwhile, the adverse effects on agriculture, albeit on crops that are prone to ozone, such as wheat, rice and soyabeans are an increasingly threatening factor to global food security. The results of AOT40 measures, health burden estimations, and simulation-based yield predictions supplemented each other, thus yielding an entire and interdisciplinary view of the effects of ozone on the ecosystem. The findings of the study are very supportive to the coordinated PK activity on national and international levels. They advocate maintaining additional powerful air quality policies, superior emissions inventories, and adaptable strategies in the field of the public health and of the agricultural sector. In the process of trying to control ozone in the troposphere, it is not only a scientific or technical issue that the society needs to engage in to achieve sustainable development.

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