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Spatial and Temporal Changes in the Tropospheric Ozone Concentration due to Developmental Projects under China-Pakistan Economic Corridor (CPEC)

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Acronyms

CAFE	Clean Air for Europe
CPEC	Case of China- Pakistan Economic Corridor
CFFP	Coal-Fired Power Plants
CO	Carbon Monoxide
CO2	Carbon Dioxide
DU	Dobson Unit
EIA	Environmental Impact Assessment
GHG	Greenhouse Gases
GDP	Gross Domestic Product
IDW	Inverse Distance Weighted
IPCC	Integrated Pollution Prevention and Control
MLS	Microwave Limb Sounder
NDRC	National Development and Reform Committee
NAAQS	National American Air Quality Standards
NEC	National Emissions Ceilings
NO2	Nitrogen Dioxide
NO	Nitrogen Monoxide
OBOR	One Belt One Road
PM	Particulate Matter
SBUV	Solar Backscattered Ultraviolet
SCO	Stratospheric Ozone Column
SO2	Sulfur Dioxide
TO3	Tropospheric Ozone
TCO	Tropospheric Column Ozone
TOMS	Total Ozone Mapping Spectrometer
UNFCCC	United Nations Framework Convention on Climate Change
UNECE	United Nations Economic Commission for Europe
VOC	Volatile Organic Compounds

Abstract

For sustainable development and extracting long-term benefits from socio-economic intensive projects, protection, conservation, rehabilitation and improvement of the natural environment is essential. The environmental problems associated with developmental projects makes it difficult to pursue important projects that contribute to economic growth and sustainable development. This study analyzes the effects of CPEC developmental projects, by comparing before and after the commencement of projects on the concentration of tropospheric ozone levels in Pakistan. The data were obtained from the AURA satellite using OMI and MLS instruments and processed to obtain raster images. The monthly data were checked against temperature changes to obtain winter and summer values. The results showed a significant mean change in concentration of tropospheric ozone for pre-CPEC and post-CPEC for summers at 2.29±1.27 DU and for winters at 0.94±0.64 DU, in Pakistan. This shows that with more development projects of CPEC underway, the emissions of primary pollutants such as NOX, VOCs have increased and is affecting the level of TO3 in the country. This research questioned the undertaking of the developmental projects as not environment-friendly; therefore, there is a need for mitigation technique for environmental conservation alongside development goals.

Keywords: Tropospheric Ozone; CPEC; Development; Environment; NOx; VOCs

1. Introduction

With the advent of globalization, the need for economic corridors in global societies has escalated, enhancing networks of regional, national and international connectivity and trade routes to induce economic development, industrial, social and trade activities to foster growth. Even though these corridors intend to strengthen the economies, the adverse impacts on the environment cannot be ignored. The case of CPEC, as an economic corridor is being developed as a part of a strategic partnership between China and Pakistan to commence a development mega project that aims to enhance economic and social integration with investment, trade, energy, and communication. It's a long-term plan with the time frame of 2014-2030 with total investment from China of about 46 billion dollars. The intention of CPEC is to establish linkage under the One Belt, One Road (OBOR) initiative outlined in March 2015 by China's National Development and Reform Committee (NDRC) between the western region of China and Pakistan by establishing a network of highways, railways and pipelines also, known as New Silk Road. With the advent of globalization, the global population is growing at a rate of 1.09% per year, with an estimated increase of 83 million people per year (UN, 2018). As the population increases, so does the demand for infrastructure, food, energy, industries, and transportation, adding to the pile of anthropogenic emissions in the atmosphere. CPEC is expected to fulfill the development needs of Pakistan, but exacerbated pollution problems due to environmental degradation, tend to give rise to extreme weather conditions, especially air pollution that has emerged as a hazard towards human health and agricultural yield. United Nations Framework Convention on Climate Change (UNFCCC) has identified the increase in global mean temperature up to 2ºC annually, due to rise in Green House Gases (GHGs) and short-lived climate pollutants (such as Tropospheric Ozone, CH4 and BC) with penalties on climate change (Zhang *et al.,* 2014). Air pollution has generated complications with excessive buildup of primary and secondary polluting gases in the atmosphere that threatens the survival, health, and development of humans and organisms inhabited on earth.

Pollutants give rise to environmental degradation and tend to accumulate concentrations of pollutants in an atmosphere that are beyond safe living conditions. Discharge of gases from direct source are primary pollutants such as Carbon dioxide (CO2), Carbon Monoxide (CO) Sulphur dioxide (SO2), Nitrogen dioxide (NO2), Nitrogen monoxide (NO), etc., whereas secondary pollutants are product of chemical/photochemical reactions under certain conditions and reactions with primary pollutants (sulfate aerosols, Ozone, nitrate aerosols, etc.) along with suspended Particulate Matter (PM) and volatile organic matters (Ahmad and Aziz, 2012). Nitrogen dioxide and ozone are the most imperative oxidants capable of implicating adverse effects on human health and environment (Ali and Athar 2008; Martin *et al.,* 2009; Ahmad *et al.,* 2011). NOx play a major role in the formation of tropospheric ozone and absorption of visible radiation which reduces atmospheric visibility due to photochemical smog. It can also alter the climate composition that in-turn affects weather and seasonal cycles of the environment (Varshney and Singh, 2003; Martin *et al.,* 2009; Ahmad *et al.,* 2011). Air pollution is increasing as a result of development projects mainly of transportation, infrastructure, and energy production that contribute to more GHG emissions. Energy production has the capacity to rapidly and swiftly change the atmospheric characteristics due to its harmful emissions and ultimately degrade the environment and human health. The parasite of degradation of the environment that is associated with development has its shortcomings in not procuring the expected benefits that are to be extracted in long term. In the era of industrialization, the amount of degradation of the environment is greater than the amount of conservation, pertaining to the fact that not only the ecosystem is destroyed to a great extent, but the rehabilitation of environment is not done equivalent to the degree of damage caused. The fact remains that this structural transformation prompts massive levels of energy resources that gives way to pollution and degradation of the environment.

1.1 Tropospheric Ozone

With the unprecedented change in the global industry, the consequences pertained due to the unimpeded industrialization has given way to enormous concentrations of air pollutants as discussed previously. These pollutants emitted have been the cause of 2 million premature deaths each year (WHO, 2006). Pollutants such as SO2, particulate matter (PM), CO, NOx, O3, impact on the terrestrial life is readily apparent and anthropogenic activities during the last century have apparently reached a significant magnitude of exploitation, modification and unpredictable climate change, that they are extinguishing the life on planet (Jabbar and Munir, 1993). Similar to the world known phenomenon of life on earth is reliant on water and oxygen, ozone is a crucial aspect for life on earth, deprived of which the ultraviolet radiations from sun will make earth inhabitable About 90% of ozone is found in the stratosphere and only 10% in troposphere i.e. around 10-18km from the surface of the earth. Ozone at the surface area near population areas is an important constituent of photochemical smog that comes directly in contact with humans and plantation and results in human respiratory and skin damage and photosynthesis of plants. According to Integrated Pollution

Prevention and Control (IPCC) (2001), tropospheric ozone is regarded as the third most powerful GHGs in the atmosphere after CO2 and Methane (Ueda and Izuta, 2006).

According to Haq and Tariq (2015), South Asia is experiencing air pollution with urbanization, population growth, industrialization, expanding demand for agricultural products and the rapid rise in energy consumption. Ozone is formed through reactions with Nitrogen oxides (NO2, NO) and reactive Volatile Organic Compounds (VOCs) in presence of sunlight, high temperatures, and low wind. Ozone can be highest in summers and lowest in winters. It has a life of 23 days and can travel long distances with wind direction and speed (Noreen *et al.*, 2018). Pakistan has normally more sunny days with a mean temperature of 38ºC with a maximum of approximately 48ºC. It gives a favorable condition for ozone formation given that NOx and VOCs are present in the atmosphere. With extensive industrialization and burning of coal in power plants and vehicle emissions, ozone concentrations at the tropospheric level are increasing beyond the limit. NOx is emitted during industrial burning, vehicle combustion, and biomass fuel, crop residue burning, soil emissions and lightening (Ichter and Burrows, 2002).

Three anthropogenic activities that contribute to NO and VOCs emissions are coal-fueled electric plants, transportation sources, and photochemical industries. Coal power plants and transport emissions account for approximately 75% of US total anthropogenic NOx emissions annually (EPA 1991). Carbonyl compounds are VOCs that are directly emitted from motor vehicles and incomplete combustion of hydrocarbons fuels in industrial machinery and industrial processes (Grosjean *et al.,* 1993; 1996; 2002). As ozone concentration increase with reactions with NOx and VOCs with high temperatures, adverse health impacts on human's increases too such as decreased breathing ability, coughing, acute asthma, bronchitis, lung damage with longer exposures and sensitivity to allergens especially for children and elders. Lower agricultural yield, damage to forests, wilderness and biodiversity is also due to changing ozone levels in the atmosphere.

1.2 Ground Level Ozone Conventions

Tropospheric Ozone was first acknowledged by Haagen Smit in 1952, in California due to origins of Los Angeles smog that contributed towards air pollutants and required policy initiative (Brimblecombe, 2012). Control measures were implemented for Ozone emissions in North America, European Union, and Japan during the 1960s and 1970s through national and regional policies, but no attempt was made on an international level (Fiore *et al.,* 2002). Policy makers have employed different systems to tackle indoor and outdoor ozone concentrations and ways to restrict its formation and transport through universally accepted standards. According to WHO guidelines, the level of tropospheric ozone should be less than 50ppb (100 µg/m3) (daily 8-h Average) with the potential level at 30ppb (WHO, 2006). The standards for ozone has not been updated after 2006 under WHO. Table 1 summarizes the tropospheric ozone concentration threshold on Global, Regional, EU and UK levels.

Table 1: Air quality standards and other indices used for Tropospheric Ozone

Global Measures	Human Health	Vegetation
WHO guidelines on basis of human health and exposure evidence	50 ppb daily 8-h mean	N/A
Regional Measures		
Gothenburg Protocol UNECE	Critical human level emissions 60ppb(8-h average)	*Critical level measured through vegetation loss(3 months growing season) 3000 -5000 ppb-h*
European Union		
EU Ambient Air directive 2010	Target Value: 60 ppb per 25 days over 3 years (8-h average)	9000 ppb-h for 3 months 3000 ppb-h for over 3 months
EU Alert threshold for O3	Threshold: 90 ppb per hour Alert threshold: 120 ppb	
National Measures		
UK	50 ppb does not exceed 10 times a year	9000 ppb-h achieved by 2010

Source: Fowler *et al.,* 2008; UNECE, 2007.

At the international level, the O3 comes under the category of greenhouse gases and its fundamental management is directed by guidelines issued by WHO and UNFCCC, whereas it does not fall under the umbrella of Kyoto Protocol. Due to its nature of secondary pollutant, there is no global direct policy framework in place for abatement of excessive ozone in the atmosphere, but conventions for NOx and VOCs are indirectly curtailing the baseline for reductions in tropospheric ozone (Fowler *et al.,* 2008). The regional approach for controlling O3 has been placed under the United Nations Economic Commission for Europe (UNECE), Sofia Protocol (1991) to control NOx emissions and Gothenburg Protocol (1997&2005), to mediate VOC, Ammonia and Sulphur rectification by regions including Commonwealth states, US, EU, non-EU, Eastern Europe and Canada (European Commission, 2005).

The Clean Air for Europe (CAFE) proposed the directive ambient Air Quality measure which limits the values for SO2, NOx, PM, Pb, O3, CO, and Benzene, so that the long-term effects of increased emission of air pollutants do not deem critical for humans and ecosystem. National targets are set by National Emissions Ceilings (NEC) in 2008 and Integrated Pollution Prevention and Control (IPCC), which imposed conditionalities on the industrial and agricultural production levels so that emission protocol are met according to the atmospheric air standards. The sources of O3 are identified and the compulsory reduction in emissions by energy, mineral, production of metals, chemical, waste agricultural and livestock industries are implemented. Every new development initiative requires Environmental Impact Assessment (EIA) reports so standard protocols of atmospheric emissions are followed. Recent development initiative by China and Pakistan development portfolio of CPEC can impact the environment negatively and needs impact analysis for better mitigation procedures.

1.3 The Case of China-Pakistan Economic Corridor (CPEC), Pakistan

So far the CPEC have 67 project that includes 5 Coal-fired power plants, 1 solar park, 4 wind farms, and 3 hydropower stations and Transmission lines like Peshawar to Karachi motorway, Indus highway, Gwadar via Quetta route and railway lines construction in next several years. Other projects like steel mills, airport and Gwadar port construction along with other development projects are proposed to be implemented through CPEC. The corridor is assumed to be a game changer in Pakistan economic growth and sustainable development. The investments associated with CPEC will transform regional infrastructure, economic and social aspects. The foreign direct investments will improve and attract investors from all around the world which will provide an economic boost and social wellbeing. CPEC will increase employment, improve energy, transportation and telecommunication infrastructure, improve power crisis, initiate Gross Domestic Product (GDP) growth and reduce poverty and inequality (Zhang and Shi, 2016).

While investment and construction of energy and infrastructure projects will be constructive towards Pakistan's economy, certain social and environmental threats can reverse the benefits towards destruction beyond repair. The construction of coal-fired power plants is not eco-friendly and can pose a great threat towards citizen's health and atmosphere of Pakistan. The transportation of China products through Silk Road will increase vehicle emissions and harmful gases concentration in Pakistan's environment. These adverse effects are not only associated with the operation of route but also with construction periods that may continue for years making it unfeasible for humans to live in neighboring areas with more toxic gases in the atmosphere and noise pollution. Other negative impacts are cutting glaciers, deforestation, displacement of population, degradation of air quality, water resources, soil erosion, and contamination, wildlife unpredictable climate changes etc. (Rehman, 2015).

1.4 Problem Statement

The cross-sectional analysis of the prevailing and emerging worries of the concerned authorities shows the un-easing situation in Pakistan. Pakistan businessmen and intellectuals are of the view that movement of around 7000 trucks is going to contribute towards 36.5 million tons of CO_2 emissions/annum that will surely result not only in the melting of glaciers, degradation of agriculture, tourism, water system, but also health issues, particularly in Gilgit-Baltistan (Tribune, 2017). Changes in the normal climate patterns due to CPEC mega energy projects will alter the rain patterns and results in flooding in Pakistan. It has also been established that EIA reports are not effective, as Pak-EPA has rejected reports on basis that it was incomplete and insufficient, as it lacked the damage caused by trees cutting and rehabilitation of protected forest area under CPEC. The glacier melting due to a vast network of highways will have vast environmental costs (DAWN, 2015). Experts from 'Woodrow Wilson Centre-Asia Program' has recently shown their concerns about coal-fired power plants, emissions-belching technologies, destruction of farmland and heavy consumption of water that is prerequisite for intensive development and construction under CPEC (Tribune, 2017). It is kept in consideration that projects under CPEC will not create environmental problems and Beijing will not transfer out-dated technology for Pakistan's energy sector development (DAWN, 2017). The commencement of 10GW energy projects under CPEC is expected to increase greenhouse gas emissions substantially and will worsen climate change mitigation concerns (ADB, 2018). Last but not the least, the Ministry of Climate Change of Pakistan has shown concerns over the impact on air quality will increase ash and waste, so expected negative impacts across all the constituting socio-economic sectors of the country (DAWN, 2017). This brief analysis of media outlets of Pakistan has highlighted the growing concerns for CPEC projects having an adverse impact on air quality and environment, so this study will provide evidence in terms of tropospheric ozone concentration changes from the time period 2010-2017.

1.5 Establishing a Niche

The debate remains unwavering on the degradation of air quality and deterioration of health of citizens of Pakistan due to GHG emissions. From the previous studies, we have formulated a strong stance on the impact of development projects on emissions such as CO_2, NO_x, and SO_2 along with dependency of formation of secondary pollutants, such as tropospheric ozone, aerosols and compounds of nitrates and sulfates in the atmosphere. The decision of CPEC's projects as the best way for catering to needs of development, really risk-averse towards the environment, or is it detrimental in long run for Pakistan's vulnerable communities and unpredictable climatic changes?

Research Objectives are as follows:

1) To identify spatial distribution and temporal evolution of tropospheric ozone changes in Pakistan from 2010-2017.
2) To analyze the impact of CPEC development project on the concentration on the overall tropospheric ozone after 2015.

1.6 Hypothesis

H0: There is no significant change in tropospheric ozone levels with the commencement of overall CPEC projects from 2015-2017 on Pakistan.

H1: There is a significant change in tropospheric ozone levels with the commencement of overall CPEC projects from 2015-2017 on Pakistan.

1.7 Research Questions

Does the commencement of CPEC's projects have a significant impact on concentrations of Tropospheric Ozone in Pakistan?

- What are the trends of tropospheric concentration changes in Pakistan from 2010-2017?
- Are there any seasonal differences between concentration levels of tropospheric ozone, due to changes in average temperatures?

2. Literature Review

2.1 NOx and VOCs Impact due to CFPP

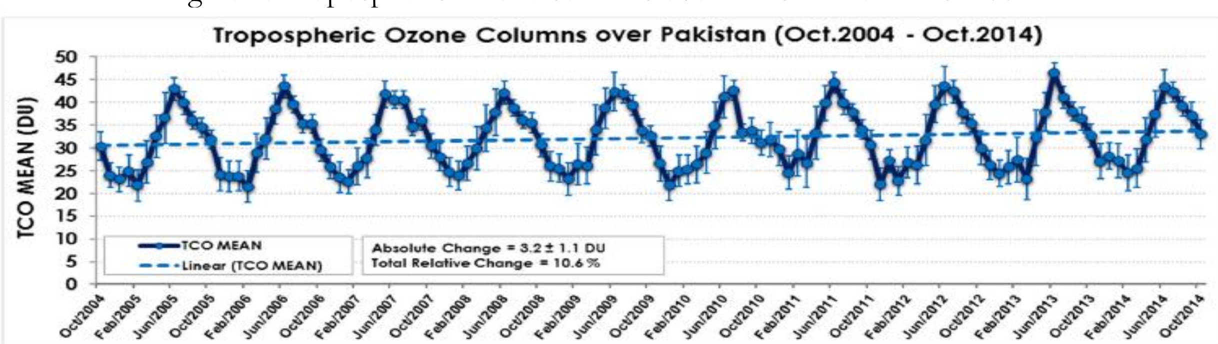
According to Souri *et al.* (2016), effective control policies in Houston based on NOx in summers and wind patterns for estimating longterm surface ozone, reduced NO2 and VOC from vehicles by -0.45 ppbv yr-1 and 44% respectively from 2000-2014, which ultimately reduced ozone during summer time by -0.63 ppbv yr-1, concluding that with low VOCs, NOX and slow wind, O3 concentrations is lower. As per US EPA (2014), National American Air Quality standards (NAAQS) threshold for Ozone is 70-75ppb with weather conditions such as dry regions (high temperature), geographical height and slow winds can more likely increase the ozone levels at about 95% at 70ppb (Jing *et al.,* 2016). Fishman *et al.* (2003) used data from Nimbus-7 (1978-1993) and Earth Probe (1997-2002) but due to technical difficulties in in 2003 due to technical difficulties in Total Ozone Mapping Spectrometer (TOMS) and stratospheric ozone data from Solar Backscattered Ultraviolet

(SBUV), data was faulty. Later Ozone is measured through OMI and Microwave Limb Sounder (MLS) from Aura satellite for analyzing the Global Modelling Chemical Transport Model for seasonal variations in Saharan desert. The OMI and MLS has given daily basis data on global level of Tropospheric Column Ozone (TCO) to and Stratospheric column ozone (SCO) continuously without any problems and give better readings on tropospheric ozone and tracking pollution at any region even any current measurements have residual and retrieval problems from instruments used in satellites (Ziemke *et al.,* 2006).

2.2 Tropospheric Ozone in Pakistan

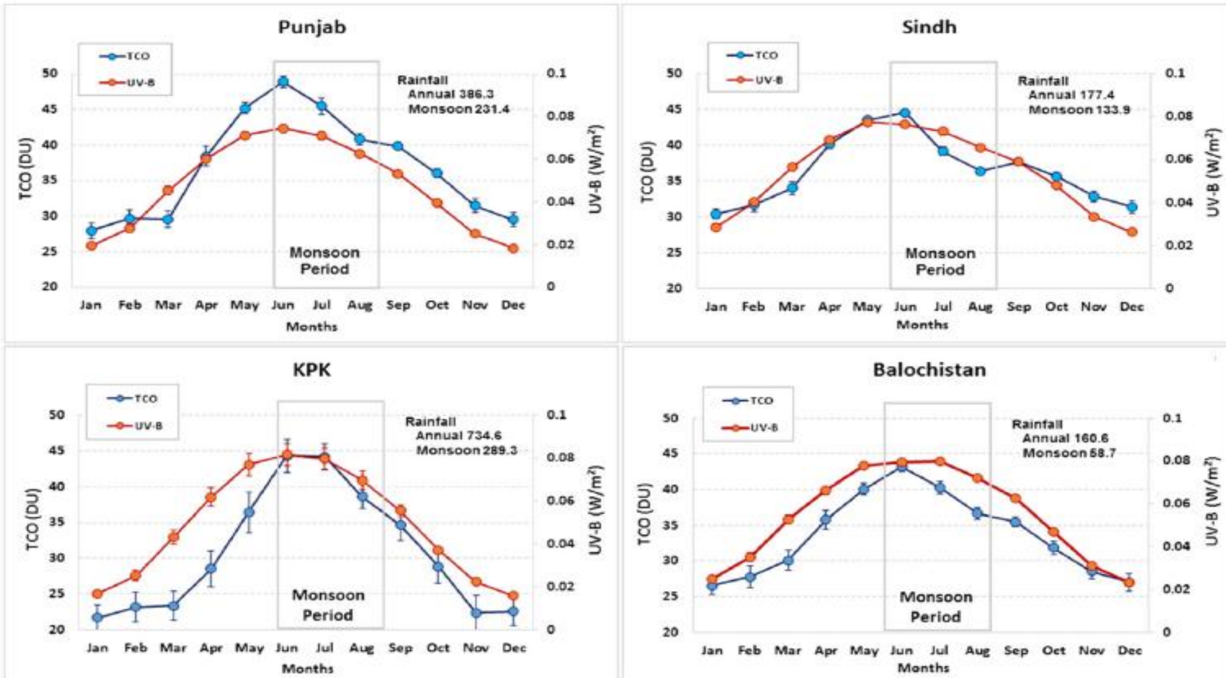
For the case of Pakistan, study is conducted to find the tropospheric ozone levels from Aura satellite and got an observation from OMI and MLS and by using the residual method, used to evaluate changes from 2004-2014. The results showed an overall increase of 3.2 ± 1.1 DU over Pakistan, pertaining to the fact that Punjab and Sindh showed a temporal increase in O3 due to urbanization, high population density, and anthropogenic activities. Seasonal variation showed that UV radiation and temperature have an impact on O3 formation through its precursors NOx and VOCs. The study shows the troughs and peaks of tropospheric Ozone for 11 years that shows the mean Tropospheric ozone changes in October-January, February- May, and June-September, which shows mean concentration of almost 30 DU in October which lowers to 18 DU in February and ultimately rises to 44 DU in June for the year 2004. Similar changes are seen for the next years and peaks at tropospheric ozone concentration is higher in summers and lowest in winters. Total relative change is calculated as 10.6% throughout the years as shown in Figure 1 and 2. Punjab has a greater level of Tropospheric ozone levels with respect to mean temperature, indicating other factors that might be contributing to increased ozone. It could be more concentration of NOx, VOCs or wind speed variation or increased population or urbanization on the ozone level (Noreen *et al.,* 2018).

Figure 1: Tropospheric Ozone columns over Pakistan from Oct 2004-14



Source: Noreen *et al.,* 2018.

Figure 2: Shows the annual average changes in tropospheric ozone from 2004-2014 as compared to UV-B (temperature) throughout the year for provinces of Pakistan



Source: Noreen *et al.,* 2018.

3. Research Design & Methodology

Ozone can be measured from the satellite AURA that is controlled by NASA, using OMI and MLS instruments. The tropospheric column ozone (TCO) and Stratospheric column ozone (SCO) derived from OMI and MLS instruments and Total Ozone Mapping Spectrometer (TOMS) instrument from the NASA database. The procedure entails subtracting SCO from OMI total column ozone to get residual tropospheric column Ozone, after adjusting for inter-calibration differences of the two instruments using convective cloud differential method. The derived TCO gives continuous daily hourly based, monthly and yearly data since August 2004 until now (Ziemke *et al.,* 2006). It is used for the global seasonal and regional study of Ozone and other pollutants like NOx, CO2, SO2, Particle matter, and aerosols. The data on tropospheric will be abstracted from 2010-2017 from NASA website. The data provided was in an unprocessed form that is per month readings for each day observations from Aura through OMI and MLS at all latitudes and longitudes covering the vertical atmosphere of the Earth that measures Tropospheric Ozone levels.

The method used in this paper deployed monthly data to be divided into winters and summers based on the average temperature per month. April to September was selected as summers due to an average temperature higher than 20ºC and from October till March was selected as winter due to a lower temperature. This dissection of data was done to handle the large data set and assimilating the data into smaller portions so it's easier to explain and identify the changes. Raster images for winters and summers were constructed using ArcMap 10.5 and Rstudio. The spatial analyst extracts data by the mask and then Inverse Distance Weighted (IDW) was used to interpolate images from latitude and longitude concentration values. Per year change was obtained from raster calculator from subtracting later year map from the previous one. For the analysis of Pre-CPEC and Post-CPEC concentration levels of tropospheric ozone, the average was taken for years 2010 till 2014 and year 2015 till 2017. Later average map for 2015-17 was subtracted from average raster image of 2010-14 using raster calculators to obtain changes in TO3 levels.

4. Results

Pakistan is South East Asian Country that is located at latitude 24º to 37º N and longitudinal extension of 61º to 76º E and with total areas of 7,960,951 square kilometers. The North of Pakistan is covered with Karakoram and Himalayas range and it separates Pakistan from Chinese Boarder. As for the Project of CPEC, New Silk Road, the aim is to construct a road network from Kashgar to Gwadar for the trade route. The mean temperature in summers is estimated at 38ºC and maximum at 48ºC. The monsoon rain occurs from July to August with May and June being the hottest days in Pakistan. Through the temperature data and keeping in context the effect of high temperature in providing favorable conditions for tropospheric ozone formation, we take April till September as months for high-temperature months and October till March as low-temperature periods as shown in Table 2.

Table 2: Monthly mean temperature for the year 2010-2015

	2010	2011	2012	2013	2014	2015	Average per Month	Summer	Winter
January	10.3	8.5	7.9	9.3	9.3	9.6	9.2		X
February	11.9	11.4	9.1	10.9	10.4	10.5	10.7		X
March	19.9	17.3	16.4	14.7	15.9	15.9	16.7		X
April	24.7	21.7	21.9	21.9	22.1	23.1	22.6	X	
May	27.3	28.1	26.3	27.1	25.8	27.1	27.0	X	
June	28.5	30.0	28.9	29.8	30.2	29.3	29.5	X	
July	28.9	29.0	29.7	29.6	29.8	28.7	29.3	X	
August	27.8	28.2	28.2	27.7	28.4	27.7	28.0	X	
September	25.4	25.6	25.3	26.7	26.3	25.2	25.7		
October	22.7	21.9	21.0	23.3	22.3	22.3	22.2		X
November	15.9	17.5	16.1	15.8	15.9	16.1	16.2		X
December	10.0	10.4	11.1	11.1	10.2	10.8	10.6		X

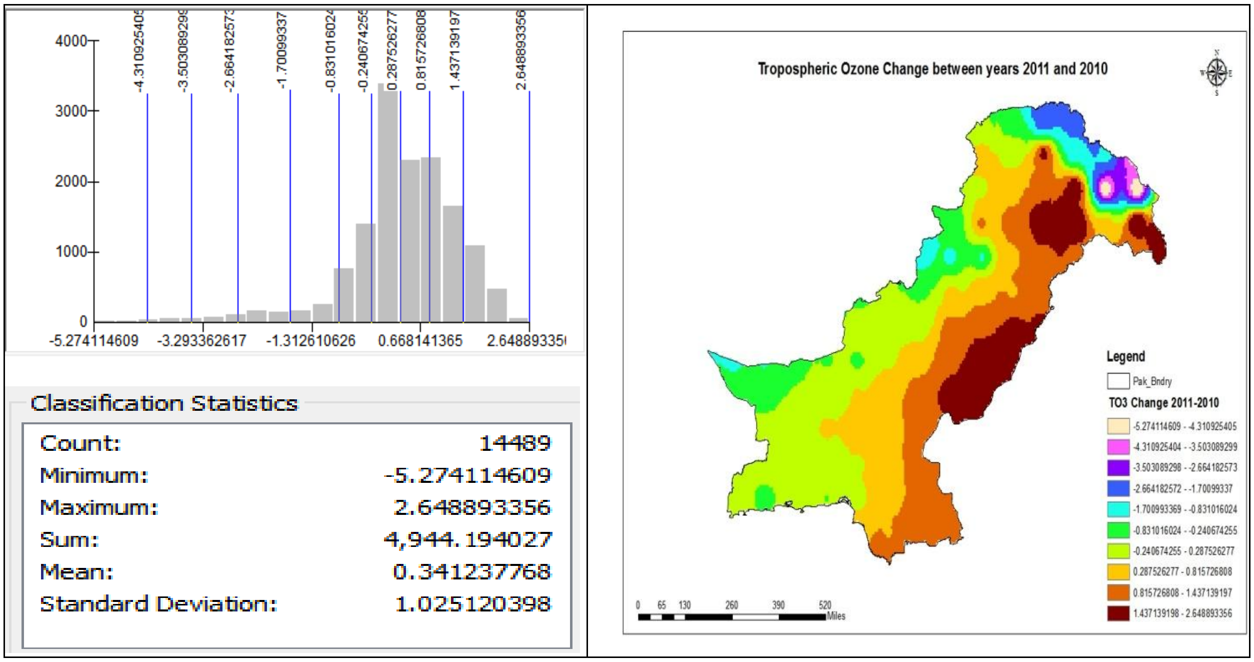
Source: World Bank, 2018.

4.1 Changes per Year in Tropospheric Ozone Concentrations in summer

Through applying IDW and extract by mask instruments through GIS mapping, per year raster images were constructed for summers and winters from 2010-2017. The per annual change was calculated and the results are shown from Figures 3 to 18 where tropospheric ozone level was measured in Dobson Unit and major changes in different regions are highlighted through different color schemes, given dark brown color represents a maximum increase in TO3 levels and beige color represents a minimum change in TO3 levels in Pakistan.

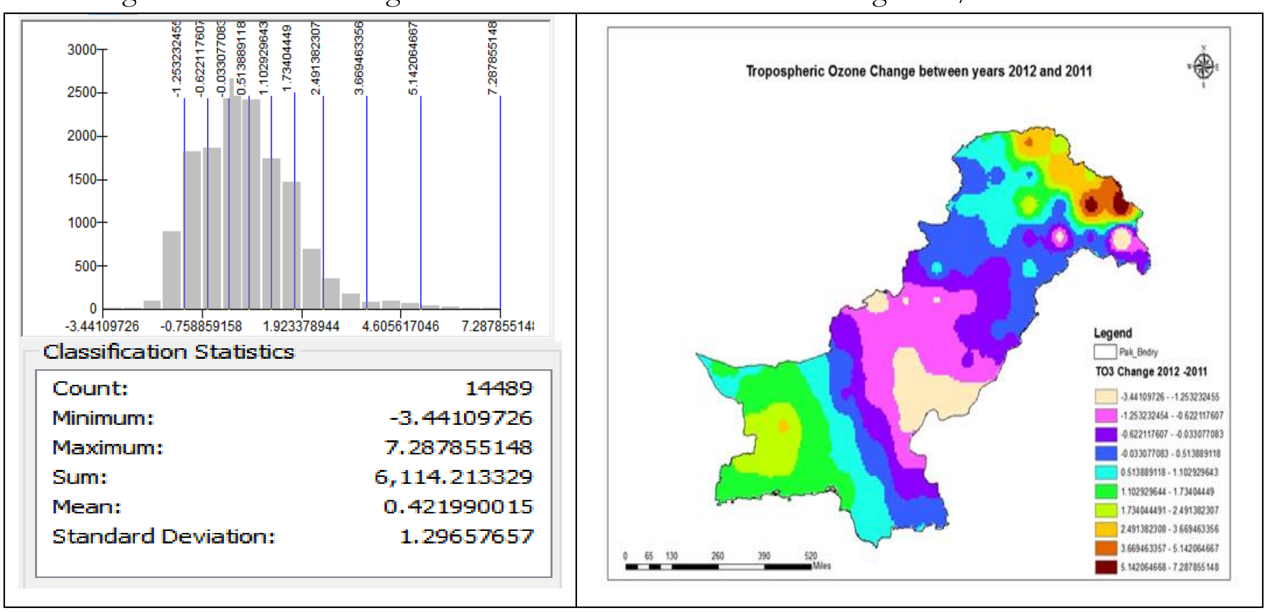
The summer tropospheric ozone change per year is denoted by the raster images from 2010-2017 from Figures 3 to 9, showing mean change of 0.34±1.05 DU in 2010-2011, 0.42±1.30 DU in 2011-2012, 0.66±1.87 DU for 2012-2013, 0.075±0.73 DU for 2013-2014, 1.34±1.12 DU for 2014-2015, -0.75±1.36 DU for 2015-2016 and 0.712±2.51 DU for 2016-2017. The concentration has been highest for the year 2016-2017 where maximum change was seen throughout Pakistan, especially in Sindh with a maximum change of 3.80 DU and other parts of Punjab and Baluchistan as shown in Figure 9. For the year 2015-2016, there has been a decrease in TO3 levels of maximum increase of 2.5 DU and decrease of 9.20 DU in lower Punjab, Baluchistan, and Sindh as illustrated in Figure 8. The increase was only recorded in Gilgit Baltistan region. This unusual result can be further studied and reasons for the decrease in TO3 can be investigated more extensively. The year 2011-2012 have a maximum change in Kashmir region, Punjab, KPK, and Sindh have decreased in TO3 levels as shown in Figure 4 and the increase in Baluchistan and Northern Areas of Pakistan. For the year 2014-2015, the mean change 1.34±1.12 DU is greater as compared to 2013-2014, i.e., 0.075±0.73 DU. This also shows that there is a significant increase in TO3 levels in 2015, due to the commencement of CPEC projects. Further evidence will be provided on it in the next section.

Figure 3: Summer change in TO3 between 2010 and 2011 using OMI/MLS instruments



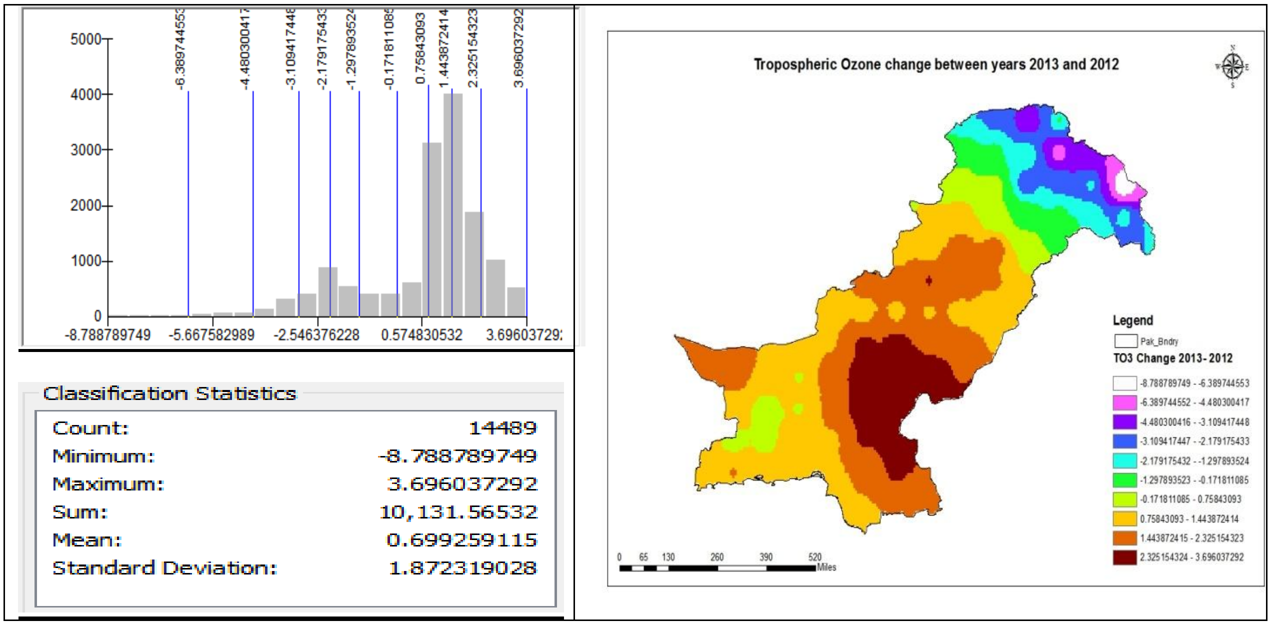
Source: Based on Authors' own analysis.

Figure 4: Summer change in TO3 between 2011 and 2012 using OMI/MLS instruments



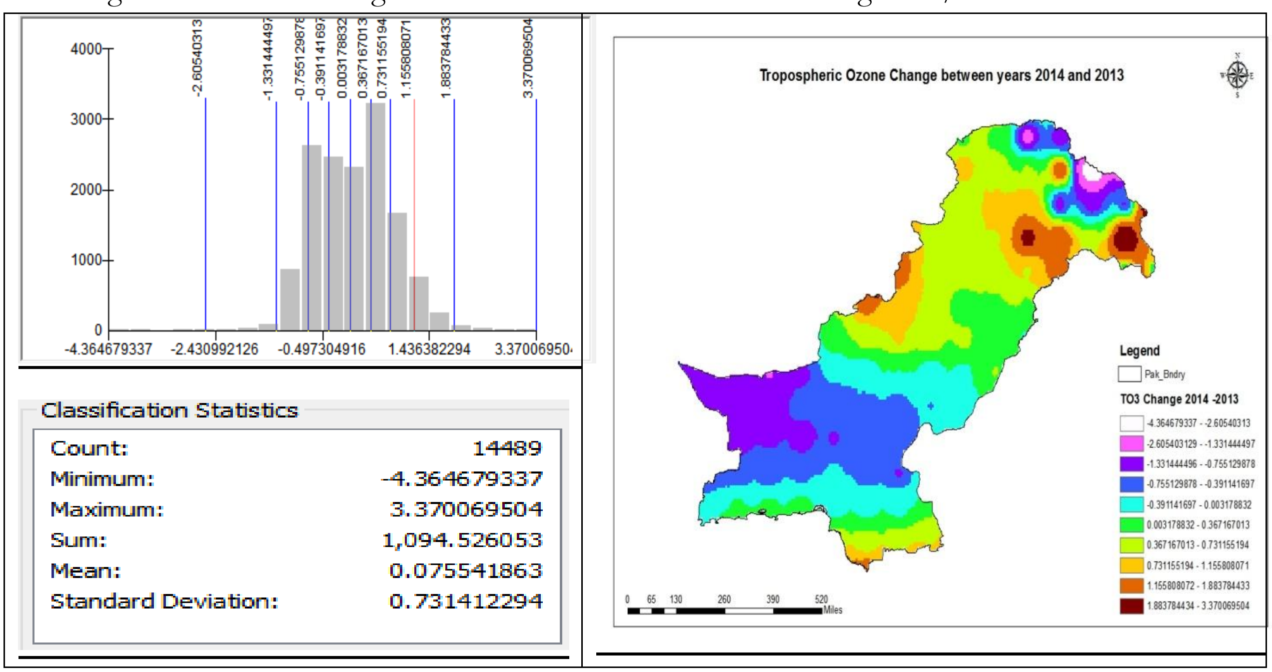
Source: Based on Authors' own analysis.

Figure 5: Summer change in TO3 between 2012 and 2013 using OMI/MLS instruments



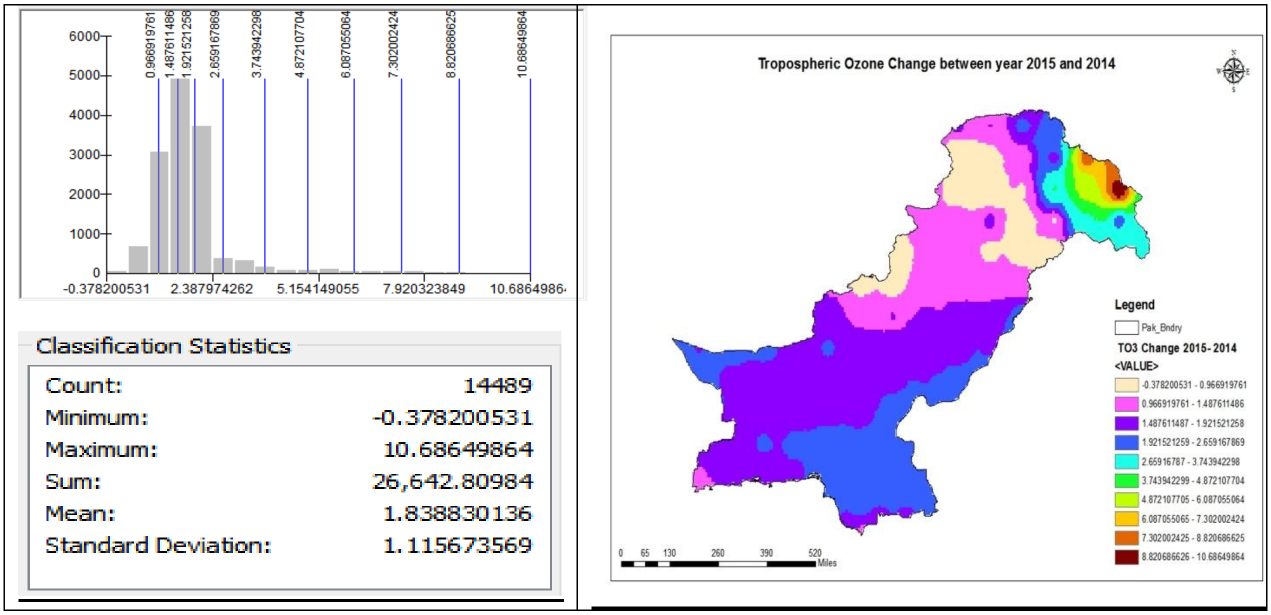
Source: Based on Authors' own analysis.

Figure 6: Summer change in TO3 between 2013 and 2014 using OMI/MLS instruments



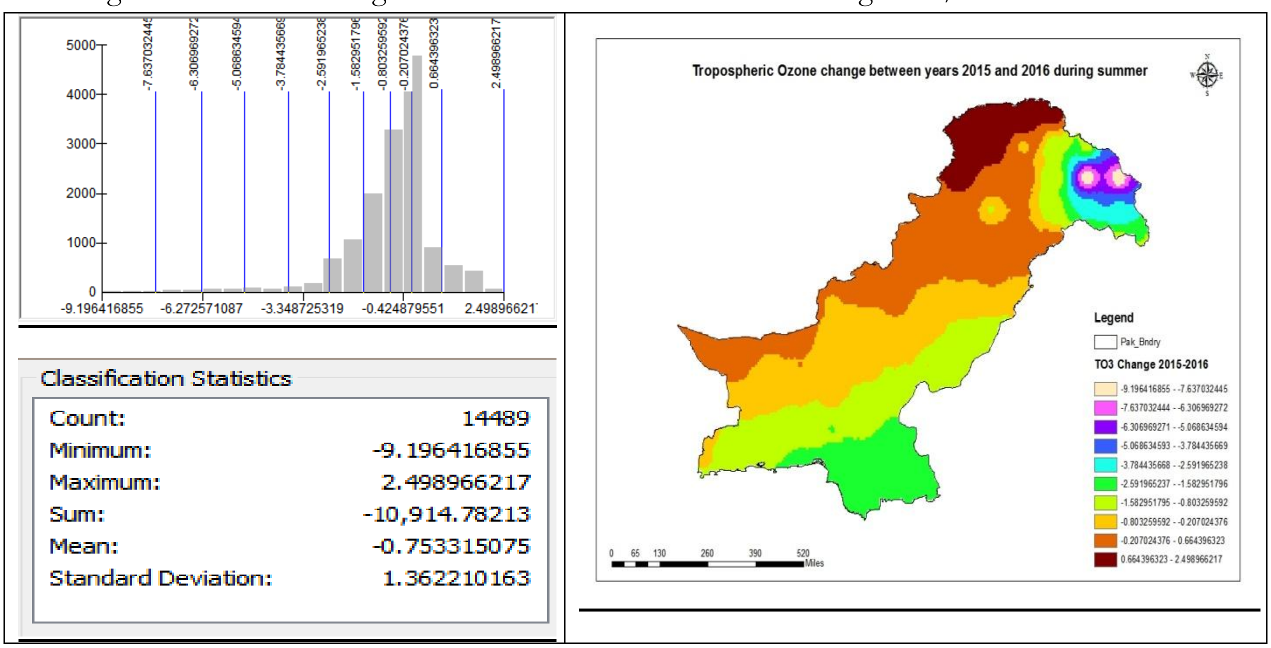
Source: Based on Authors' own analysis.

Figure 7: Summer change in TO3 between 2014 and 2015 using OMI/MLS instruments



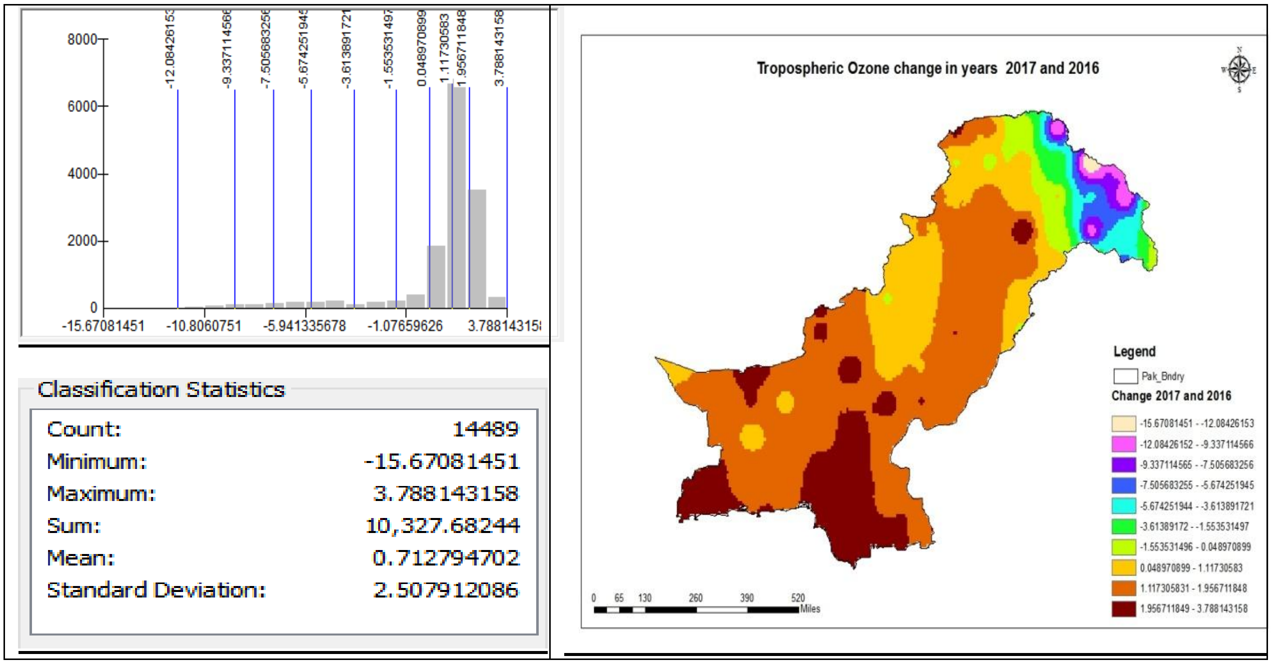
Source: Based on Authors' own analysis.

Figure 8**:** Summer change in TO3 between 2015 and 2016 using OMI/MLS instruments



Source: Based on Authors' own analysis.

Figure 9: Summer change in TO3 between 2016 and 2017 using OMI/MLS instruments

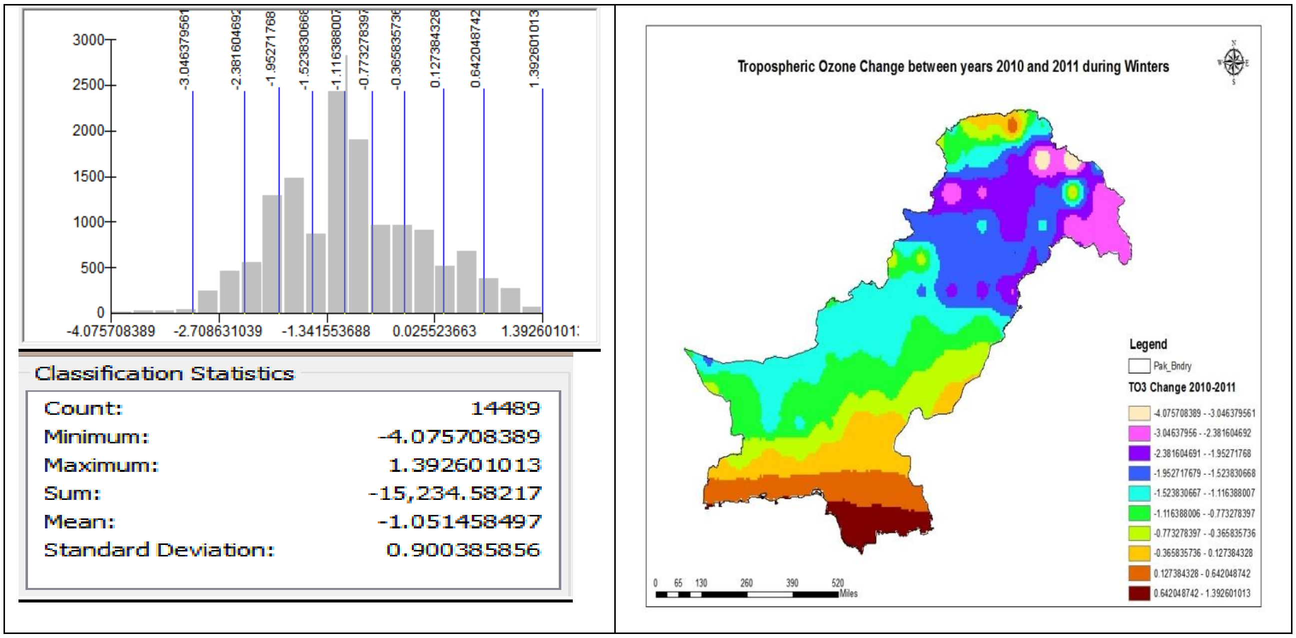


Source: Based on Authors' own analysis.

4.2 Changes per Year in Tropospheric Ozone Concentrations in winters

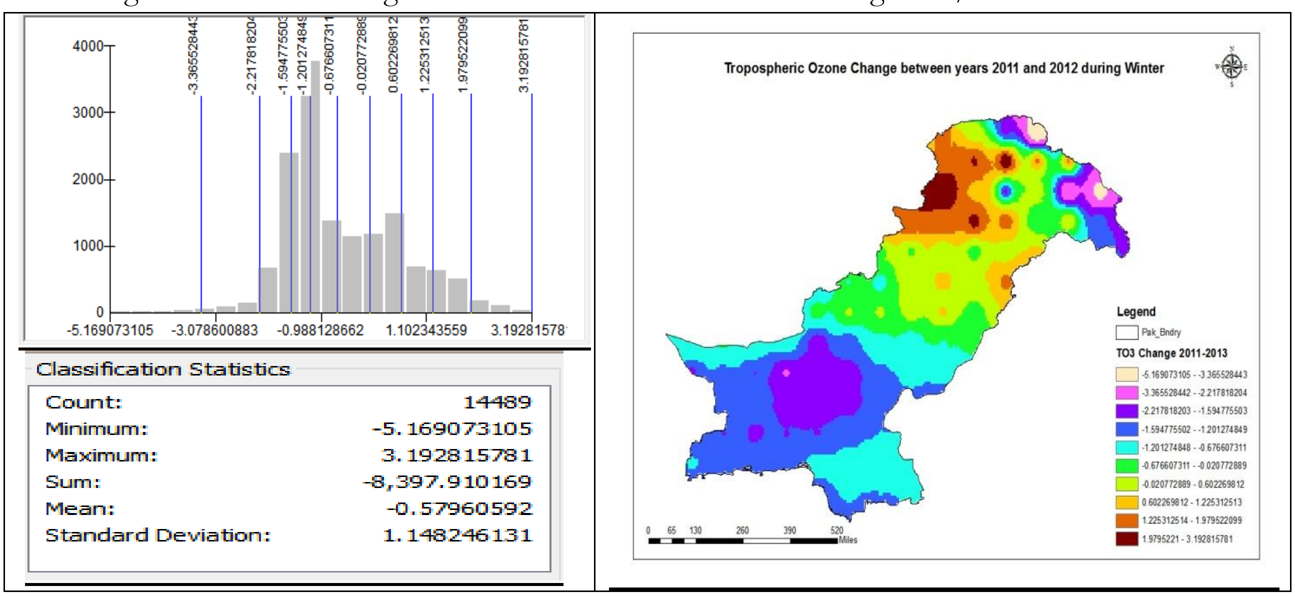
From the rater calculator, changes between raster images of each year, maps for per year change are constructed using ArcMap software as discussed in methodology. The winter mean changes are from denotes increase and decrease in tropospheric ozone levels, i.e., 2010-2011 at -1.05±0.99 DU, 2011-2012 at -0.57±1.15 DU, 0.82±0.93 DU in 2012-2013, -0.30±1.10 DU in 2013-2014, 0.81±1.29 DU for year 2014-2015, -0.26±0.86 DU for 2015-2016 and 1.47±2.23 DU for 2016-2017 as shown in Figures 10 to 16. Mostly due to lower temperatures, the TO3 is formed at a lesser rate from its precursors, but in 2015-2016 and 2016-2017, the change is significant as compared to other years as TO3 level as shown in Figures 15 and 16. Even though mean change for 2015-2016 is negative, but raster image shows an increase in TO3 with a maximum range of 1.5 DU with brown regions mainly in lower Sindh and lower Baluchistan where CPEC energy and other projects are under construction. It also showed certain regions in Punjab where TO3 formation level is higher despite the lower temperature in winters. For 2016-2017, mean change is highest with a maximum increase at 4.92 DU with maximum change distributed in Baluchistan, lower Sindh, and Punjab as shown in Figure 16.

Figure 10: Winter change in TO3 between 2010 and 2011 using OMI/MLS instruments



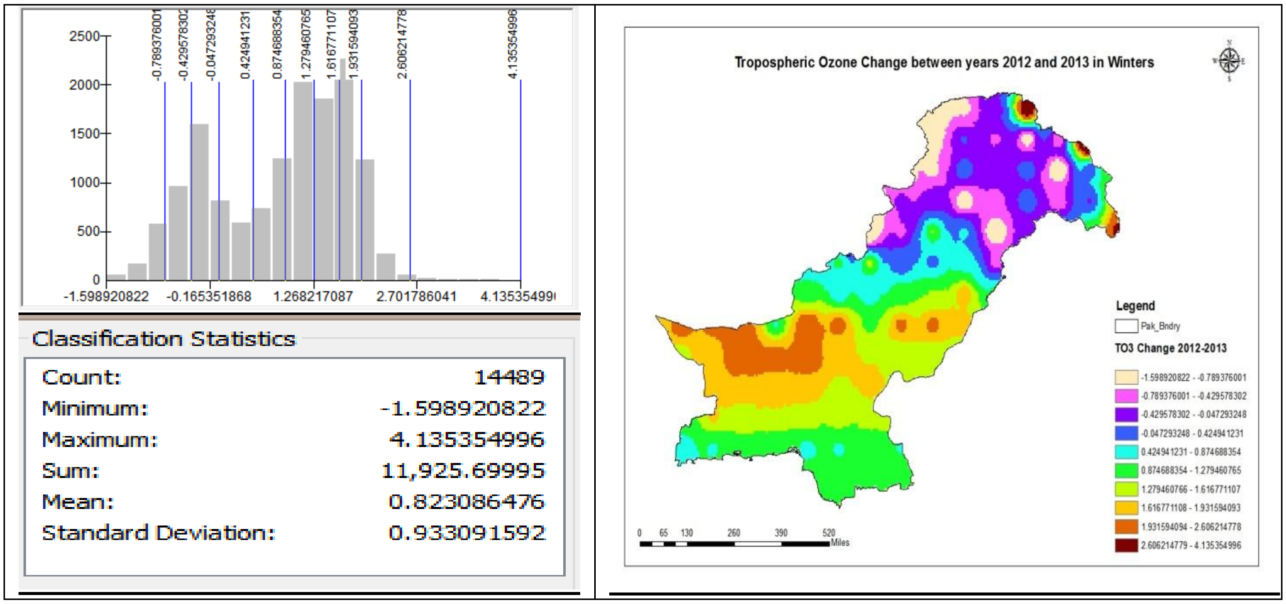
Source: Based on Authors' own analysis.

Figure 11: Winter change in TO3 between 2011 and 2012 using OMI/MLS instruments



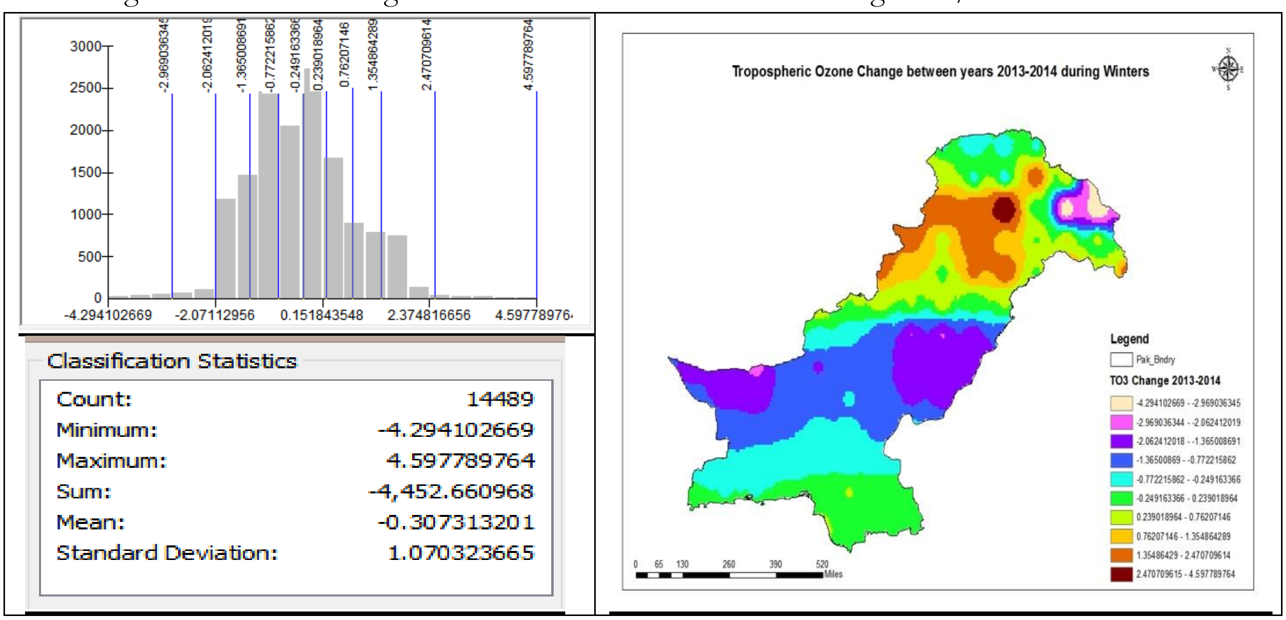
Source: Based on Authors' own analysis.

Figure 12: Winter change in TO3 between 2012 and 2013 using OMI/MLS instruments



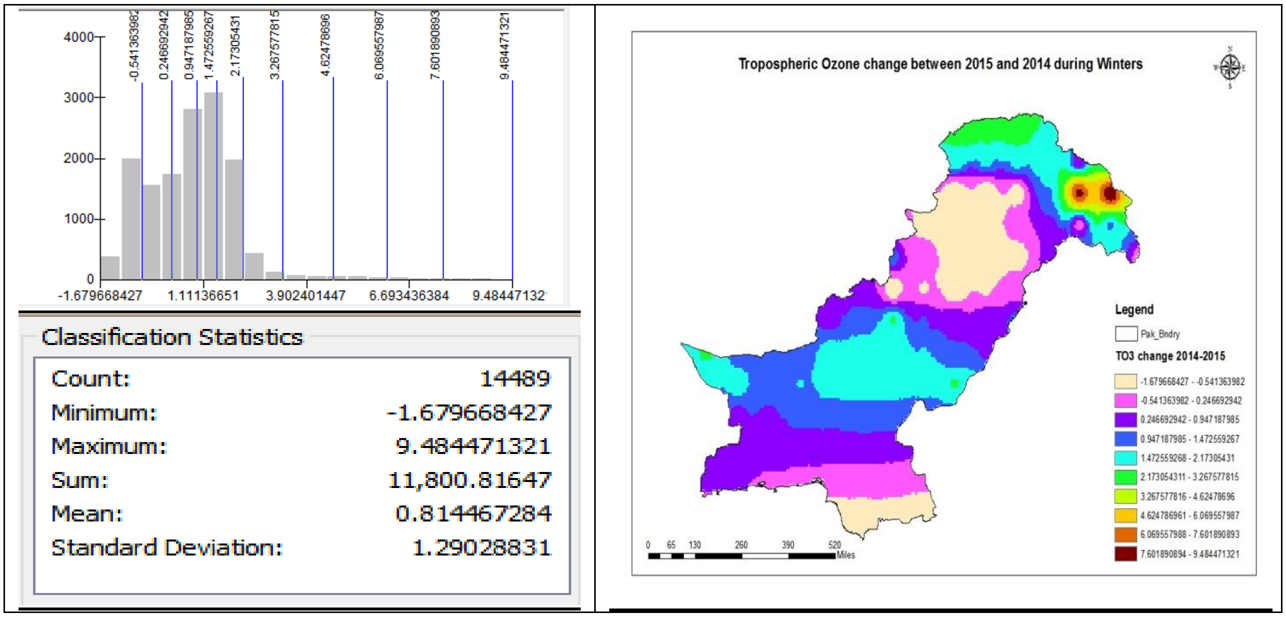
Source: Based on Authors' own analysis.

Figure 13: Winter change in TO3 between 2013 and 2014 using OMI/MLS instruments



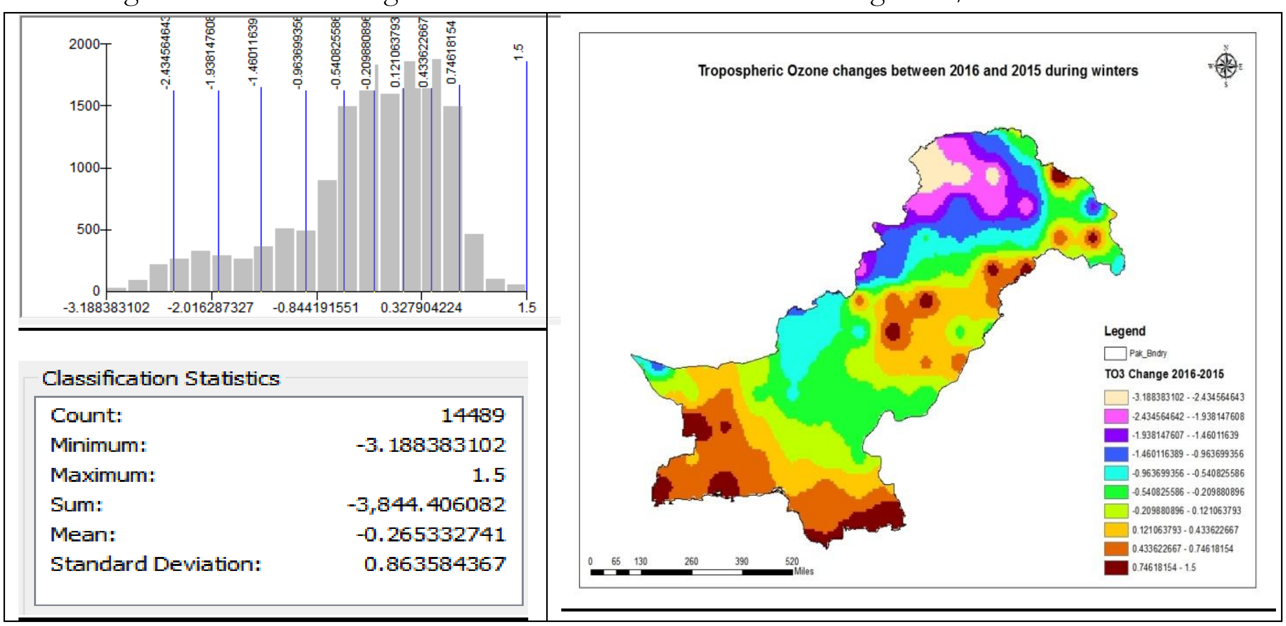
Source: Based on Authors' own analysis.

Figure 14: Winter change in TO3 between 2014 and 2015 using OMI/MLS instruments



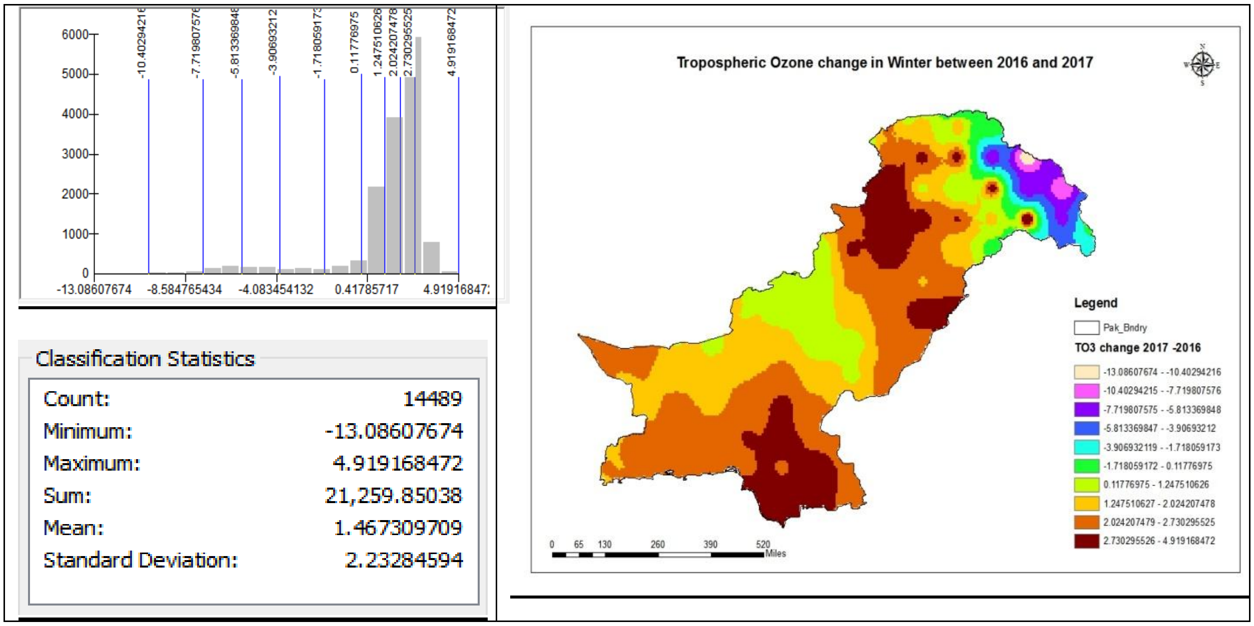
Source: Based on Authors' own analysis.

Figure 15: Winter change in TO3 between 2015 and 2016 using OMI/MLS instruments



Source: Based on Authors' own analysis.

Figure 16: Winter change in TO3 between 2016 and 2017 using OMI/MLS instruments

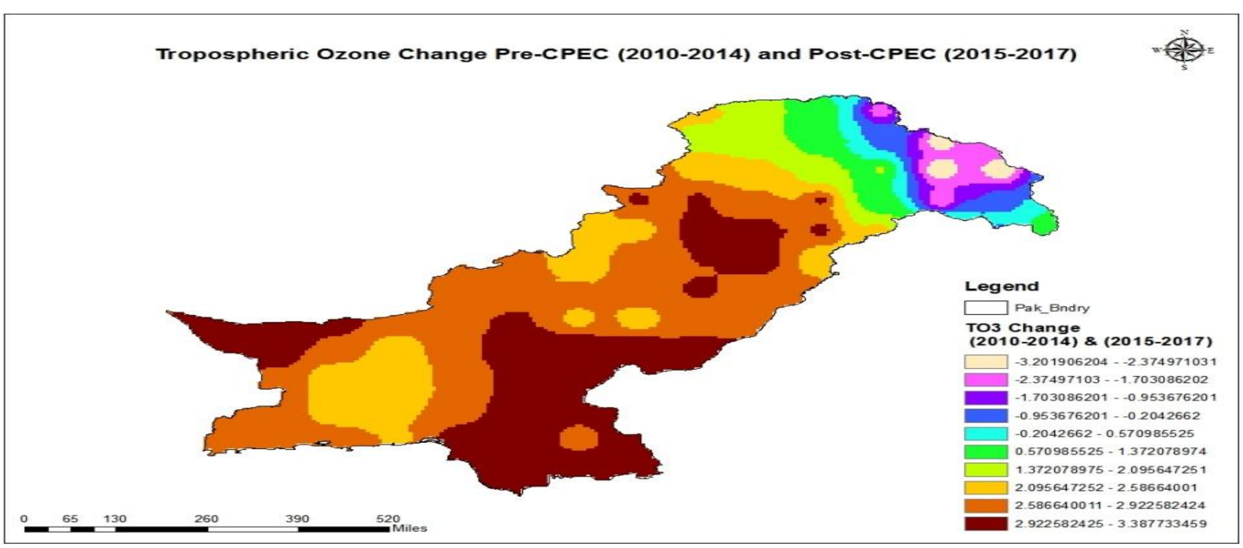


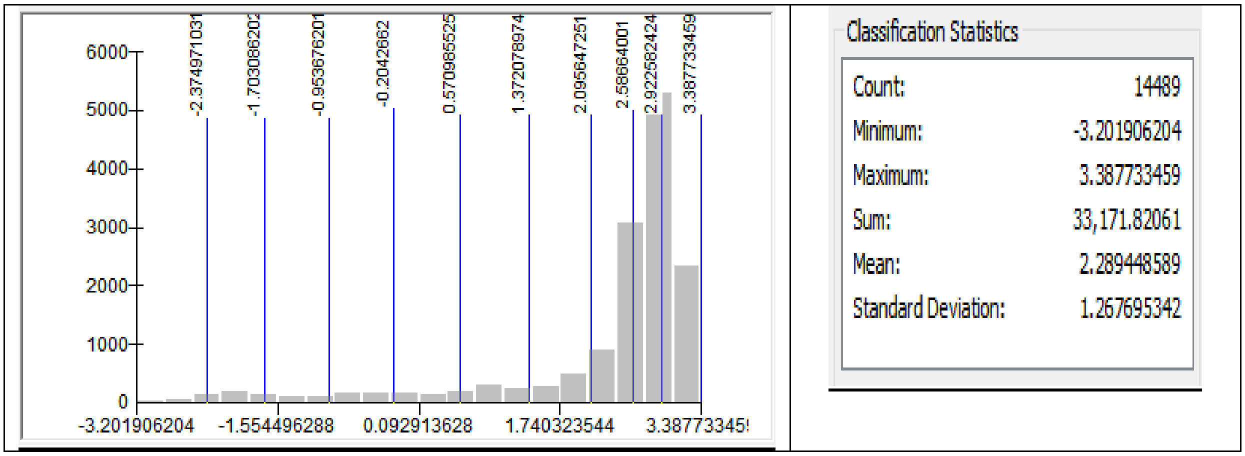
Source: Based on Authors' own analysis.

4.3 Pre-CPEC and Post-CPEC Changes in TO3

Figure 17 shows, changes in Tropospheric Ozone concentration before the advent of CPEC projects and after its commencement in 2015 in summer. The mean change was recorded at 2.29±1.27 DU, with a maximum increase of 3.39 DU and decrease of 3.20 DU. The histogram shows the maximum frequency of change between 2.59 DU to 3.39 DU covering up to 5500 pixels. The most change is distributed in Punjab, Baluchistan and mostly in Sindh.

Figure 17: Comparison of summer change in TO3 pre-CPEC and Post-CPEC

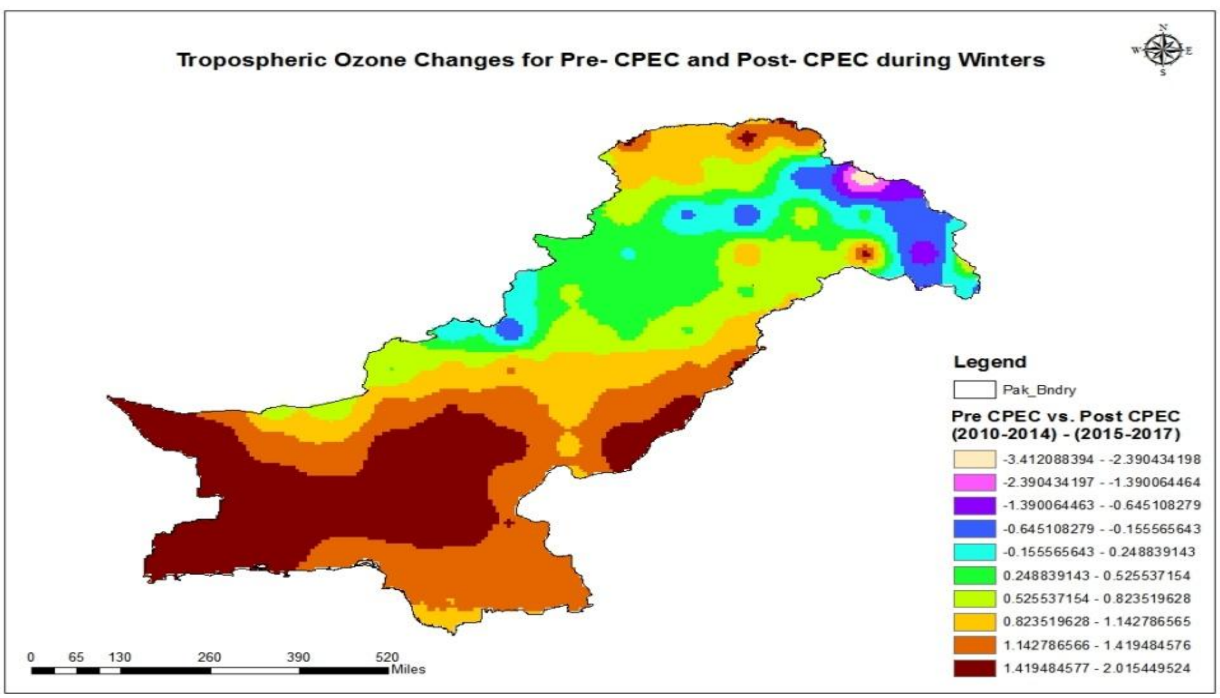


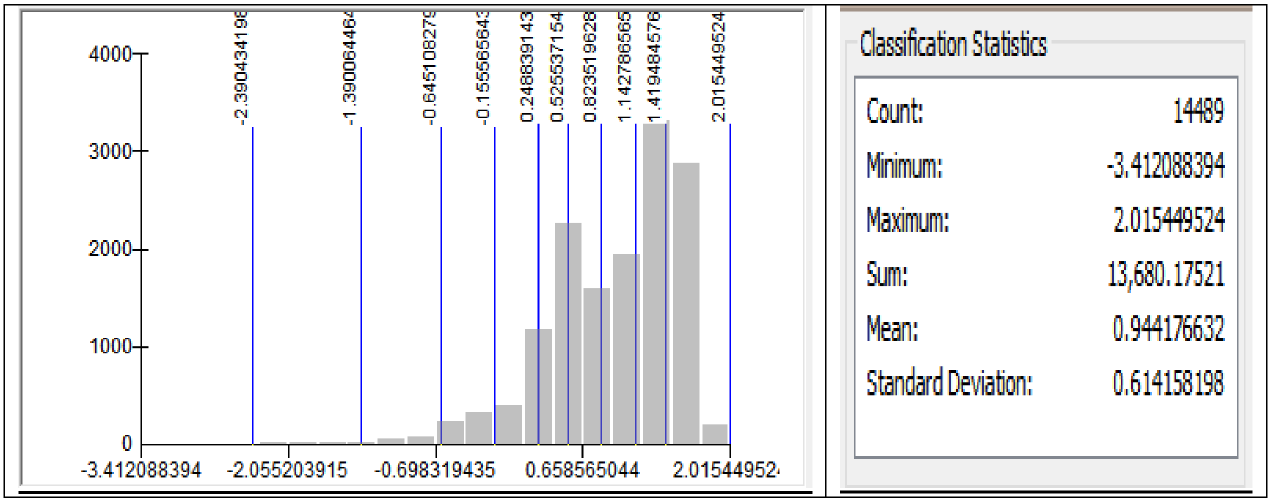


Source: Based on Authors' own analysis.

Figure 18 shows, changes in Tropospheric Ozone concentration before the advent of CPEC projects and after its commencement in 2015 in winter. The mean change was recorded at 0.94±0.61 DU, with maximum increase of 2.01 DU and decrease of 3.41 DU. The histogram shows the maximum frequency of change between 0.53 DU to 1.42 DU covering up to 3500 pixels. The most change is distributed in lower Punjab, Baluchistan, and Sindh.

Figure 18: Comparison of winter change in TO3 for pre-CPEC and Post-CPEC





Source: Based on Authors' own analysis.

5. Findings and Discussions

To estimate Tropospheric Ozone in Pakistan Figures 3 to 16 shows the distribution of Tropospheric Ozone in Pakistan from 2010-2017 for summers and winters. Results showed the increase in the concentration of TO3 in summers as compared to winters with a significant increase in overall levels of tropospheric ozone in Pakistan from 2010-2017 from 44.0 to 49.5 DU. For winters emissions were low as compared to summers ranging from 35.5 to 39.62 DU from 2010-2017 respectively. This shows that summers have higher concentration of Tropospheric Ozone as compared to winters due to reason low temperature from October till March, as analyzed in this study, hence providing similar results with Pudasainee *et al.* (2006) that indicates an increase in TO3 levels due to rise in temperature from March-August and maximum UV radiations in summer time as compared to winters.

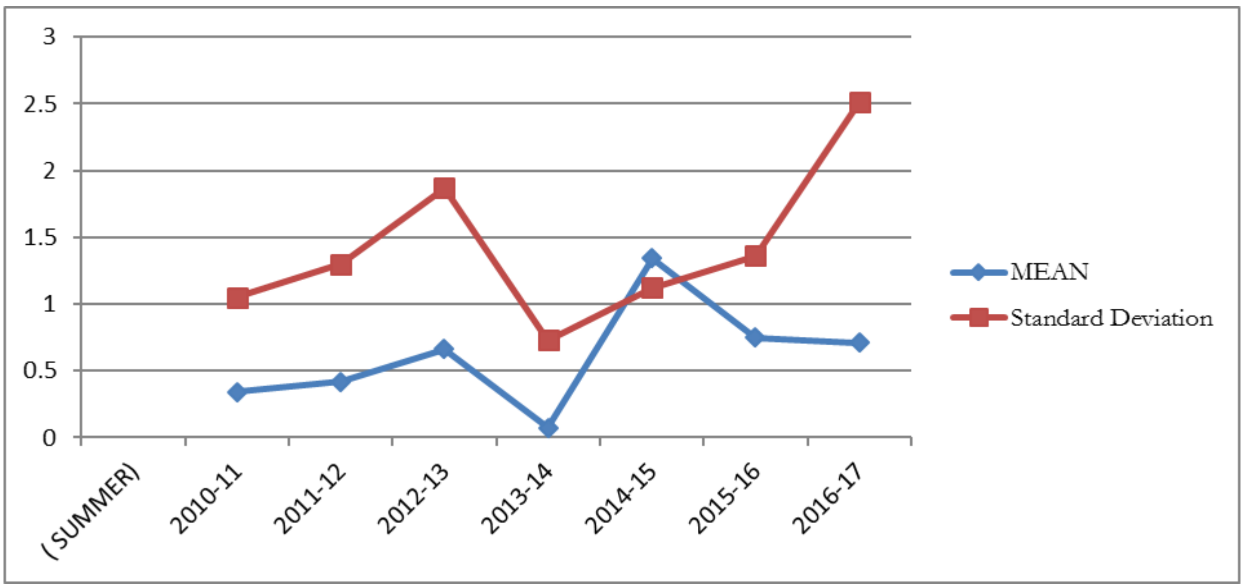
In Table 3 per year change in TO3 for summers from 2010- 2017 show the mean change of 0.34 ± 1.05 between 2010-11, 0.42 ± 1.30 between 2011-12 and 0.66 ± 1.87 change between the year 2012-13. Further 2013-2014 shows decrease mean concentrations of 0.075 ± 0.73 but that further increased drastically with the mean change between 2014 and 2015 of 1.34 DU with a standard deviation of 1.12 indicating to the impact of the start of CPEC in Pakistan. For 2015-16 and 2016-17 per year mean change were recorded at 0.75 ± 1.36 and 0.71 ± 2.51, respectively. The result showed the significant increase in overall tropospheric ozone concentration in Pakistan after 2015 with the highest standard deviation of 2.51 between 2016 and 2017 as shown in Figure 19 graph.

Table 3: Frequencies per year change in TO3 during summer in Dobson Units

Per Year Change in TO3 (Summer)	MEAN (DU)	Standard Deviation (DU)	Maximum (DU)	Minimum (DU)
2010-11	0.34	±1.05	2.65	-5.27
2011-12	0.42	±1.30	7.28	-3.34
2012-13	0.66	±1.87	3.70	-8.79
2013-14	0.075	±0.73	3.37	-4.36
2014-15	1.34	±1.12	10.69	0.38
2015-16	0.75	±1.36	2.5	-9.20
2016-17	0.71	±2.51	3.80	-15.7

Source: Based on Authors' own analysis.

Figure 19: Graphical representation of frequencies per year change in TO3 during summer in Dobson Units



Source: Based on Authors' own analysis.

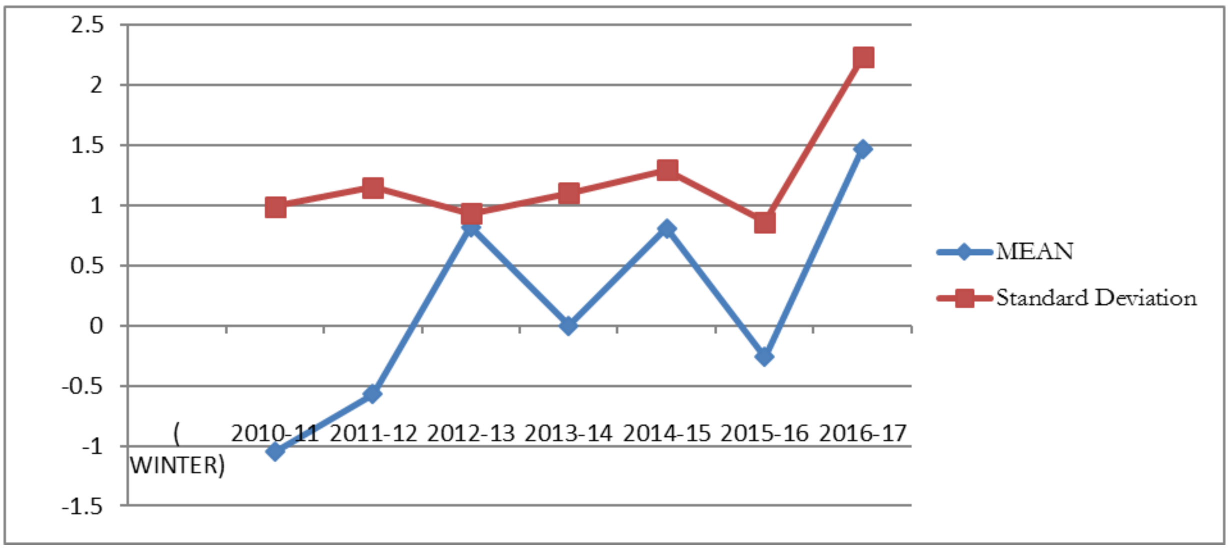
Table 4 shows, per year change in TO3 for Winters from 2010- 2017, showing a mean decrease in years 2010-11, 2011-12, 2013-12 and 2015-16 of -1.05±0.99, 0.57±1.15, 0.3± 1.10 and 0.26±0.86 DU respectively, whereas increase in TO3 was found out in 2012-13 of 0.82±0.93, 0.81± 1.29 DU and maximum increase between years 2016-17 with 1.47±2.23 DU as shown in Figure 20. This substantial rise in tropospheric ozone can be regarded in more NOx emissions in the atmosphere and favorable conditions like temperature, slow winds and presence of precursors of tropospheric ozone (NO, NO2, VOCs) for its formation (Noreeen *et al.,* 2018). Further reasons can be found in depth study. Even though the concentration of TO3 is lower in winters, but because of global warming, glacier melting, climate change as an effect of recent developmental projects under CPEC going on in Pakistan, a significant rise was expected.

Table 4: Frequencies per year change in TO3 during winter in Dobson Units

Per Year Change in TO3 (WINTER)	MEAN(DU)	Standard Deviation (DU)	Maximum (DU)	Minimum (DU)
2010-11	-1.05	±0.99	1.39	-4.07
2011-12	-0.57	±1.15	3.19	-5.16
2012-13	0.82	±0.93	4.13	-1.6
2013-14	-0.3.	±1.10	4.6	-4.29
2014-15	0.81	±1.29	9.48	-1.68
2015-16	-0.26	±0.86	1.5	-3.18
2016-17	1.47	±2.23	4.92	-13.09

Source: Based on Authors' own analysis

Figure 20: Graphical representation of frequencies per year change in TO3 during winter in Dobson Units



Source: Based on Authors' own analysis.

Ever since the construction of the new Silk Road network and energy projects along with other development projects under CPEC multi-billion portfolios, the environmental degradation is immense. With 7000 trucks commuting on a new silk trade route, will not only increase CO2 emissions but also are a major source of VOCs, NOx, carbonyl compounds through incomplete combustion of fuel (Grosjean *et al.,* 1993; 1996, 2002; Tribune 2017; ICUN 2016), can have a significant impact on TO3 levels. The results presented in Table 5 shows, changes in TO3 concentration before CPEC and after CPEC during summer and winters, which indicate significant change in TO3 level due to CPEC with mean change from years (2010-14) and (2015-2017) for summers at 2.29±1.27 Dobson units and 0.94±0.64 increase in winters, so the proposed hypothesis in chapter 1 is that H0 is rejected:

H0: There is no significant change in tropospheric ozone levels with the commencement of CPEC projects from 2015-2017 in Pakistan.

H1: There is a significant change in tropospheric ozone levels with the commencement of CPEC projects from 2015-2017 in Pakistan.

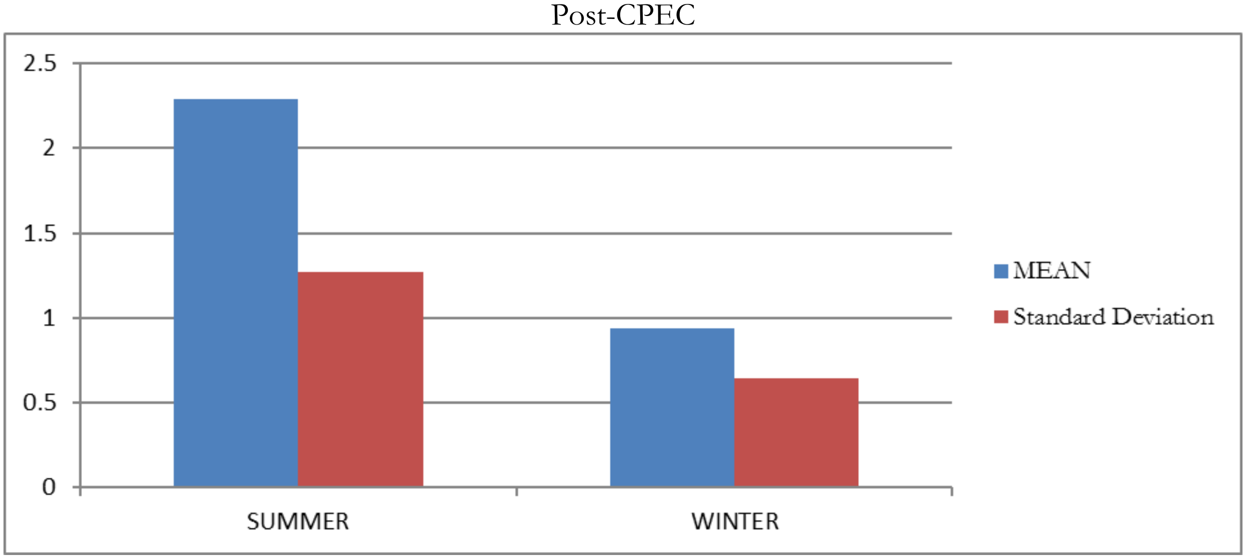
So we conclude from this result that there is a significant change in tropospheric ozone levels with the commencement of CPEC energy projects from 2015-2017. Figure 21 shows mean and standard deviation for both winters and summers for Pre-CPEC vs. Post CPEC changes.

Table 5: Comparison of winter and summer change in TO3 pre-CPEC and Post-CPEC

Changes Pre-CPEC vs. Post CPEC	MEAN	Standard Deviation	Maximum	Minimum
SUMMER	2.29	±1.27	3.39	-3.26
WINTER	0.94	±0.64	2.01	-3.41

Source: Based on Authors' own analysis.

Figure 21: Graphical representation of winter and summer change TO3 for pre-CPEC and Post-CPEC



Source: Based on Authors' own analysis.

6. Conclusions

With the advent of globalization and acceleration in urbanization, the need for socio-economic intensive projects to cater to the needs of growing population, sustainable green development without impacting vulnerable communities, environment and climate change is important. Pakistan's collaborative development deal under CPEC trade route for connectivity has initiated 1+4 projects that include Coal Fired power plants that could intensify air pollution in coming years if conservation, protection, and mitigation techniques are not applied in present. This study tried to evaluate the impact of development projects of CPEC on Tropospheric Ozone Concentration in Pakistan, specifically effect of CPEC projects after 2015. The methodology extracting data from NASA website on Aura satellite from the year 2010-2017. It included GIS mapping by making raster maps and measuring mean changes in TO3 levels per year. The gap of research with no evidence of CPEC as environment-friendly and impact of development projects have on the atmosphere.

This study showed a significant increase in tropospheric Ozone concentration due to CPEC with mean change from years (2010-14) and (2015-2017) for summers at 2.29 ± 1.27 Dobson units and 0.94 ± 0.64 increase in winters, therefore aligning with results of Noreen (2018) about impact of temperature and presence of TO3 precursors and slow winds on tropospheric Ozone levels in Pakistan. This concluded that with more development projects under CPEC underway, the emissions of primary pollutants such as NOX, VOCs have increased and is affecting the level of TO3 in Pakistan.

7. Policy Recommendations

The concerns of environmentalists about air pollution and environmental degradation are ensured and reassurances by Pakistani and Chinese officials can be critically analyzed in the future in reference to environmental protection and preservation. The threat of increased air pollution in future can be assumed from this study because if concentration has increased substantially above the standard levels allowed, for the secondary pollutant, so the assumptions that primary pollutants emissions can be far greater. The probability of smog incidence in Pakistan for future years is high and air quality degradation and impact on human health and agricultural yield is adamant if effects are not mitigated in a proactive manner.

8. Future Study Area

Further studies can be conducted in finding the relationship of NOx in the formation of TO3 and finding the effect of temperature and winds on the TO3 formation. This study can be done in the coming years when all CPEC projects will be operational and more data will be available on Aura Satellite for analysis. The need for mitigation and adaptation policies for environment preservation and decreased vulnerability of Pakistan towards climate change is essential. Revision of standard emissions levels for GHGs is required and importance on adverse impacts of secondary pollutants like TO3 needs to be incorporated in the national policy for the environment. Need for proper monitoring and EP reports for individual CPEC projects and implementation of climate change and environment policies is of high priority in current years, given the transition of country's development through mega CPEC portfolio, so that destruction to the environment is mitigated alongside development goals in Pakistan before it's too late. To mediate this transgression at the part of the ecosystem, sustainable development is targeted as the policy agenda, so substantial compensation is projected towards the restoration of the environment with technological, economic and social progression.

Conflict of Interest

The authors whose names are listed immediately below certify that they have 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.

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