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Intervention of Urban Criteria Pollutants in Air Quality: A Satellite Based Analysis of World's Smog-Induced City

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Abstract

Land use land cover (LULC) change, economic activities and urbanization are the leading reasons to change urban environment and air quality. Therefore, the aim of the present study is to use the satellite data to identify the affected towns by criteria pollutants *i.e.*PM_{10}, $PM_{2.5}$ during 2019 and 2021 in Lahore. Results of the study indicate that long term change in LULC is one of the causes to deteriorate the air quality. Stubble burning and metrological factors *i.e.* low rainfall and high humidity also helped to elevate the level of PM_{10} and $PM_{2.5}$. Environmentally, among nine towns of Lahore, Wagah and Aziz Bhatti towns are identified with high concentration of criteria pollutants. Furthermore, high magnitude of PM_{10} and $PM_{2.5}$ are evaluated in November as compared to October. In the light of above results, suitable site has been identified using satellite technique to install Smog Tower for the air filtration. Parallel to this, Liquid Trees may be installed near residential areas with the help of Forest Department and Parks and Horticulture Authorities to maintain the air quality of Lahore.

Keywords: Air Pollution, Liquid Tree, $PM_{2.5}$, Smog Tower, Wagah Town

Full-length article **Corresponding Author*, e-mail:shaziapervaiz@gmail.com

1. Introduction

Smog [1] is the form of intense air pollution [2] composed of a mixture of smoke and fog [3]. Incomplete combustion [4] of fossil fuels [5] emit [6] numerous unburnt invisible tiny particles into the ambient air which are the main constituent of particulate matter [7]. The unburnt carbon particles [8] are known as smoke which on combination with humid air gives birth to smog [9]. In addition, meteorological variables support the smog phenomenon such as low rainfall, wind speed and humidity. Mainly, the vehicular and industrial emissions [10] as well as burning of leftovers of the harvested crops especially rice stubble[11] are the major contributing factors in smog formation (Fig. 1). Every year during October and November, the rice crop [12] is harvested in India and Pakistan and the residues of rice crop are burnt at large scale [13]. The fumes of stubble burning produce smoke and transport to other parts of the region which not only deteriorate air but also produces smog [14].Similarly, Lahore is one of the worst-affected cities by smog having high particulate matter pollution owing to suspended dust, vehicular, industrial and stubble burning emissions [15]. Smog pollution [16] is time-dependent [17]and variable in different locations due to the influence of atmospheric factors [18] and criteria pollutants mainly particulate matter (PM_{10}, $PM_{2.5}$).During winter months [19, 20], particulate matter[21] and atmospheric aerosols [22]accumulate[23] in the boundary layer [24, 25]and presence of high relative humidity [26], low temperature [27] and stable wind speed [28] accelerate the process of smog formation [29, 30]. In addition, land use and land cover (LULC) change increase the quantity of particulate matter [31].

Transformation of LULC, expansion of residential settlements and industrial clusters increase the concentration of particulate matter into the air. Therefore, the present study is conducted to highlight the long-term transformation of LULC over 1992 to 2021with the objective to examine the spatial trend of particulate matterand stubble burning in the nine administrative towns of Lahore by considering the variation in metrological variables such as humidity and rainfall in October and November during 2019 and 2021.

2. Materials and Methods

2.1. Site description

Lahore [32] is 26th [33] mega [34] city in the world [35, 36] and ranked second largest in Pakistan [37, 38]. It is one of the historic cities of Indian subcontinent [39]. The cultural city [40] is the capital [41] of Province, Punjab [42] and a well-known Mughal city [43] of gardens [44]. It is located in the north-east of Punjab [45] and serves as a commercial hub of trade and higher education. Geo-spatially [46], it lies at 31°15'-31°45'North, 74°01'74°39' East [47] and consists of nine [48] administrative towns [49] and one military cantonment [50] (Fig. 2). India [51] is its neighboring country [52]located in its east [53]. Climatically [54], Lahore [32, 54] lies in semi-arid zone [55] where weather conditions [56] vary in summer, autumn winter and spring [57]. Summer [37] in Lahore [58] is associated with monsoon season [59]

while winter [60] is observed from November [61] to February [62]. However, metrological variables of Lahore such as [54] rainfall [63], temperature [64], high humidity [65], wind speed [30] influence the air quality [66] during winter season [67.]Furthermore, Lahore is rich in residential areas [68]; consists of major educational institutes (Fig. 3) [69],commercial organizations [70] including hospitals and parks. The city is also well-known for its largest hub of retail business [71]. On the other side, the institutional and residential density is affecting the environmental quality by creating traffic [72] congestion in Shalamar, Samanabad, Data Gunj Baksh, Aziz Bhatti and Gulberg Towns. While, low-density urban areas increase trip distances [73] worsening air quality.

The city [74] has 2,150 [75] registered small, medium and large industrial units. Its major industrial produce are steel [76] auto parts [77], marble sheets [78], chemicals [79], pharmaceuticals [80], construction materials [1] and engineering tools. In the industrial units, more than two hundred [81] largest steel furnaces [82] are located in the north-eastern and north-western parts of Lahore [83]. The un-planned mushroom growth of industrial units in the high-density residential areas such as Badami Bagh [74] and Data Nagar where steel industries have subsequently built within low to middle-class areas have altered the local environment. However, brick kilns clusters are located in the Shalamar, Wagah [1], Nishtar and Iqbal Towns due to the availability of abundant raw materials[84].

2.2. Data and Method

2.2.1. Satellite data

This research consists of comparative analysis and is based on satellite data [85]. Spatial observation [86] is an economic tool to ascertain information to overcome field monitoring [87]challenges[88] to collect data.

2.2.2. Ancillary data

Air quality is determined by metrological parameters [89]. Therefore, city level data of temperature (centigrade), rainfall (millimeter) was procured from Pakistan Metrological Department (PMD) to evaluate the air quality (Table 1).

Table 1: Description of metrological data

Year	Min. Temp. (°C)	Max. Temp. (°C)	Rainfall (mm)	Rainy Days
2019	17.5	33.8	27.6	6
2021	21.5	35.0	47.8	2

2.2.3. Geographic Information System (GIS)

For analysis, the data is processed using ArcGIS software version 10.5 [1].While, the schematic flow chart diagram [90] for data [1] processing [48], analysis and mapping is presented in Fig. 4.

3. Results and Discussion

3.1. Land Use and land cover

Spatial maps of 1992 and 2021 (Fig. 5) indicate the extent and pattern of LULC classes which are quantified into four dominant land use categories *viz.* water bodies, vegetation, soil and built-up area [90]. Satellite imagery of 1992 and 2021 LULC [91]exhibited that the built-up area of Lahore has been expanded as compared to 1992 and highlighted that Lahore has lost a significant proportion of its tree cover with the passage of time [32]. Similarly, reported results of vegetative cover depletion supported findings of the current study as presented in the early study of Lahore [90]. However, the driving forces behind the LULC change are economic development and haphazard unplanned housing societies. Therefore, LULC scenario consisting of three decades has shown that the city has witnessed vulnerable environment caused by the combination of criteria pollutants (Fig. 5) escalated by human activities.

3.2. PM_{10} trends in October and November (2019 and 2021)

PM_{10} is reported [92] as a criteria pollutant having adverse impact on dwelling environment. Based upon the spatial results of PM_{10} in October 2019 and 2021 given in Fig. 6, it has been observed that highest level of PM_{10} is found in Wagah and Aziz Bhatti Towns. Reasons include the population density, industrial growth and commercial activities as reported in the previous study [1]. On comparison of results of Fig. 6, industrial town *i.e.*Wagah [93] has been noted as the most affected towns by PM_{10} in 2019 and 2021. Moreover, informal industrial clusters established in the Nishtar Town located in the south-eastern part of the city has shown high trend of PM_{10}. Basically, the high level of PM_{10} in Lahore's towns is associated with the economic activities, combustion of substandard fuel and vehicular emissions with the inclusion of metrological elements *i.e.* less rainfall and high relative humidity.

3.3. $PM_{2.5}$ trends in October and November (2019 and 2021)

Fig. 7 demonstrated the trend of $PM_{2.5}$ in the north and north-eastern part of Lahore (2019 and 2021). Results highlighted the increased level of $PM_{2.5}$ during November2021 in Lahore and lowest range was observed in 2019 when lockdown was imposed in the city. Highest values of $PM_{2.5}$ may be attributed to the multiple contributors of air pollution such as stubble or refuse burning, construction and industrial activities, vehicular growth, LULC change and illegal housing societies. However, highest contribution to generate $PM_{2.5}$ relates to the vehicular and fugitive dust *i.e.* 72%whereas industrial role is16% and 12% received from steel industries [83]. Metrological variables of 2019 and 2021 were also the key reasons to elevate the concentration of particulate pollution as reported in the earlier study EEA [94] which support findings of the present study. Significant reduction in $PM_{2.5}$ may be encouraged by reducing air pollutants at source such as by installing pollution control devices in vehicles and industries to get clean air and chance of a healthier environment.

3.4. Stubble burning trends during October and November (2019 and 2021)

Agricultural processes [95] such as 'slash and burn' [96]are the major contributing agents of criteria pollutants creating smog[97] and other is rice straw burning [98]. Stubble burning not only emits greenhouse gases but also release particulate matter into the ambient air which typically peaks during the first week of November [99]. Crop burning emissions combined with vehicular, industrial pollutants and with high relative humidity generate the blanket of air pollution over Lahore.

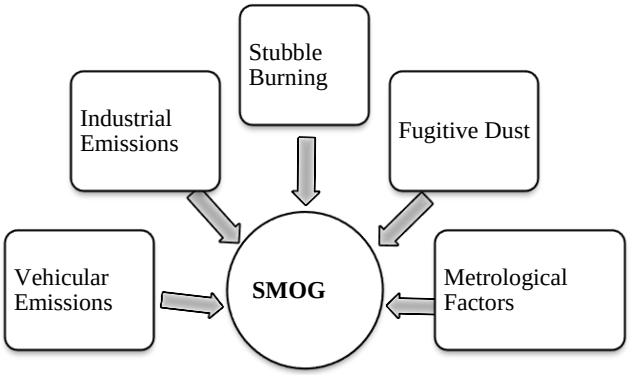

Fig.1. Contributing factors of criteria air pollutants in smog formation

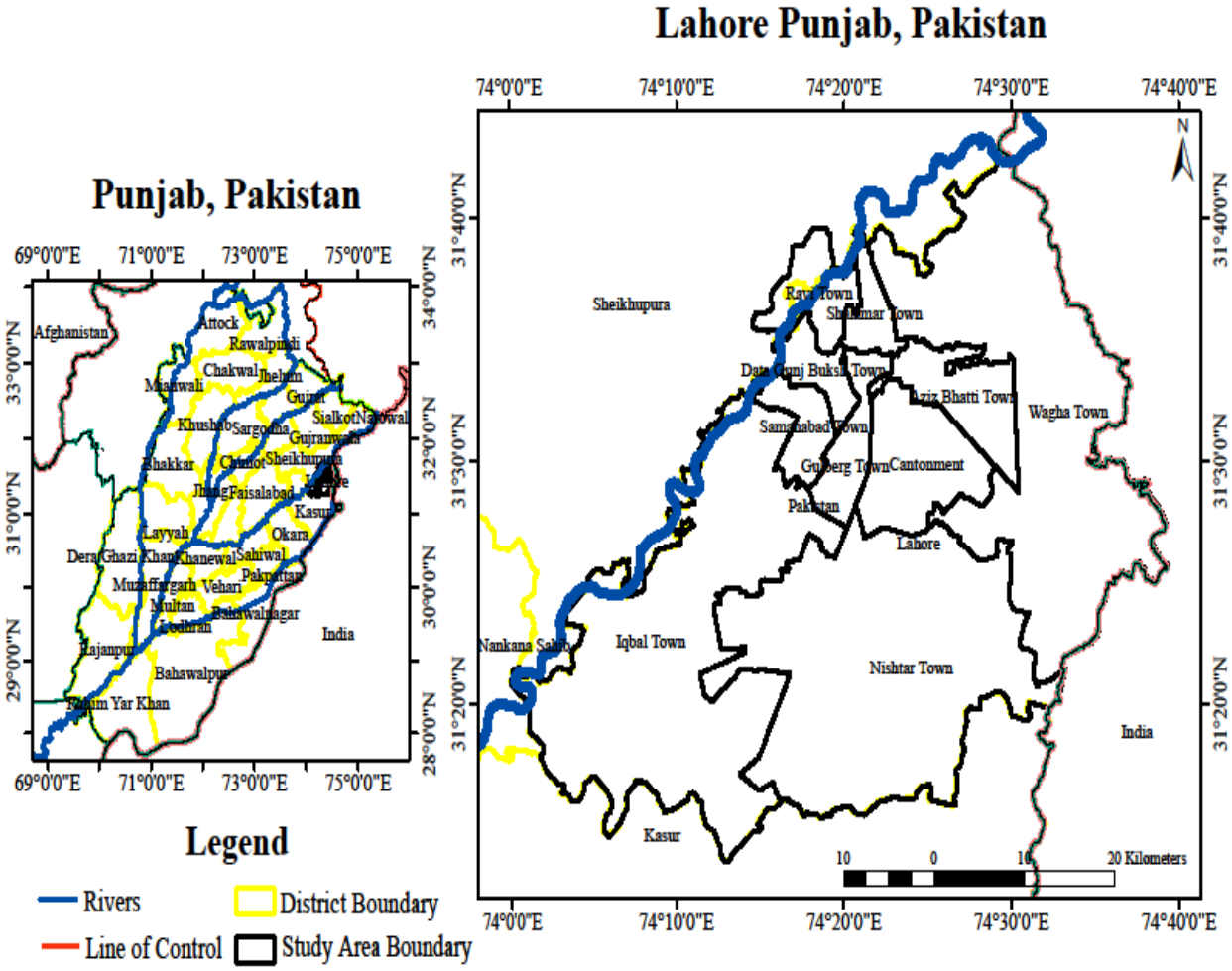

Fig. 2. Map of the study area

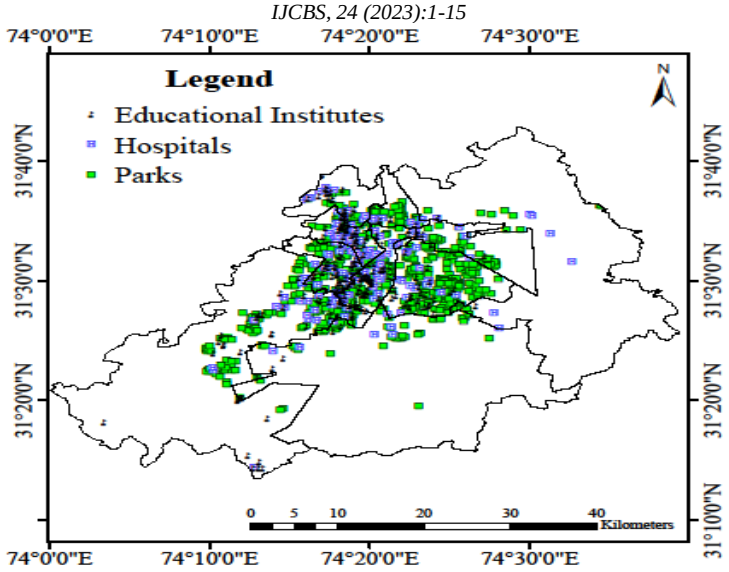

Fig. 3. Spatial Location of educational institutes, hospitals and parks in Lahore

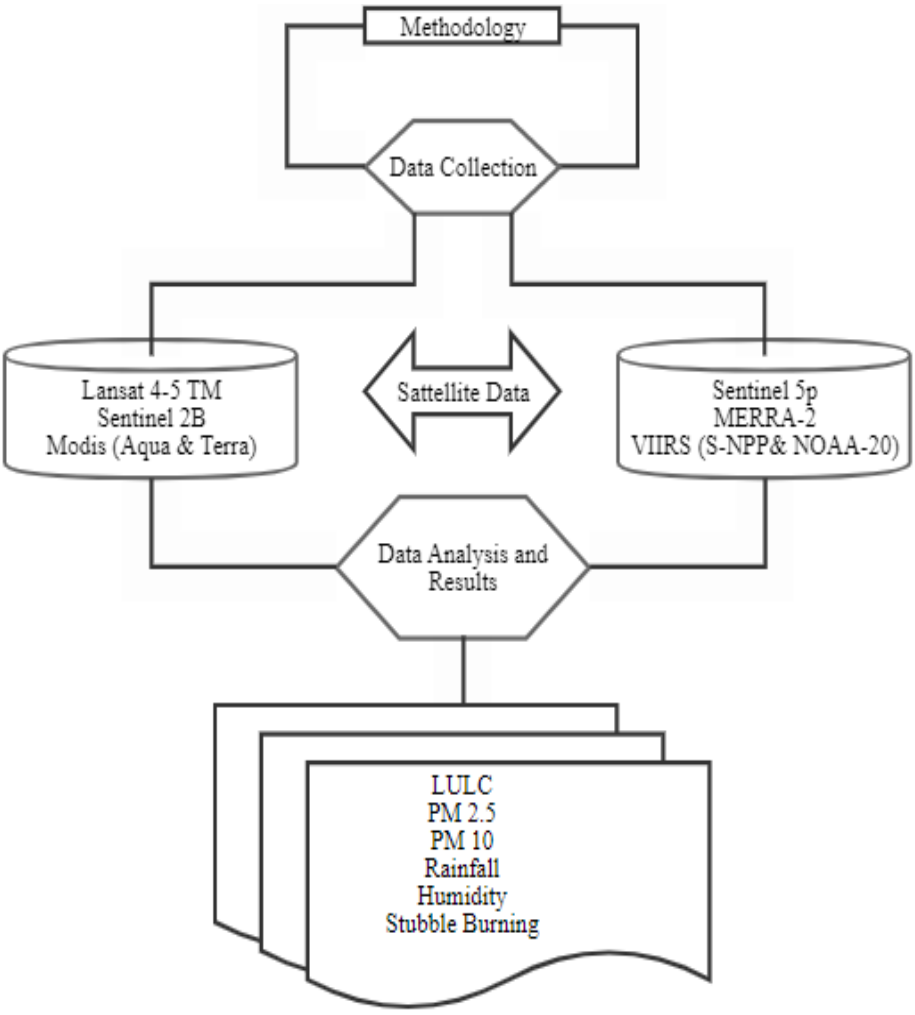

Fig. 4. Flow chart of the methodology

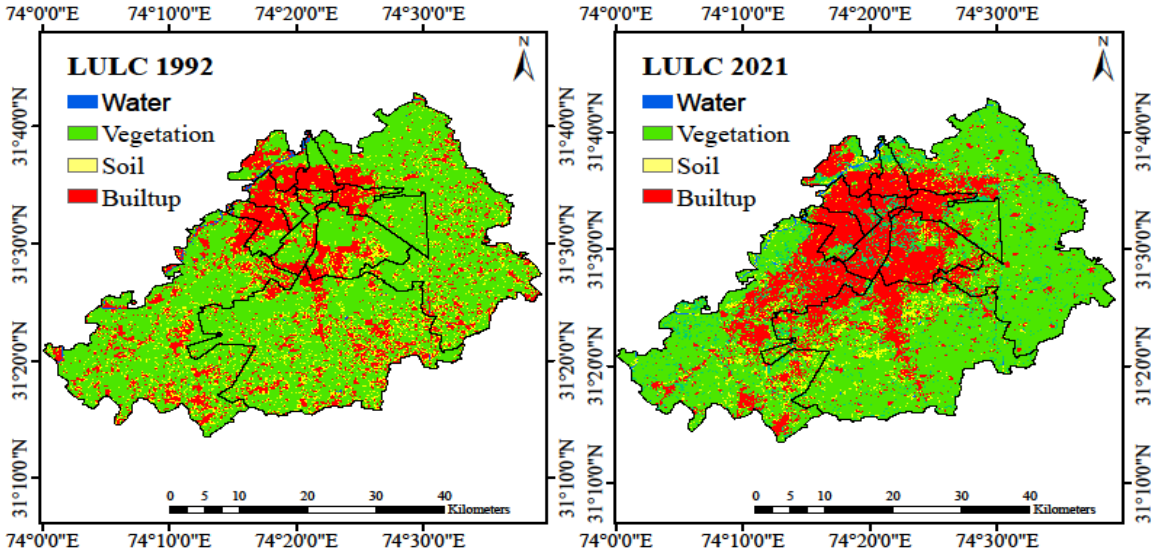

Fig. 5. Land use and land cover of Lahore in 1992 and 2021

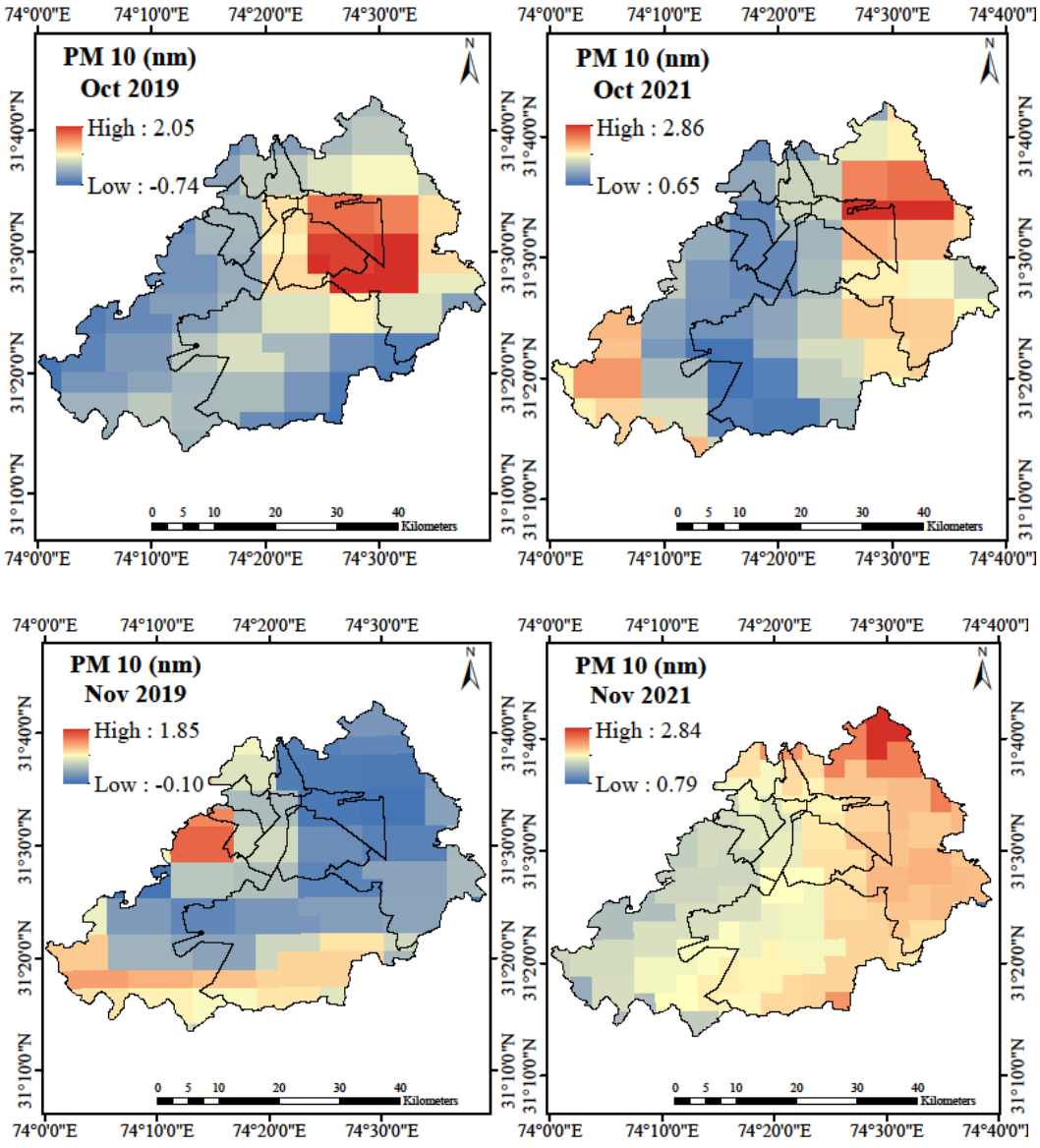

Fig. 6. PM_{10} trend in October and November (2019 and 2021)

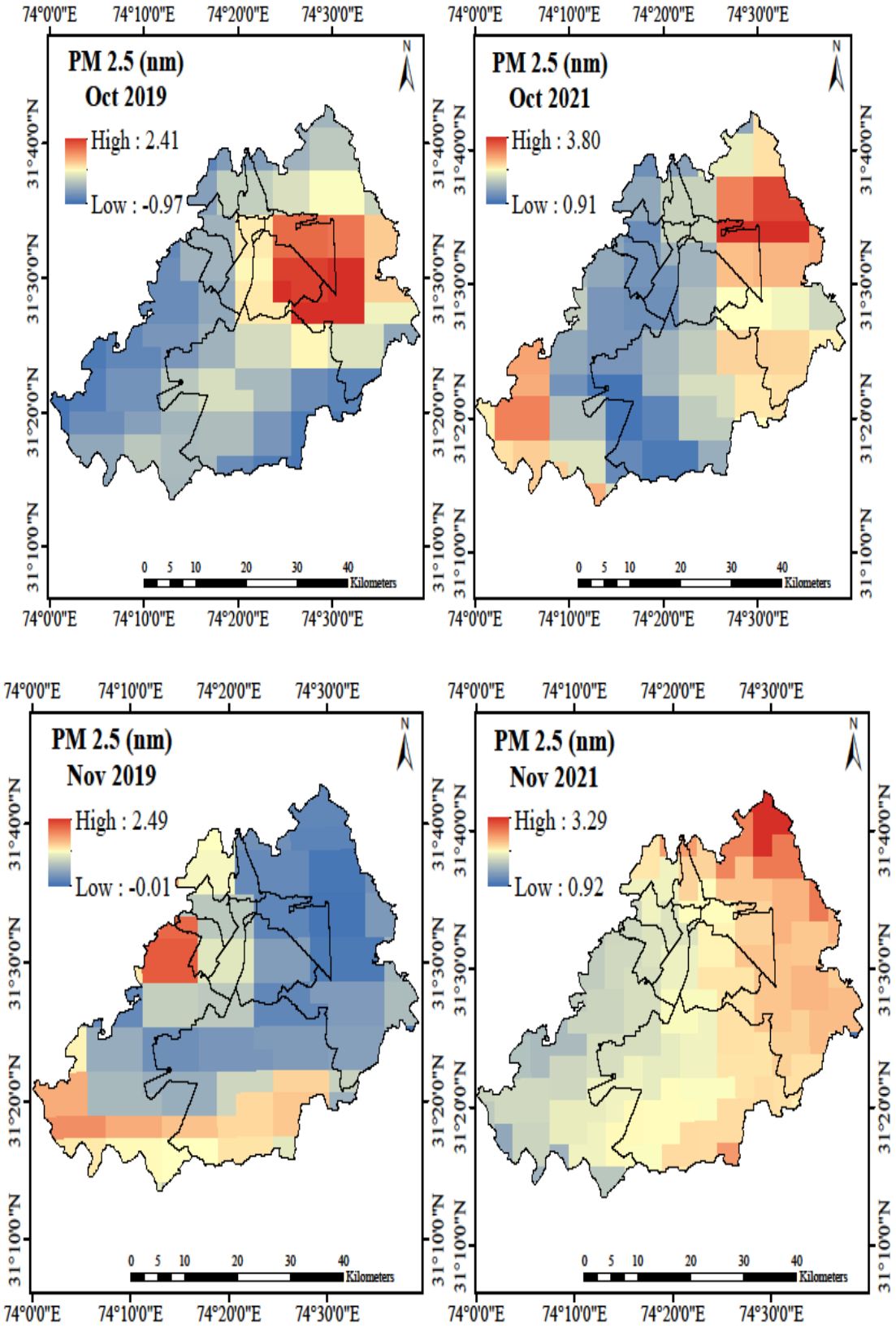

Fig. 7. $PM_{2.5}$ trend in October and November (2019 and 2021)

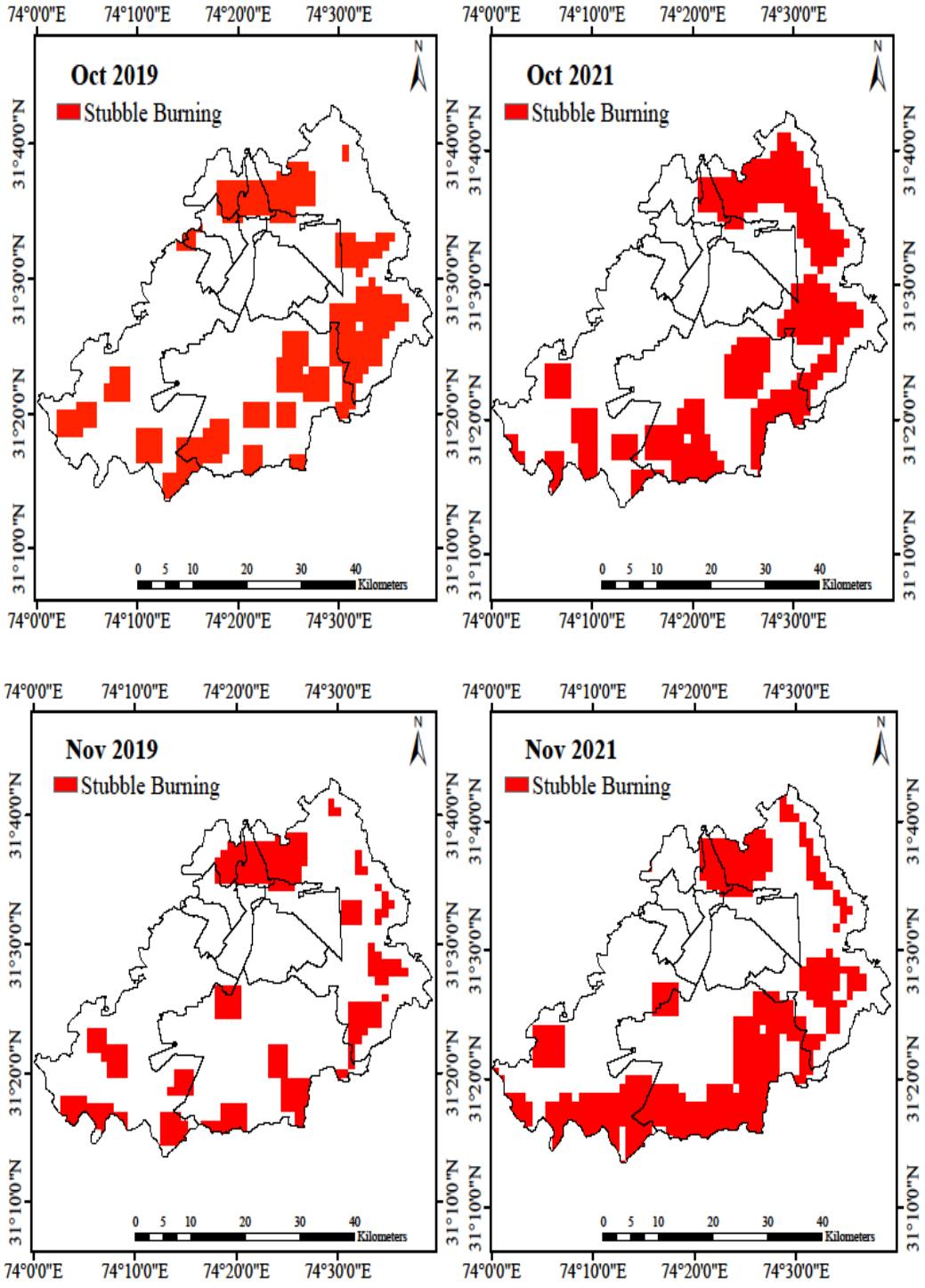

Fig. 8. Stubble burning trend in October and November (2019 and 2021)

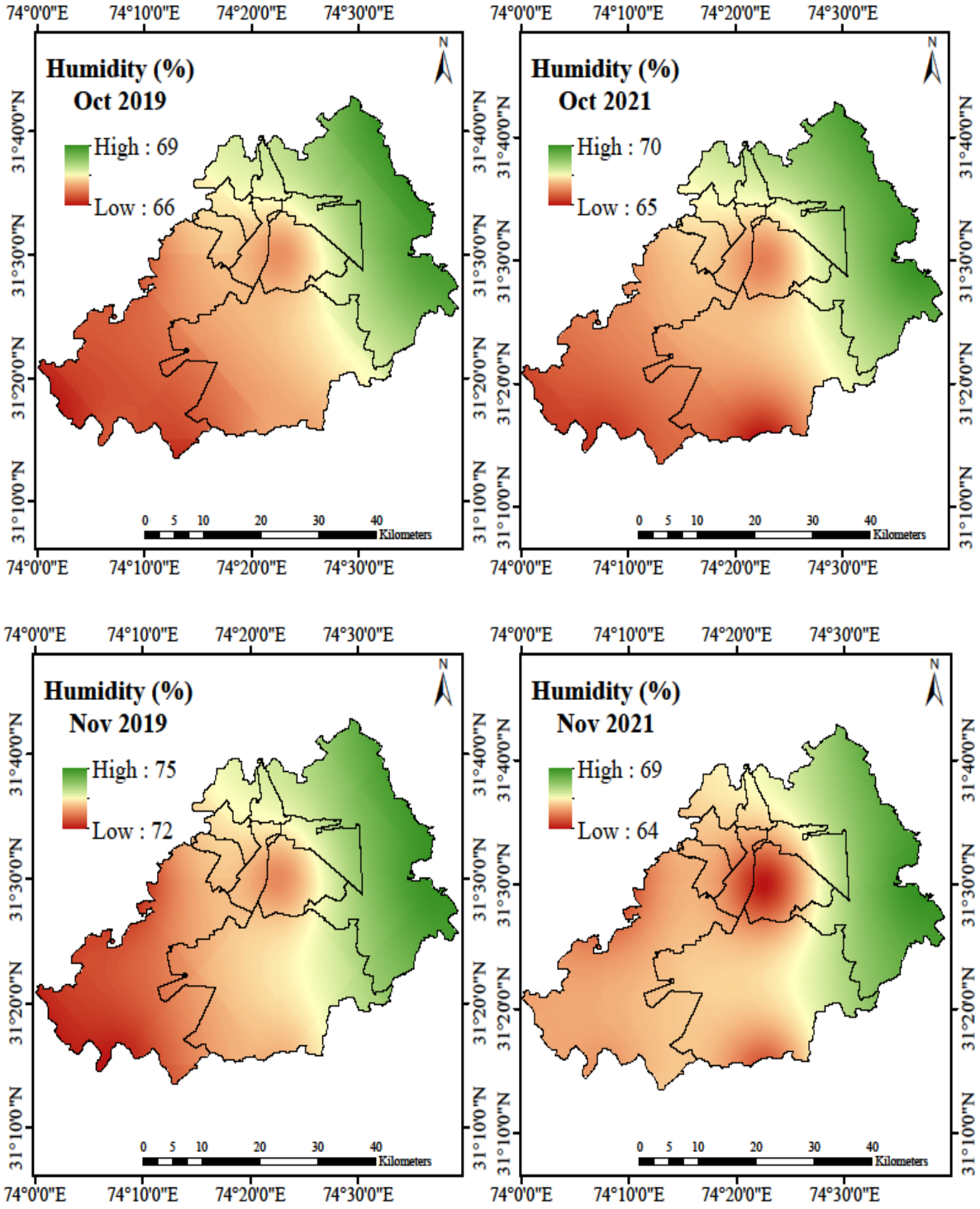

Fig. 9. Humidity trend in October and November (2019 and 2021)

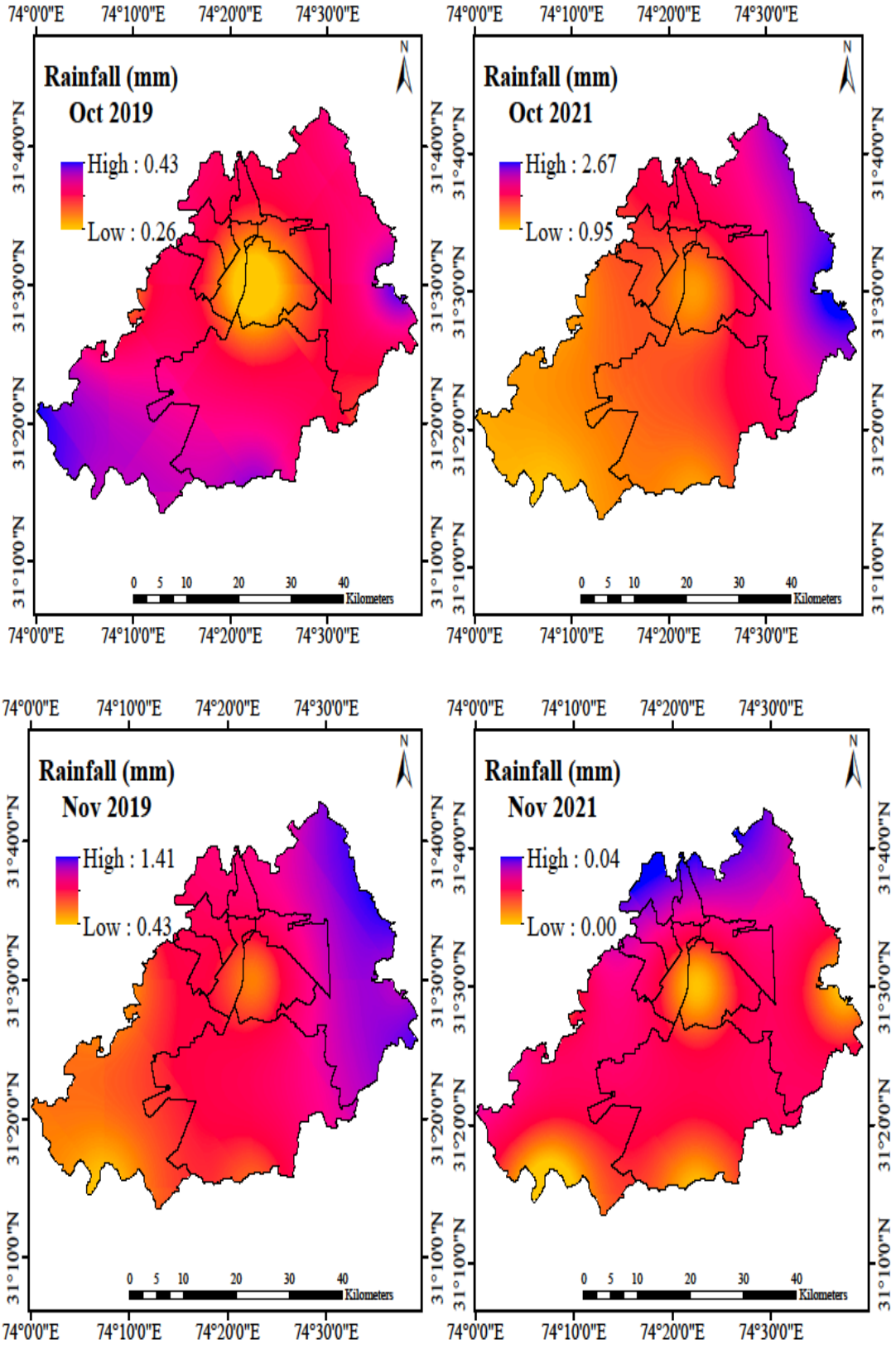

Fig. 10. Rainfall trend in October and November (2019 and 2021)

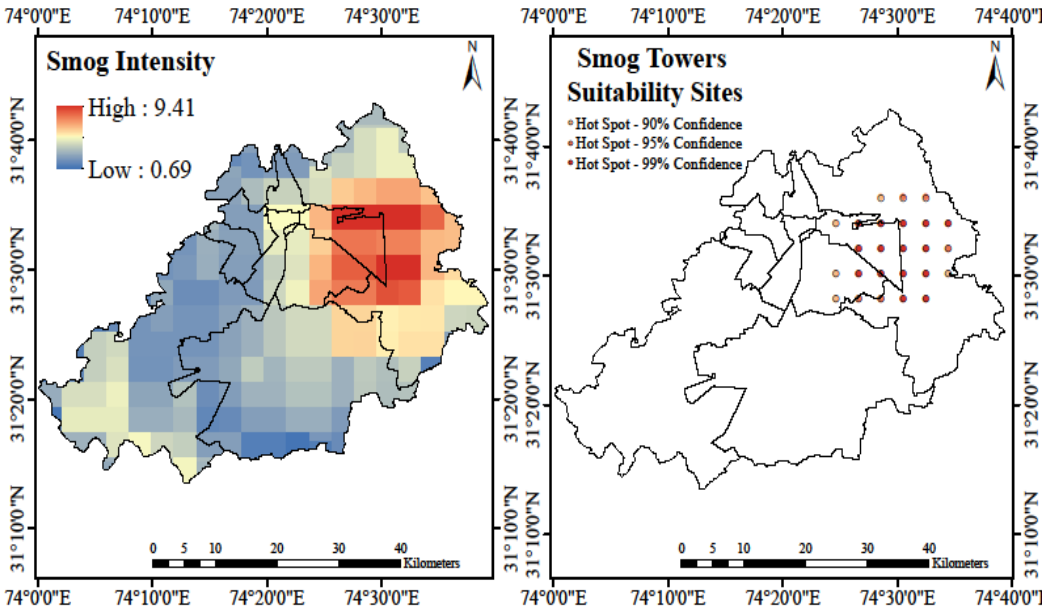

Fig.11. Spatial location for smog tower in Lahore

In rice cultivation areas, the stubble burning practice is based on farmers' misconception as they believe that burning rice stalks is helpful to improve soil fertility. However, it is evident that mechanized harvesting [100] is creating smog problem every year. Results of Fig. 8 exhibited that the highest level of stubble burning was recorded in October 2021, which may be attributed to a significant increase in the sowing area of rice crops. Whereas the high magnitude of stubble burning in north-east, east and south-east Lahore is causing filthy and foul air.

3.5. Humidity trend during October and November (2019 and 2021)

In particular, high relative humidity [65] is the reported metrological parameter affecting the air quality by halting the criteria pollutants in the lower atmosphere. Fig. 9 illustrates that eastern parts of Lahore have been recorded with high humidity level which helped to trap $PM_{2.5}$ in the atmosphere. On comparison of November 2019 and2021, high rise in the relative humidity is noted which help to form smog [101]. It is pertinent to mention here that stubble burning is one of additional sources to release particulate pollution in the air and deteriorate air. Further, Fig. 8 results illustrated that Wagah and Nishtar Townswhere stubble burning occur in November have been recorded with high particulate pollution when combined with high humidity. So, there is a dire need to mitigate criteria pollutants to curb practice of stubble burning which supported results of the previous study [102].

3.6. Rainfall trend during October (2019 and 2021)

Metrological factor [103]such as rainfall [104] helps to reduce the concentration of criteria pollutants [105]. Fig. 6 and 7 depict that no drop in PM_{10} and $PM_{2.5}$level has been observed due to the low rainfall in Lahore (Table 1). Spatial results illustrated that rainfall is received in the north and north-east parts of Lahore but no reduction and dilution of PM_{10} and $PM_{2.5}$isanalyzed in these parts. Similar results supported findings of the earlier study [106] by highlighting [1] that once air pollutants level is increased, the rate of dilution of air pollutants becomes relatively slow irrespective of rainfall received. In the light of above facts, new innovative approaches are required to adopt as a long-term solution to reduce the exposure of particulate pollution in Lahore. For this, smog tower is an adopted technology by India [107] and China [108] to control over air pollutants. Smog tower [109] is a tall vacuum cleaner [107] which sucks air pollutants [110] and releases [111] clean air. In this regard, a site has been selected to install smog tower shown in Fig. 11. Liquid Tree is another innovative solution adopted by Belgrade, Serbia to mitigate air pollution.

4. Conclusions

Results of the present study exhibited the importance of remote sensing tool in the evaluation of spatiotemporal variations of LULC, criteria air pollutants, stubble burning and metrological variables in nine towns of Lahore during October and November(2019 and 2021). Present study has shown that economic development, urbanization as transformed the LULC within three decades having adverse influence on the local air quality and environment. Moreover, densely residential and commercial areas of Lahore have experienced high concentration of $PM_{2.5}$. Stubble burning is also one of the major causes in the elevation of $PM_{2.5}$levelin Lahore. Considering above facts, in the era of economic development, suitable solution is required to get rid of filthy air. Amongst them, relocation of air pollution causing industries is one of the options. But this option is viable only for new industries and ineffective for existing industrial set-up as it will create economic burden to build supply chain network by developing new infrastructure. So, for existing industrial units, installations of efficient air pollutants capturing devices area suitable option to avoid smog forming agents. Parallel to this, it is essential to install

Smog Tower adopted by neighboring countries like China and India and implication towards Liquid Tree like Serbia to improve the quality of environment.

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Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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