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Spatio-Temporal Analysis of Aerosol Optical Depth (AOD) Pattern and Vulnerable Areas in Punjab Using Remote Sensing and GIS

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Abstract: The presence of complex nature aerosols is a constant phenomenon, and their interaction with solar radiation, earth, and atmospheric gases brings a change in temperature profile, which threats the lives of living organisms on the earth's surface. Urban and industrial emissions are significant contributors to producing aerosols and particulate matter. In all the major cities of Pakistan, the existing concentration of aerosols and ozone with variant values depends on urban and industrial growth, temperature, and amount of received precipitation. Overall southern parts of the country have more concentration of aerosol and ozone than northern parts. MODIS has a wide range of values, and in this study complete range of MODIS Aerosol Optical Depth values was adopted for image analysis. In this regard, data of 10 years from 2011 to 2020 was collected and processed. Images of MOD-08-M3 version 6 were processed, and AOD for each month was retrieved by applying the scale factor approach while through the same process for O_3 concentration. O_3 values for each month were retrieved. The present study shows the inverse relationship between AOD and O_3, which means whenever AOD values increase, O_3 values decrease due to seasonal and localization effects.

Keywords: Aerosols, Precipitation, Radiation, Ozone, Vulnerable

1. INTRODUCTION

Aerosols are particle complex organic or inorganic nature, present in the atmosphere in the suspended position either in the form of liquid or solid or in the combination of both. These particles form a significant impact on climate and the environment as these particles have considerable interaction with solar radiation, earth, and the gases of the atmosphere. This interaction significantly modifies the atmosphere's characteristics, particularly the atmospheric temperature, profile, and features of the earth's surface and its temperature (Kumar, *et al.*, 2011; Gupta, *et al.*, 2013). Besides, changes in temperature and climate, when the aerosols combine with particulate matter, cause a significant threat to life on the surface of the earth (Pope, *et al.*, 2009; Levy, *et al.*, 2007). (Ali, *et al.*, 2020) are of the view that Aerosols Optical Depth is a vital parameter for assessing climate change on a regional and global level. Less rainfall and high-temperature support the increasing trend of AOD (Kumar, *et al.*, 2011; Ali, *et al.*, 2020).

Aerosols Measuring Parameters

There are specific reasons for aerosols being the most essential parameter;

- The impact of aerosols is considered the most considerable uncertainty in predicting climate change.
- There are specific air pollutants that affect human health, especially related to the respiratory system, and aerosols are considered the major air pollutants.
- The information related to aerosols is an excellent tool for atmospheric correction in satellite imagery.

A close relationship exists between the fine particulate matter of unnatural origin and all living organisms' health systems. In this regard, urban and industrial emissions are very significant, producing and adding aerosols to the atmosphere. (Pope, *et al.*, 2009; Gupta, *et al.*, 2013). The aerosols parameters can be measured

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in both ways, either in-situ or from the ground surface, and remotely sensed tools and devices such as air crafts and satellites. At present, satellite remote sensing is widely used for mapping aerosols detection and presence in the atmosphere, which ultimately helps in assessing spatial distribution and properties of aerosols over a larger area (Escribano, *et al.*, 2014)

The collected data from satellite sensors provide the present situation and enhance the capacity of prediction of future climatic conditions by aerosols. Various datasets have a variant spatial resolution (low and medium-AVHRR to high resolution-SPOT) that have been applied for measuring troposphere aerosols. Satellite-based information is more recent and accurate (He, *et al.*, 2014). Since its launching, MODIS has been providing information related to aerosols and other particulates regionally and worldwide as it can best monitor the migration of aerosols and other pollutants. Besides, MODIS, MERIS, and ENVISAT can also help in extracting required information pertinent to aerosols, etc. (Kaskaoutis, *et al.*, 2010)

Ozone Condition in Past Decades over Pakistan

Ozone concentration and presence in major cities of Pakistan vary a lot. The research carried out by (Shen, *et al.*, 2019) reveals that Karachi's average ozone concentration ranges 36µg/m^3 to 50 µg/m^3 in 1992, while in 1986-1988 the ozone concentration showed variance at upwind and downwind sites. At upwind sites area that was 2 µg/m^3 50 µg/m^3 and at downwind site area maximum level was 80 µg/m^3 to 100 µg/m^3. Another research study was conducted in Sindh Industrial Trading Estate to measure ozone concentration where the O_3 minimum level was 15 µg/m^3 to 38 µg/m^3 at day time. The Pak-EPA/JICA (2001) report shows the ozone concentration in three major cities of Pakistan; Lahore, Rawalpindi, and Islamabad, where the level of O_3 was 17 µg/m^3, 34 µg/m^{3,} and 20 µg/m^{3,} respectively. Meanwhile, at Port Qasim, the value of O_3 was 24 µg/m^{3,} and the maximum average of 8hrs in downtown areas was 9.6 µg/m^3, residential areas had 13 µg/m^{3,} and the industrial area had 19 µg/m^3. (Butt *et al.*, 2018) in their research witnessed the 48-hrs mean concentration of ozone in three main cities of Pakistan as Karachi 50 µg/m^3, Quetta 48 µg/m^3, Peshawar 46 µg/m^3, Lahore 44 µg/m^3, Islamabad 36 µg/m^3 and Rawalpindi 34 µg/m^3. (Kaskaoutis, *et al.*, 2010) found an increasing trend in the concentration of ozone in Lahore city as, according to them, in the year 2005-2006, the concentration of ozone in Lahore was 209 µg/m3, 20 times higher than the WHO guidelines. During their research study, (Gupta *et al.*, 2012) discovered that Lahore city has greater Aerosols Optical Depth than its surroundings. Lahore shows a decreasing pattern in AOD during the last decade with a slope of -0.07. Overall in southern parts of Pakistan, there is a higher concentration of ozone than its northern areas (Tariq and Ali, 2014). The maximum concentration was recorded in afternoon hours during the summer season. At present, Pakistan has 100 µg/m^3 (8hrs) mean according to the standard recommended by WHO but most likely to increase due to No_2 emission by CNG vehicles in the urban centers (Otaibi *et al.*, 2019; Ali, 2020).

2. MATERIALS AND METHODS

In 1999 the space sensor MODIS was launched by NASA's Terra Earth Observatory System. This sensor is operating at altitude of about 700km. being Polar Orbiting satellite, MODIS is able to provide data pertinent to aerosols on daily basis (Gupta et al 2013). MODIS Terra has scanning swath of 2330 km cross the track and 10 km along the track. There are 36 different channels with different wavelengths suitable for various purposes and applications. (Wijeratne, 2003

Data Type	Purposes/Characteristics
1. Modis Terra aerosol Cloud Water Vapor Ozone Monthly L3 Global 1 Deg CMG	Ozone Variables. Aerosols Optical Depth.
2. level-3(L3) MODIS Atmosphere Monthly Global Product MOD08_M3	Properties of aerosols particle. Cloud optical. Water vapor in atmosphere. Atmospheric profile. Total burden of ozone.

Both variables were retrieved by using the sub-setting technique and applying a scale factor of 0.001, which recovered the data values in parts per million (ppm). In general, the MOD-08 product comprises 3000 data subsets. MODIS has a wide range of values, and in this study complete range of MODIS Aerosol Optical Depth values was adopted for image processing. In this regard, data of 10 years from 2011 to 2020 was collected. Finally, month-wise then all months were staked into years then image processing was executed for both selected variables of ozone and AOD.

3. RESULTS AND DISCUSSIONS

Aerosols Optical Depth (AOD) Assessment

Images of MOD-08-M3 version 6 were processed, and AOD for each month was retrieved by applying the scale factor approach (Fig 3-13). As for the monthly assessment of AOD, most Punjab districts have a value of more than 5 ppm in January. Only some districts such as Sialkot, Narowal, Gujranwala, and Sialkot have AOD value near 4 ppm; however, northern Punjab areas also have less AOD than South Punjab. The high AOD in most Punjab districts is winter season with the lowest temperature in January with thick Smog and dense air, which results in high AOD values. It is worth noting that the western part of Punjab has some fewer AOD values compared to the south and eastern part of the province (Fig. 3). When the season starts changing itself, thickness in the air and foggy conditions are also going to end in February. One can see in (Fig. 4). that the AOD values drop to less than 2 ppm in most areas of Punjab districts. This is due to the spring season's start, which brings some rainy days in the upper and lower basins of Punjab plains. Values of AOD are still less than two ppm in March 2011-2020 (Fig. 5). In April, the summer season will be start and temperature increases gradually with dust storms and thunderstorms in upper parts of Punjab province. That's why AOD values are going to high with more than four ppm. No district has AOD value of less than three ppm in the months of April 2011-2020 (Fig. 6). higher AOD values of >4 ppm in the months of May 2011-2020 due to the pre-monsoon season with almost no rainy days in the whole Punjab can be seen in (Fig. 7).. June is considered the hottest month of the year, with a full dry period and dust storms in lower Punjab parts. This month, values of AOD are even greater than five ppm in the whole Punjab (Fig. 8). In Pakistan and particularly in Punjab, the monsoon period starts in July, but due to changing climate patterns, July was also a hot and dry month in 2011-2020 with no rainy days. That's the reason, resulted from image have more than five ppm AOD values in whole Punjab (Fig. 9). In August and September 2011-2020, many Punjab plain areas received frequent rainfall, and it results in low AOD values (< 5 ppm) compared to June and July. Only some western parts like Chakwal, Mianwali, Khushab, Bhakar, and Sargodha have higher AOD values of >5in August, which is lower AOD < 4 ppm in September 2017 (Fig.10-11). The monsoon period ends in September. The season will be changed again in October and in winter comes in November with very few rainy days, and resulted in AOD values are once again higher even > 5 ppm in many districts Punjab (Fig.12-13)

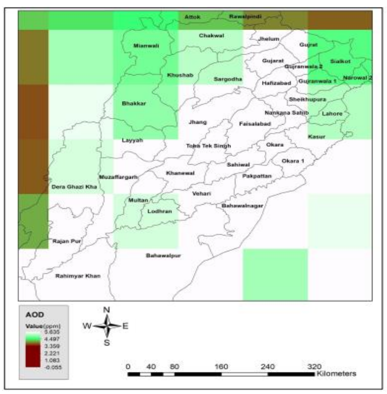

Fig. 2.AOD concentration over Punjab (Jan 2011-2020)

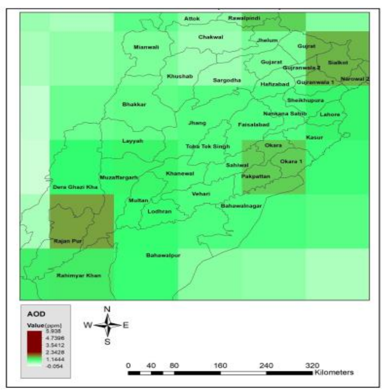

Fig. 3. AOD concentration over Punjab (Feb 2011-2020)

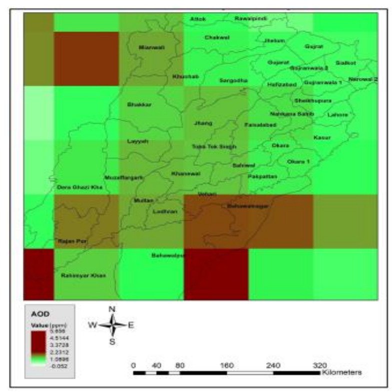

Fig. 4. AOD concentration over Punjab (Mar 2011-2020)

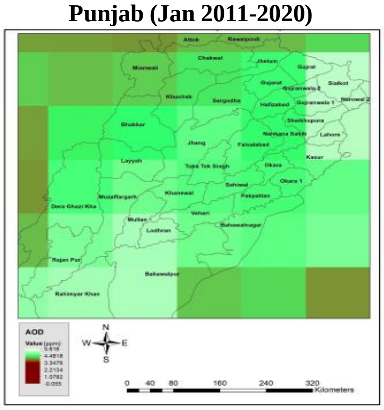

Fig. 5. AOD concentration over Punjab (Apr 2011-2020)

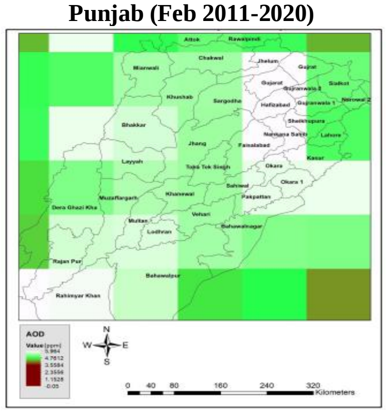

Fig. 6. AOD concentration over Punjab (May 2011-2020)

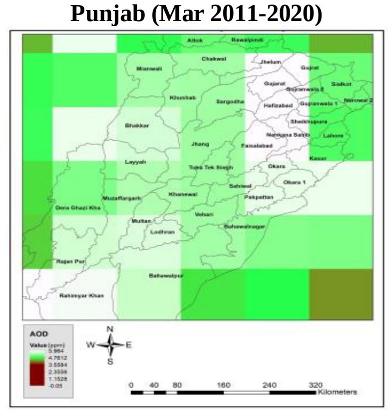

Fig. 7. AOD concentration over Punjab (Jun 2011-2020)

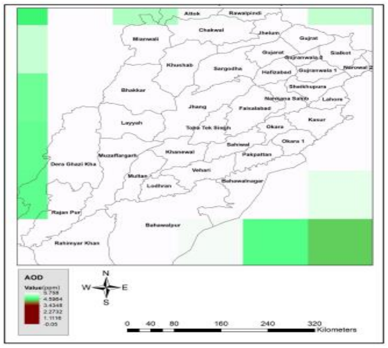

Fig. 9. AOD concentration over Punjab (Jul 2011-2020)

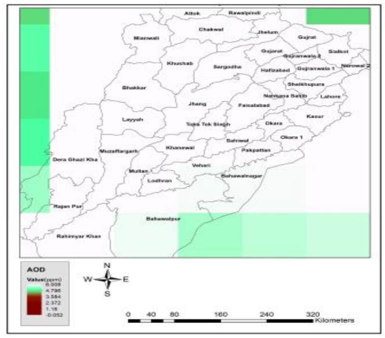

Fig. 9. AOD concentration over Punjab (Aug 2011-2020)

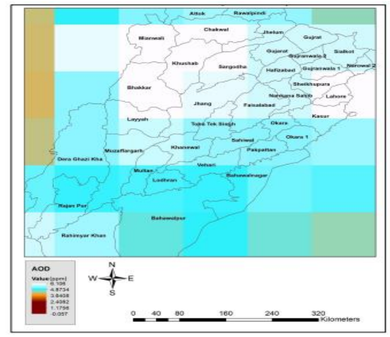

Fig. 9. AOD concentration over Punjab (Sep 2011-2020)

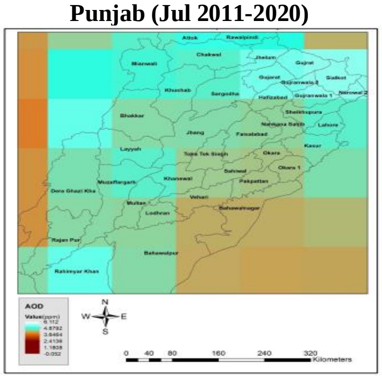

Fig. 11. AOD concentration over Punjab (Oct 2011-2020)

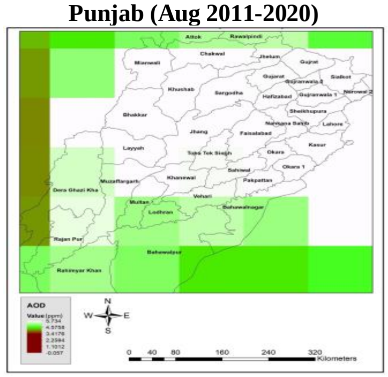

Fig. 12. AOD concentration over Punjab (Nov 2011-2020)

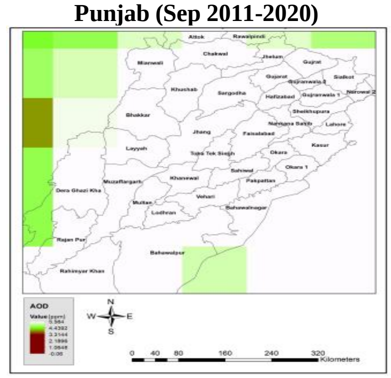

Fig. 13. AOD concentration over Punjab (Dec 2011-2020)

MOD-08-M3 version 6 was processed for ozone concentration assessment over Punjab and O3 values for each month were retrieved by applying the same scale factor approach as used for AOD (Fig 14-24). As for the monthly assessment of O_3, most Punjab districts have a value of more than four ppm in January. Only some districts such as Okara, Pakpattan, Bhakkar, and Faisalabad have O3 values near eight ppm (Faisalabad and Nankana Sahib > 11 ppm). However, northern Punjab areas also have less O3 compared to South Punjab. The reason for high O_3 in most Punjab districts in the winter season, with the lowest temperature in January with a thick fog and dense air, results in high O_3 values. It is worth noting that the western part of Punjab has some less O3 values compared to the south and eastern part of the province (Fig.14). When the season starts changing itself and thickness in air and foggy conditions also going to end in February. One can see in (Fig.15). that the O_3 values increase to more than six ppm in most areas of Punjab districts and more than 12 ppm in Lahore, Kasur, and some parts of Rawalpindi district. This is due to the spring season's start, which brings some rainy days in the upper and lower basins of Punjab plains. O_3 molecules increases in the spring season naturally. Further, values of O_3 are still higher than 8 ppm in March 2017 (Fig.16). In April, the summer season is going to be start, and temperature increases gradually with dust storms and thunderstorms in the upper parts of Punjab province. That's why O_3 values will be lower with < 6 ppm in many parts of Punjab. However, some western parts of Punjab still have > 14 ppm values of O_3. No district has an O_3 value of less than four ppm in April 2017 (Fig. 17). One can also see in (Fig.18). that the higher O_3 values of >7 ppm in May 2017 due to the pre-monsoon season with almost no rainy days in the whole Punjab. June is considered the hottest month of the year, with a full dry period and dust storms in lower Punjab parts. This month, values of O_3 are even < 4 ppm in the whole Punjab (Fig.19). In Pakistan and particularly in Punjab, the monsoon period starts in July, but due to changing climate patterns, July was also a hot and dry month in 2017 with no rainy days. This is why the resulted image has < 5 ppm O3 values in the whole Punjab except some areas like Rajanpur, Jhang, Okara, Pakpattan, Muzaffargarh. These areas have > 10 ppm values (Fig. 20).

In August and in September 2017, many areas of Punjab plain received Frequent rainfall results in moderate O3 values (< 8 ppm) compared to June and July. Only some western parts like Chakwal, Mianwali, Khushab, Bhakar, and Sargodha has less O_3 values of <3 ppm in August, which is still lower in September 2017 (Fig.21-22). The monsoon period ends in September and the season will be changed again in October, and winter comes in November with very few rainy days. Here resulted in O_3 values are once again higher, even > 5 ppm in many Punjab districts (Fig.23-24). Gujrat, Jhelum, and some parts of Gujranwala and Hafizabad have very high O_3 values > 18 ppm, which is exceptional and strange in November 2017

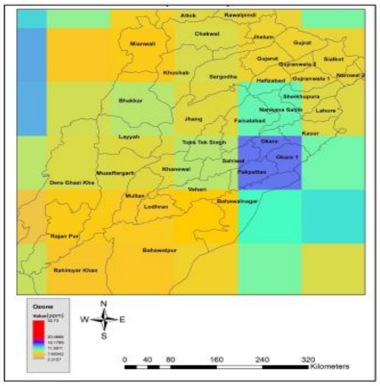

Fig. 14. Ozone concentration over Punjab (Jan 2011-2020)

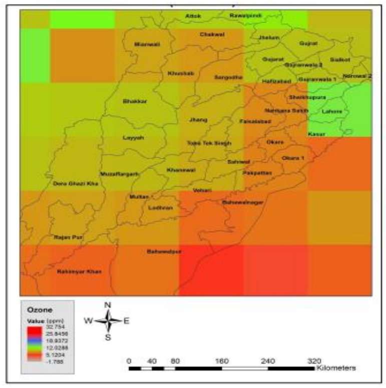

Fig. 15. Ozone concentration over Punjab (Feb 2011-2020)

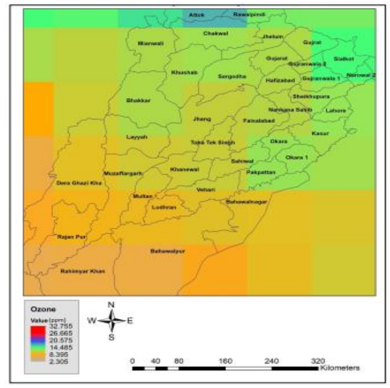

Fig. 16. Ozone concentration over Punjab (Mar 2011-2020)

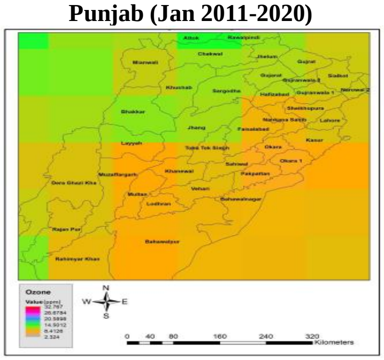

Fig. 17. Ozone concentration over Punjab (Apr 2011-2020)

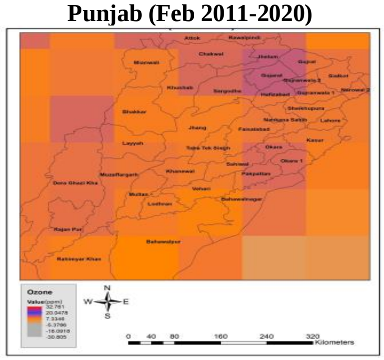

Fig. 18. Ozone concentration over Punjab (May 2011-2020)

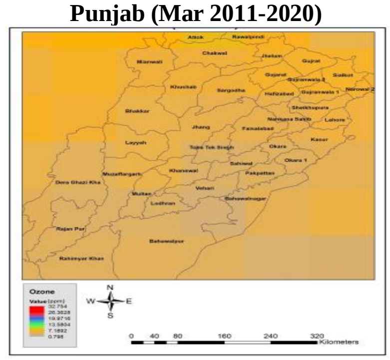

Fig. 19. Ozone concentration over Punjab (Jun 2011-2020)

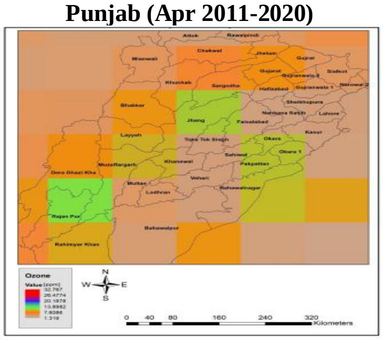

Fig. 20. Ozone concentration over Punjab (Jul 2011-2020)

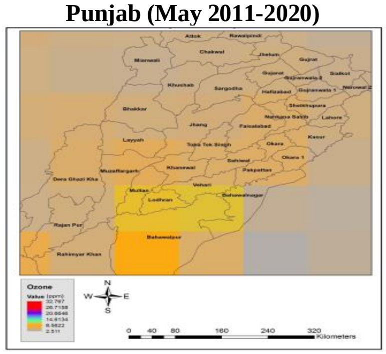

Fig. 21. Ozone concentration over Punjab (Aug 2011-2020)

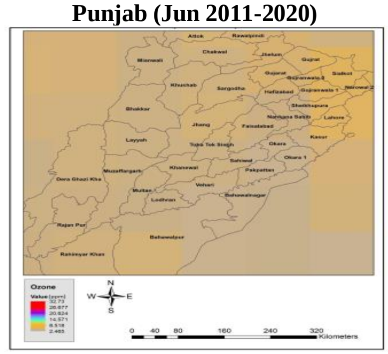

Fig. 22. Ozone concentration over Punjab (Sep 2011-2020)

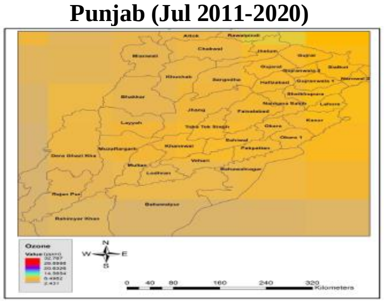

Fig. 23. Ozone concentration over Punjab (Oct 2011-2020)

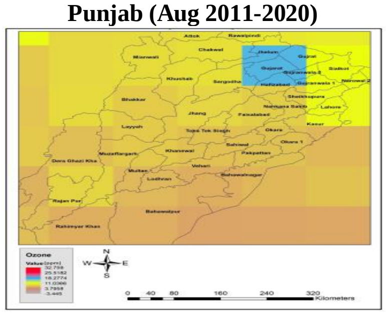

Fig. 24. Ozone concentration over Punjab (Nov 2011-2020)

5. CONCLUSION

In a recent study, major air quality parameters (AOD & O3) were analyzed with MODIS data, and their concentration level for the last ten years was also performed. It is concluded that northern areas of Punjab have less AOD as compared to South Punjab. The reason for high AOD in most Punjab districts is the winter season with the lowest temperature in January with thick Smog and dense air, which results in high AOD values. As for the monthly assessment of O_3, most Punjab districts have a value of more than four ppm in January. After the processing and evaluation of 22 images, finally it is also concluded that whenever AOD values increase O_3 values decrease. Some areas have exceptional higher values as compared to their surroundings. The reasons may be anthropogenic activities and a higher population density, which cause pollution.

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