INNSPUB

Journal of Biodiversity and Environmental Sciences (JBES)
ISSN: 2220-6663 (Print) 2222-3045 (Online)
Vol. 18, No. 5, p. 71-79, 2021
http://www.innspub.net

RESEARCH PAPER OPEN ACCESS

Impact of climate change on wheat yield using remote sensing technique

Summra Erum, Sheikh Saeed Ahmad*

Department of Environmental Sciences, Fatima Jinnah Women's University, Rawalpindi, Pakistan

Article published on May 30, 2021

Key words: Wheat, Total column ozone, CO_2, Regression

Abstract

The present study demonstrates the ability of GIS and RS in capturing the spatial temporal data. The changing climatic conditions in the country effects the agriculture. The impacts of climate change are not only restricted to the agricultural productivity of the Pakistan but changing climate also impose destructive impacts on the Land use change practices. Three districts of Punjab i.e. Attock, Multan and Gujrat were selected for analysis of climatic effect on wheat production. The time span that is used for analyzing the change in these areas was from 1999-2014. Climatic changes are not always negative ones but sometimes climatic changes are favoring the increased agricultural production. As the change in temperature and rainfall pattern affects the crop conditions, which changes the net production. It is concluded that for real time prediction of crop yield satellite remote sensing could be used for timely management of food crisis in Pakistan as well as in the world.

***Corresponding Author:** Sheikh Saeed Ahmad ✉ sheikh.saeed@gmail.com

Introduction

Pakistan is an agricultural country and produces different crops including, wheat, rice, cotton, sugar cane, various types of vegetables and fruits. Therefore, Pakistani economy depends on agricultural products, and a growing agricultural trend contributes to 24% of gross domestic product (GDP). This growing trend is not only important for food production, but also for the agricultural industry. Due to increase of population, the demand for food puts pressure on farmers to increase their yield. Therefore in Pakistan, two main approaches are being taken to increase agricultural production. One is to increase acreage by converting areas of other classes into agricultural areas and second is to increase yield per hectare (Qasim *et al.*, 2011). However, according to some studies, growing population, poverty level and limited arable land and made Pakistan extremely vulnerable to food insecurity.

Interestingly, climatic conditions hugely impact agriculture, which is a major economic strength. The changing in metrological variables makes it susceptible to the definite productivity of the agricultural sector, making it economically and physically vulnerable. Production is usually influenced by different climatic conditions, including rainwater routing, heating, and improving sowing, along with collection days, water accessibility, and soil suitability. Local climate change may not have major general side effects, but local side effects are usually very intense. Therefore, climate change is seen as one of the main factors influencing agricultural yield in Pakistan. Climate change is mainly triggered by anthropogenic interferences that lead to global warming. While higher carbon dioxide concentrations can have a beneficial effect on the harvest, increasing temperatures, and lower rainfall have a negative impact on the biological complex. Changes in climatic conditions have jeopardized agricultural productivity, reduced agricultural productivity and reduced income growth (ADB, 2009). In the Earth's atmosphere, the trace gases which are most important, experience hasty changes in their concentration which are mainly caused by human activities. The most important variations include the surge in atmospheric tropospheric ozone (O_3) and carbon dioxide (CO_2). Starting from the pre-industrial era, two major anthropogenic greenhouse gasses that have been responsible for changes in global temperature are CO_2 and O_3. Nevertheless, both these gases have multiple effects on crop productivity. Based on empirical data, photosynthesis rates are stimulated and perhaps the water consumption of plants is reduced if CO_2 concentration is increased, which ultimately affects the plant growth and final yield positively. On the other hand, tropospheric O_3 very phytotoxic if used as a strong oxidizing agent as it results in a negative effect on plant growth and causes yield loss by preventing many physiological processes and photosynthesis by causing oxidative stress in the plant cells after using stomata for penetrating the leaves. There is a clear lack of research regarding how CO_2 and O_3 interact with each other which has resulted in a huge knowledge gap in this area, even though, extensive research has been done on the independent effect of tropospheric O_3 atmospheric CO_2 on plant performance. Since it has been proven by scientific evidence that the crop quality is also affected by either CO_2 or O_3, in the coming times it will be of vital concern for food security, because this aspect is equally important as the impact caused by CO_2 or O_3 on crop yield. Many physiochemical processes can be affected by an increase in either CO_2 and/or O_3 which, as a result, may ultimately affect the quality of the harvested products by affecting the chemical and physical composition of the crops. In order to analyze the risks on agricultural production that are caused by climate variability, plant models can be utilized as a tool for regional yield potential in a variety of environmental situations, for managing risk variables and for increasing productivity or yield (Meinke *et al.*, 1998).

Many researches have conducted in-detail research to study the overall long-term impact on crop production caused by climatic changes (Cantelaube and Terres, 2005; Challinor and Wheeler, 2008). Literature suggests that, the predicted increase or decreases in wheat production in term of climate change are as follows: In southern Sweden, it is estimated that, by 2050 the wheat production in winter is expected to increase by 10–20% (Eckersten *et al.*, 2001). On the other hand, by 2050, it is estimated that England's wheat production capability may increase by about 15-23% (Richter and Semenov, 2005). However, the situation is not promising in South Australia, where even under all climatic change scenarios, it is expected that the wheat production might shrink by 13.5% to 32% (Luo *et al.*, 2005).

The aim of present study was to estimate the crop yield using remote sensed data and to quantify the impact on crop yield caused by climate change in different climate change scenarios.

Materials and methods

Study Area

For the purpose of this study, three districts of Punjab province were selected i.e. Attock, Multan and Gujrat. Punjab lies between latitudes 27.42° and 34.02°N and longitudes between 69.18° and 75.23°E with the total covering area 205, 344 km². For agricultural purposes, the area of Punjab can be categorized into two regions: Barani and Irrigated. According to the irrigation department Punjab, out of 11.83 million hectares under cultivation in Punjab, 73.66% (8.7 million hectares) of area is irrigated and 26.20% (3.1 million hectares) area depends on rain water for irrigation and agricultural activities.

Methods

To achieve the goals of the study, accurate image acquisition was carried out for the selected districts of Punjab. Satellite images for 1999 and 2014 with zero cloud cover were acquired from USGS Glovis and downloaded from Earth Explorer for all the districts. The present study looked at the climate change from 1999 to 2014 and the effects on agricultural productivity, in particular the wheat harvest in the Attock, Gujrat and Multan districts.Grid data on CO_2 mole fractions was retrieved from report written by Nakamura *et al.*, 2015 and Satellite-based instrumental Total Column Ozone (TCO) data sets was archived from report of Greg *et al.*, 2018.

Results and discussion

Wheat production for all selected districts from 1999-2014 was acquired from Federal Bureau of Statistics. Fig. 01 indicated that there is shifting production in the area. In year 2000-2001, lowest production, and in year 2006-2007, highest production in tons was observed. Yield is also changing one and no persistent yield was found during the study time period. Fig. 02 indicated that there is unstable production in the area. 2000-01 and 2010-11 were the least productive years. 2008-09, 2010-11 and 2012-13 are the highest production years. Overall no significant increase in wheat cultivated was observed.as compared to 1999 yield decreased in 2014-15. In 2000 yield decreased drastically but gradually increase after 2001. Multan wheat production showed overall increasing trend from 1999 to 2014. In Fig. 03 the lowest production was observed in year 2007 and 2011 and highest production in tons was obtained in the year 2008 and 2014. There is least variation observed in the wheat growing area between time periods of 1999-2014. Many factors are accountable for low production. The lowest yield was obtained in all districts in 2010 due to devastating floods. It severely inhibited agriculture in Punjab, and thus this year less space was used for growing wheat. Therefore, minimal production was obtained and productivity was also low. A huge area of wheat cultivation was observed in 2007, and production amounted to 2 2321 million tons, which is the highest result in the country's history, an increase of 11.7 percent compared to last year. However, Akhtar *et al.* (2010) suggested that 23.3 million tons of wheat crops were generated in Pakistan, which was record production in Pakistan's history and caused a fall in wheat prices across the country in 2007.

To control wheat prices from falling before harvest, the government allowed 0.5 million exports tons of wheat in April 2007. The area of crops grown for wheat has grown in recent years for a number of reasons, such as a change in cultivation method and greater crop intensity. Even thanks to the smaller area, the yield has enhanced in recent years due to the use of the best wheat seed varieties for cultivation, the use of fertilizers, the appropriate irrigation system and plant protection products used beside pests and weeds. Many climate parameters have a direct and indirect impact on Pakistan's agriculture, especially when it comes to high monetary yields. Climatic irregularity is not only a problem for Pakistan, but its effects are all over the world. The three climate parameters are plotted in Fig. 04-09 to display their varying patterns.

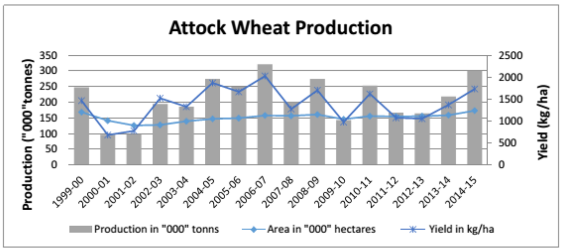

Fig. 01. Wheat production in Attock from 1999-2014.

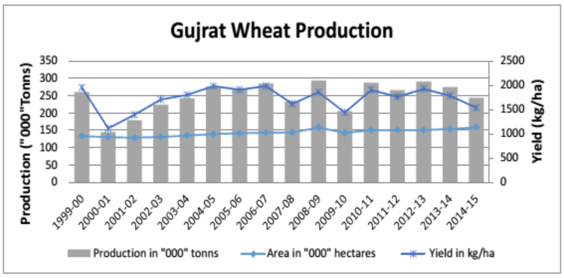

Fig. 02. Wheat production in Gujrat from 1999-2014.

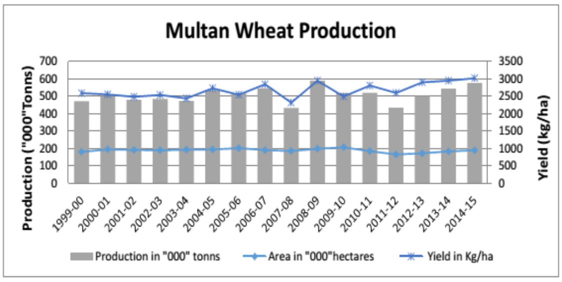

Fig. 03. Wheat production in Multan from 1999-2014.

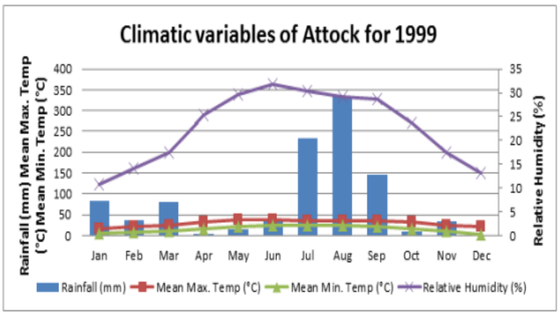

Fig. 04. Changing climatic variables for Attock in 1999.

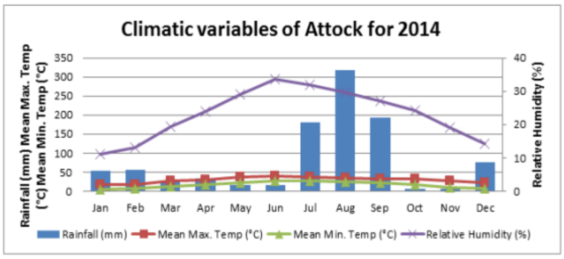

Fig. 05. Changing climatic variables for Attock in 2014.

For the wheat growing period, it lasts from December to early May, and these variables are very vital. Lowest rainfall in April and May and the highest temperature were recorded in May and June. In the case of humidity, it is recorded twice as humidity at 8 am and humidity at 17:00 in the evening. The peak rainfall occurs in August as the monsoon season. In contrast, April and December are months without registered rainfall.

May and October with least rainfall and the highest temperature was recorded in the month of May and June for both the years. The highest rainfall is recorded during monsoon season in the month of August whereas; no rainfall in April and December was recorded.

Fig. 06 and 07 are displaying the changing climatic patterns of district Gujrat in 1999 and 2014. The graphs display no rainfall in November, December and January while highest rainfall recorded in August. The maximum temperature was recorded in June and considered hottest month. However, in September highest humidity level is observed. For district Multan in 1999, three climatic variables are plotted in a graph and the variation in these variables is presented in the Fig. 08. Heaviest rainfall was recorded in the month of July and April whereas, May, June, November, December were the months with no rainfall at all.

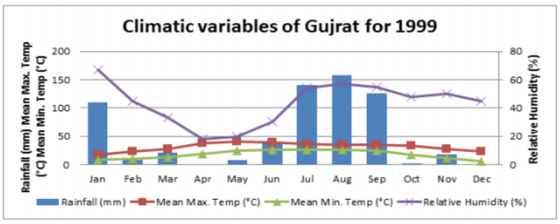

Fig. 06. Changing climatic variables for Gujrat in 1999.

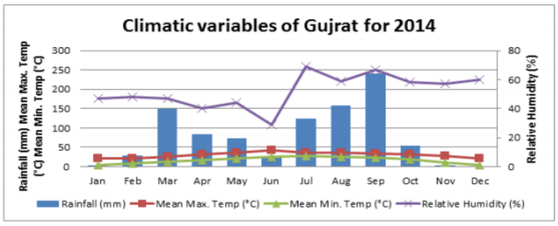

Fig. 07. Changing climatic variables for Gujrat in 2014.

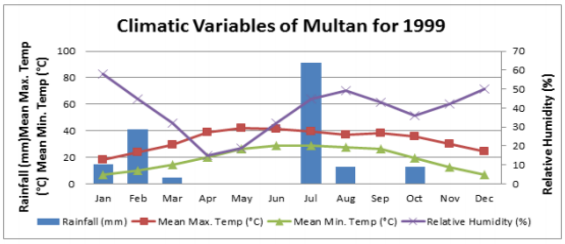

Fig. 08. Changing climatic variables for Multan in 1999.

In the year 2014, Fig. 09 is showing the changing climate for the District Multan. The result indicates that in July highest rainfall was recorded whereas; no rainfall was observed in January, June, November and December. Lowest temperature was noted in the winters as to date, average changes in climate variables with previous weather data have been used to develop climate change scenarios for impact assessment. For example, temperature changes can have a major impact on dry matter production, because high and low temperatures reduce the dry matter production rate and, in extreme cases, can halt production. Variability considerations are important based on estimates of the effects of climate change on world agriculture and food supply.

If the climate becomes incontinent, the distribution of plant occurrences is likely to increase and a short classification of low yield years is likely, with increased severity consequences for global foods. The changing climate applies to wheat crops, and the intensity of the damage varies at different stages, because a variation in temperature or a rise in temperature disturbs all stages of growth. Precipitation is also a significant factor that changes the yield overall since rain in the initial periods is valuable for crop growth, but at the harvest phase higher rainfall is accountable for a decrease in overall production.

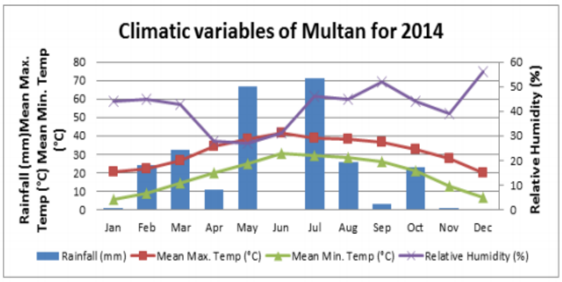

Fig. 09. Changing climatic variables for Multan in 2014.

The graphs in Fig. 10-12 are presenting the variation in rainfall pattern and temperature for all districts. The year 1999 is showing the less rainfall as compared to 2014 for all the districts. Furthermore, the results are showing a fluctuating but increasing trend of rainfall in the recent years as compared in the past especially for 2010, 2011 and 2014 (flood years).

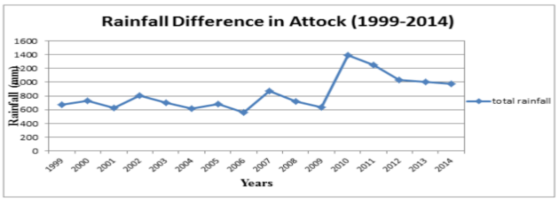

Fig. 10. Changing Rainfall pattern for Attock.

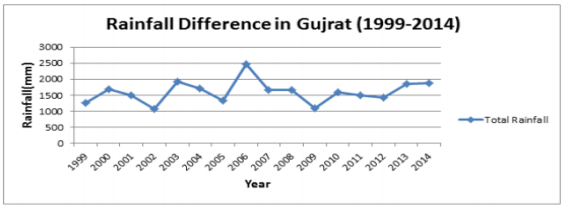

Fig. 11. Changing Rainfall pattern for Gujrat.

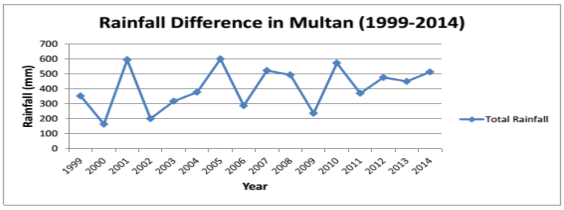

Fig. 12. Changing Rainfall pattern for Multan.

The right quantity of precipitation is the one that affects yields during the wheat growing season (Ashfaq *et al.*, 2011). It is assumed that precipitation has a positive effect on wheat production. But the right amount and duration of rainfall matters. Early rainfall helps promote crops.

Research lead by Khan *et al.* (2004) establish that if timely rainfall increase 1% and availability of water occur due to precipitation, this would increase wheat production by 0.68 percent.

Negative effects of temperature increase stop grain production. Saseendran *et al.* (2000) suggested a rise in temperature reduces yields by six percent, and harvest maturity can fall to eight percent. A 1°C rise in temperature can cause a 7.5% drop in wheat yield during the growing season. Pakistan contributes little to climate change, not only having one of the lowest per capita greenhouse gas emissions in the world, but only 0.5% of total global emissions. At the same time, the country is one of the most serious victims of climate change, steadily falling into a category that is particularly sensitive to many indicators of the effects of climate change -including the Maple Croft Index and the Index Columbia University Vulnerability. The country's real vulnerability to climate change is not a scientific secret, but a logical certainty given its geographic location, altitude and demographics. Air pollution due to population growth is a rapidly growing problem in developing countries, including Pakistan. Other factors contributing to the increase in air pollution include unregulated industry and emissions from vehicles, brick kilns and industry, and air pollution causes several commercial activities, hotels, restaurants, households, and solid waste management. As a result, concentrations of toxic gases such as CO, NOx, and SOx, as well as smoke and dust in the air have increased in recent years (Wahid, 2006). The impact of air pollution on human health has been given much attention in larger cities and suburban areas, but its impact on agricultural production and quality has been less well considered. In many developing countries, especially in parts of Asia, environmental air pollution greatly affects the yield and productivity of forest products. Average wheat yields in Pakistan stagnated between 2000 and 2007, and the population grew significantly, widening the gap between basic food demand and supply (Wahid, 2006).

A comparison of yearly maps of total column ozone (TCO) from GLS observations for the years 1999-2014 is presented in Fig. 16-18. In general, tropospheric Ozone columns have increased in all districts. For Attock, Gujrat and Multan district TCO ranges from 286-311, 286-307, 275-298 respectively. Lowest TCO were observed in 2002. Overall 0.2% increase in TCO was observed in all the districts under study.

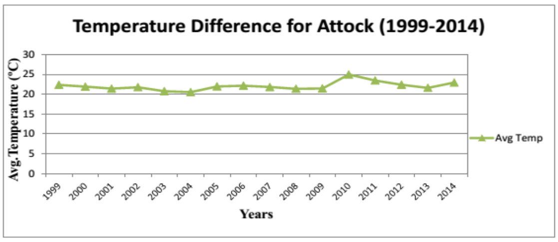

Fig. 13. Change Temperature for Attock.

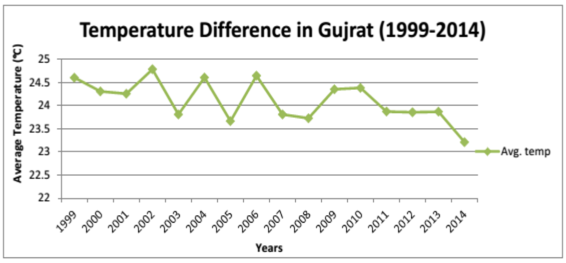

Fig. 14. Change Temperature for Gujrat.

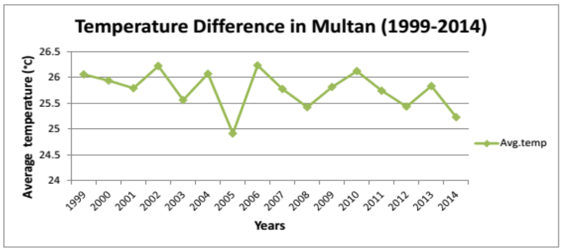

Fig. 15. Change Temperature for Multan.

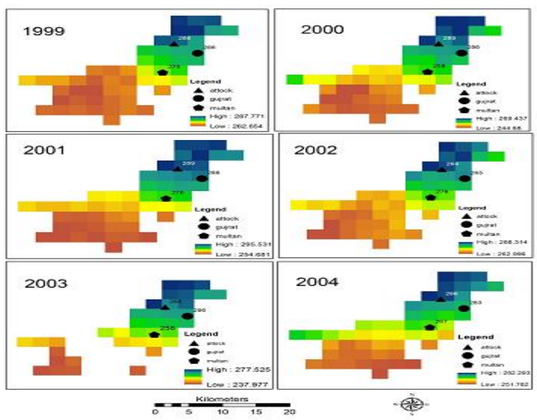

Fig. 16. Total Column Ozone for Attock, Gujrat and Multan 1999-2004.

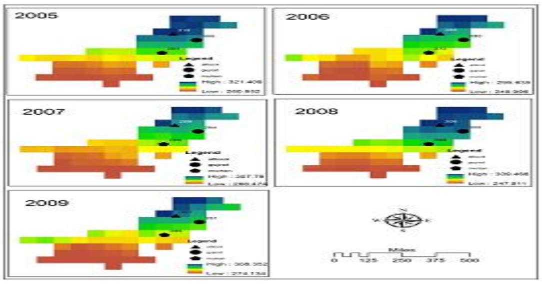

Fig. 17. Total Column Ozone for Attock, Gujrat and Multan 2005-2009.

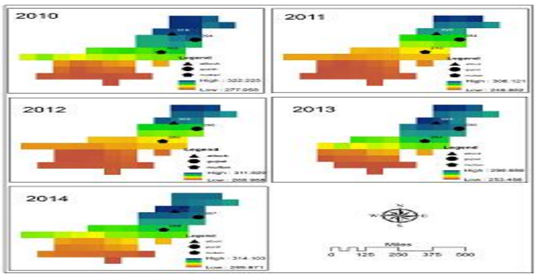

Fig. 18. Total Column Ozone for Attock, Gujrat and Multan 2010-2014.

CO_2 values were also mapped for study period of 1999-2014 for all the study sites and presented in figs 19-21. Overall 0.3% increase has been found in CO_2 concentration. The values observed for Attock, Gujrat and Multan were 369.4-400, 368.7-401.8, and 369.2-401.5 respectively.

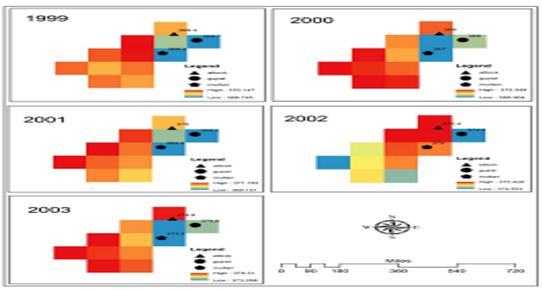

Fig. 19. CO_2 values for Attock, Gujrat and Multan 1999-2003.

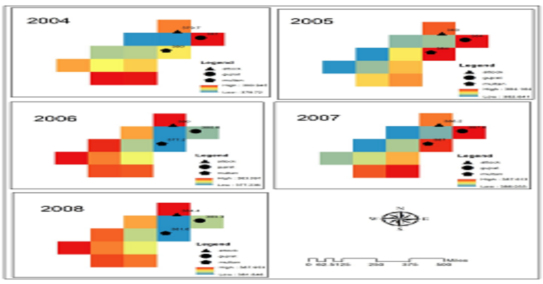

Fig. 20. CO_2 values for Attock, Gujrat and Multan 2004-2008.

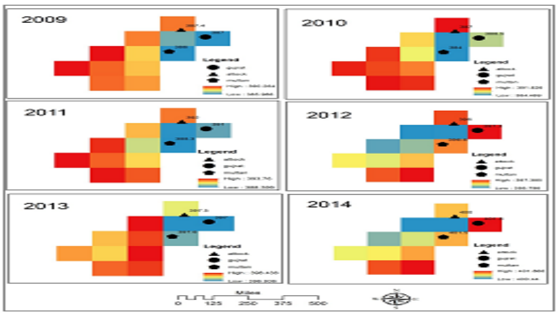

Fig. 21. CO_2 values for Attock, Gujrat and Multan 2009-2014.

Over the past few years, anthropogenic activity has increased the concentration of carbon dioxide (CO_2) and tropospheric ozone (O_3) in the atmosphere. CO_2 improves plant growth, and O_3 surface levels are phytotoxic contaminants. Higher carbon dioxide (EC) showed growth parameters in wheat plants, while elevated O_3 (EO) exposure showed an inverse trend than in EC. With increased $CO_2 + O_3$ (ECO) exposure, fully raised CO2completely protects wheat varieties from the negative effects of O3. In 1980, Pakistan's carbon emissions were documented at 32,067 kilowatts (kt) (World Development Index), and emissions increased by 8%, 10% per year. Total CO_2 emissions in Pakistan have reached 158,000 kilograms (kt) since 2014. The main reason for the large increase in CO_2 emissions is the combination of Pakistan's main energy supply.

In Pakistan, environmental O_3 concentrations have been found to reduce the production of various wheat, rice and soybean cultivars on the Lahore margin (Wahid *et al.*, 1995 and Wahid, 2006). Harvest losses here were estimated at about 40% for wheat and 57% for soybeans and rice. Given the deterioration of air quality and the potential effects of these toxins on crop yields, research is urgently needed to assess the effects of air pollution on crop production and the nutritional value of plants in Pakistan as the agricultural sector is sensitive to the effects of pollution and is critical to the maintenance of a rapidly growing human population (Wahid *et al.*, 2006).

Conclusion

This study shows the capacity of GIS and RS to record spatial time data. The error in estimating satellite yield is due to the variability in wheat phenolic cycle at the time of satellite data collection and field measurements. This study identifies the usefulness of satellite remote sensing methods to obtain agricultural information for large areas in a cost-effective manner that assists relevant agencies. As an agricultural country, we should be able to secure domestic consumption by increasing wheat production levels, and surpluses of production can be exported abroad to earn on currency exchange. To deal with every emerging threat of climate change, the agricultural sector in Pakistan needs some adjustment strategies. Sustainable agricultural development is one of the desirable ways to alleviate climate problems and air pollution, which will further strengthen agricultural infrastructure to ensure a healthy and rich life.

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