Impact of Heat Index and Ultraviolet Index on COVID-19 in Major Cities of Pakistan

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Introduction: The world population is under the grip of global pandemic of COVID-19. The present study analyzed relationship between meteorological parameters and COVID-19 in three major cities of Pakistan, that is, Karachi, Lahore, and Peshawar. **Methods:** The impacts of heat index (HI) and ultraviolet index (UVI) over daily COVID-19 cases have examined to identify its transmission and propagation. The significance of basic reproductive number (R_0), growth rate (G_r) and doubling time (T_d) of COVID-19 with HI and UVI was determined. **Results:** Both indices show a significant positive correlation (at 5% significance level) to R_0, T_d, and G_r of COVID-19 patients. Our results showed that the minimum threshold temperature of 33 °C for HI (with a positive variation of 3 °C to 5 °C) put a significant impact on new cases. **Conclusion:** HI and UVI impacted significantly to decline COVID-19 cases over the region.

Keywords: basic reproduction number, COVID-19, doubling time, growth rate, heat index, ultraviolet index

The first outbreak of Novel corona virus was reported in December, 2019 which impacted the 11.08 million inhabitants of Wuhan, Hubei Province, China. Later, the World Health Organization (WHO) declared health emergency on January 30, 2020 and the emerged virus was named SARS-CoV-2 in February, 2020. The WHO declared COVID-19 a pandemic in, March 2020. More than nine million corona cases with a death toll of 474,508 have been recorded across the world till June 23, 2020. The first case of corona was reported on February 26, 2020 in Pakistan, whereas the cases start to report since March 11, 2020 across the country. The foreign transmission of corona was almost 80% at the start which is now reduced to approximately 10%. Pakistan is ranked 12th among the world with positive cases of 185,034 along with deaths toll to 3946 till June 23, 2020 (https://www.worldometers.info/coronavirus/).

Corona virus is spreading extensively and seized the socio-economic activities of six billion people of the world. Numerous studies have shown that weather plays significant role to diminish the spread of infectious epidemics like flue, influenza, and pneumonia occurs during winter season, whereas typhoid, chicken pox, and dengue fevers occurs in summer season. Moreover, all the chorionic diseases are highly related to diurnal temperature range.[1–5]

In recent times, few studies across the globe tried to relate COVID-19 cases to meteorological parameters, that is, temperature and humidity and found reasonable relationship among them.[6–9] Another recent study conducted over New York, USA showed that the temperature (average and minimum) and air quality suppresses the COVID-19 pandemic significantly.[10] Many studies show that UV light control the spread of microbial disease and remained very effective for influenza suppression.[11–14]

The outbreak of COVID-19 has negatively affected the world socio-economic-health sector and positively to environment and climate. The industrial and economical growth rate was significantly dropped around the globe including Pakistan due to COVID-19.[15] United Nations Industrial Development Organization (UNIDO) reported an average decrease of 20% in production was observed over 93% country.[16] The direct economic cost of COVID-19 associated with patient positive rate and mortality rate is lower than indirect losses. The countries with low positive and mortality rate do not mean that they have faced less economic impacts.[17] The developed nations like USA (17.061%), Canada (10.573%), Japan (10.936%), and Western European and Scandinavian countries spend high percentage of their gross domestic product (GDP) to healthcare. Whereas the four big countries of south Asia, that is, India, Pakistan, Bangladesh, and Sri Lanka spend 3.55%, 2.899%, 3.535%, and 3.811% of their GDPs to health Care. The global average expenditure stood at 10% of GDP for the year 2018.[18] Pakistan is already facing economic crises and COVID-19 has strongly affected the economy, despite of the fact the positivity and mortality rate of the country was low among the rest of the world.[19]

There was limited research information was available about behavior of this coronavirus in its early stage. The countries around the world were completely lockdown to reduce its transmission and spread. Pakistan adopted the approach of smart lock down to isolate the virus transmission and spread areas. In order to identify the impact of atmospheric variables (heat index [HI] and ultraviolet index [UVI]) on COVID-19, this study conducted over populous cities of Pakistan where majority daily cases have been observed. These both indices along with smart lockdown played a significant role to reduce its transmission and spread. The findings of this research will help the national and international health agencies, doctors, genetics microbe's researcher, and pharmaceutical agencies to better understand the COVID-19 virus and stop the future outbreak. Moreover, it may help in COVID-19 vaccine development and enable the model to incorporate this research finding to forecast its spread in future.

MATERIAL AND METHODS

Study Area

The spread of COVID-19 virus is easier in populous cities and areas.[20] Therefore; this study is conducted over the three major and populous cities of Pakistan, that is, Karachi, Lahore, and Peshawar. These cities are densely populated and total population comprises of approximately 31 million. Almost 55% of the total cases in Pakistan are observed from these three major cities, that is, Karachi, Lahore, and Peshawar, which make 85%, 49%, and 41% of total cases of Sindh, Punjab, and Khyber Pakhtunkhwa provinces of Pakistan, respectively. The geographical location of Karachi, Lahore, and Peshawar city along with elevation is shown in Fig. 1.

According to the Pakistan Bureau of Statistics (PBS) report, population density of Karachi, Lahore, and Peshawar is 5181.2,
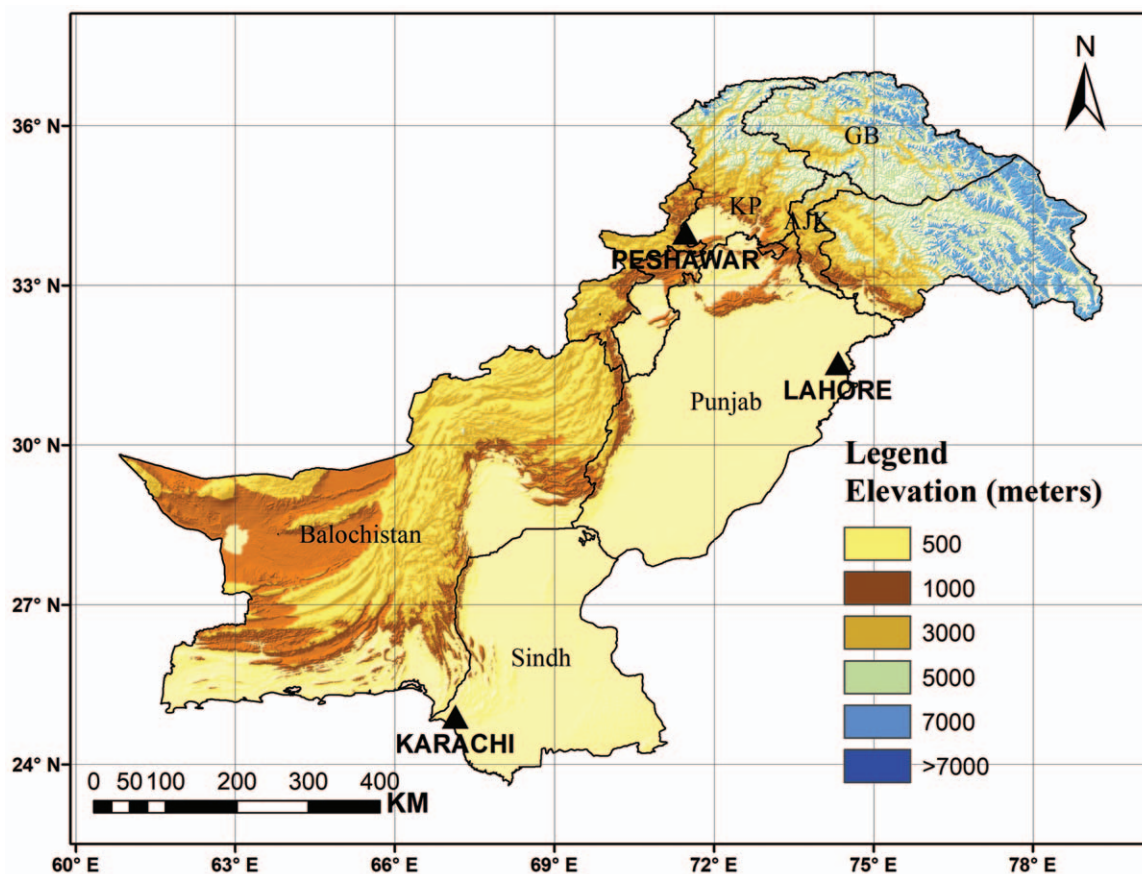
FIGURE 1. Geographical location and elevation of three cities of Pakistan.

6278.9, 3396.2 people/km^2, respectively.[21] May and June are the hottest and driest months, with maximum temperature reaches 45 °C, observed over these three cities. Summer monsoon system brings rainfall over these cities (except Peshawar) during July to September. Lahore and Peshawar are the cities that experiences cold winter and hot and humid summer. Due to maritime climate, Karachi possesses mild winter and moderate summer, as the sea breeze persists throughout the year. Monthly climate details of UVI,

mean temperature (°C), and relative humidity (%) is shown in Table 1.

The COVID-19 daily patient data were acquired from National Command and Operation Centre (NCOC) and Health Services Academy (HSA), Ministry of Health, Pakistan for the period of April 1, 2020 till June 5, 2020. The observational daily data of temperature (°C) and relative humidity (%) is obtained from Pakistan Meteorological Department (PMD). In order to incorporate

TABLE 1. Monthly Climate Summery of UVI, Mean Temperature (°C), and Relative Humidity (%) of Karachi, Lahore, and Peshawar

Months	Karachi			Lahore			Peshawar		
	UV Index	Mean Temperature (°C)	Relative Humidity (%)	UV Index	Mean Temperature (°C)	Relative Humidity (%)	UV Index	Mean Temperature (°C)	Relative Humidity (%)
Jan	6.0	18.9	48.4	3.0	17.5	69.3	3.0	11.5	64.0
Feb	8.0	21.2	51.3	5.0	20.5	62.1	4.0	13.6	59.1
Mar	10.0	25.4	55.1	7.0	25.9	55.1	5.0	17.8	59.5
Apr	12.0	28.9	59.1	9.0	30.1	40.1	9.0	23.7	52.8
May	12.0	31.1	65.6	11.0	32.6	34.6	11.0	29.4	40.6
Jun	12.0	31.9	68.5	12.0	32.9	42.9	11.0	32.8	40.7
Jul	12.0	30.5	72.6	12.0	31.0	65.7	12.0	32.2	57.9
Aug	12.0	29.2	75.0	11.0	29.6	71.4	10.0	30.9	66.6
Sep	11.0	29.4	70.3	9.0	29.6	65.0	8.0	29.0	62.4
Oct	9.0	28.7	57.9	6.0	28.7	57.8	6.0	23.8	60.1
Nov	6.0	24.7	50.8	4.0	24.0	63.6	4.0	17.8	64.9
Dec	5.0	20.5	48.9	3.0	19.0	69.6	3.0	13.0	67.2

the role of both air temperature and relative humidity (RH), we calculated heat index (combination temperature and relative humidity) for each of the city. Moreover, the daily UVI data, with a spatial resolution of $1° \times 1°$, were obtained from the Ozone Monitoring Instrument (OMI), onboard NASA's Aura spacecraft[22] and available at the following web-link: https://giovanni.gsfc.nasa.gov/giovanni/. The both indices, that is, HI and UVI are used to identify the impacts and their association with basic reproduction number (R_0), doubling time as well as growth rate of COVID-19 over three major cities of Pakistan.

Basic reproductive number (R_0) is not a biological constant for a pathogen, however, it determines the expected number of cases directly generated by one case in a population where all individual are susceptible to infection.

R_0 is the ratio between the fractions of individual susceptible per day (β) to the fraction of recoveries (γ)[23] as shown in Equation-1.

The value of R_0 more than 1 represents the spread of epidemic, whereas the R_0 less than 1 shows the reduction in the spread of disease.

Growth rate is the ratio between numbers of new cases 1 day (ΔN_d) to the new cases the previous day (ΔN_{d-1}) or it is defined as the ratio between two successive changes (Equation-2).[24]

Doubling time (T_d) is the time it takes for cases to double in size/value. The high doubling time indicates the slow growth rate (Equation-3).[25]

The coefficient of determination (R^2) was applied to identify the mutual association among HI, UVI, and R_0, T_d as well as growth rate of COVID-19. Moreover, it also indicates the variability level among the data sets. We further applied at t test to determine the significance of Pearson correlation (r) among the data sets at 5% significance level.

RESULTS AND DISCUSSIONS

Based on the daily COVID-19 cases, the basic reproductive number, doubling time, and growth rate were calculated for three major cities of Pakistan. It has found that, R_0 ranged for Karachi (1.6 to 3.4), Lahore (1.5 to 2.6), and Peshawar (1.5 to 4.5), whereas T_d was 12.2, 15.1, and 16.3 days and growth rate remained 1.14, 1.22, and 1.18 for Karachi, Lahore, and Peshawar respectively. The daily HI (°C) has been calculated and it was found that the highest HI observed after May 20, 2020 with a maximum values observed at Karachi (50.7 °C), Lahore (42.2 °C), and Peshawar (43.4 °C).

The scatter plot shows strong association of HI (°C) to R_0 and T_d as shown in Fig. 2. The highest value of R^2 between HI to R_0 and T_d has been observed at Peshawar (0.72) and Karachi (0.65), respectively. The significant decrease in R_0 and increase in T_d were observed when HI remains above 42 °C for Karachi, 31 °C for Lahore, and 32 °C for Peshawar at 5% significance level.

The Fig. 3 shows strong association of UVI to R_0 and T_d for all the three cities of Pakistan. The highest value of R^2 between UVI to R_0 and T_d has been observed at Peshawar (0.71 and 0.66),
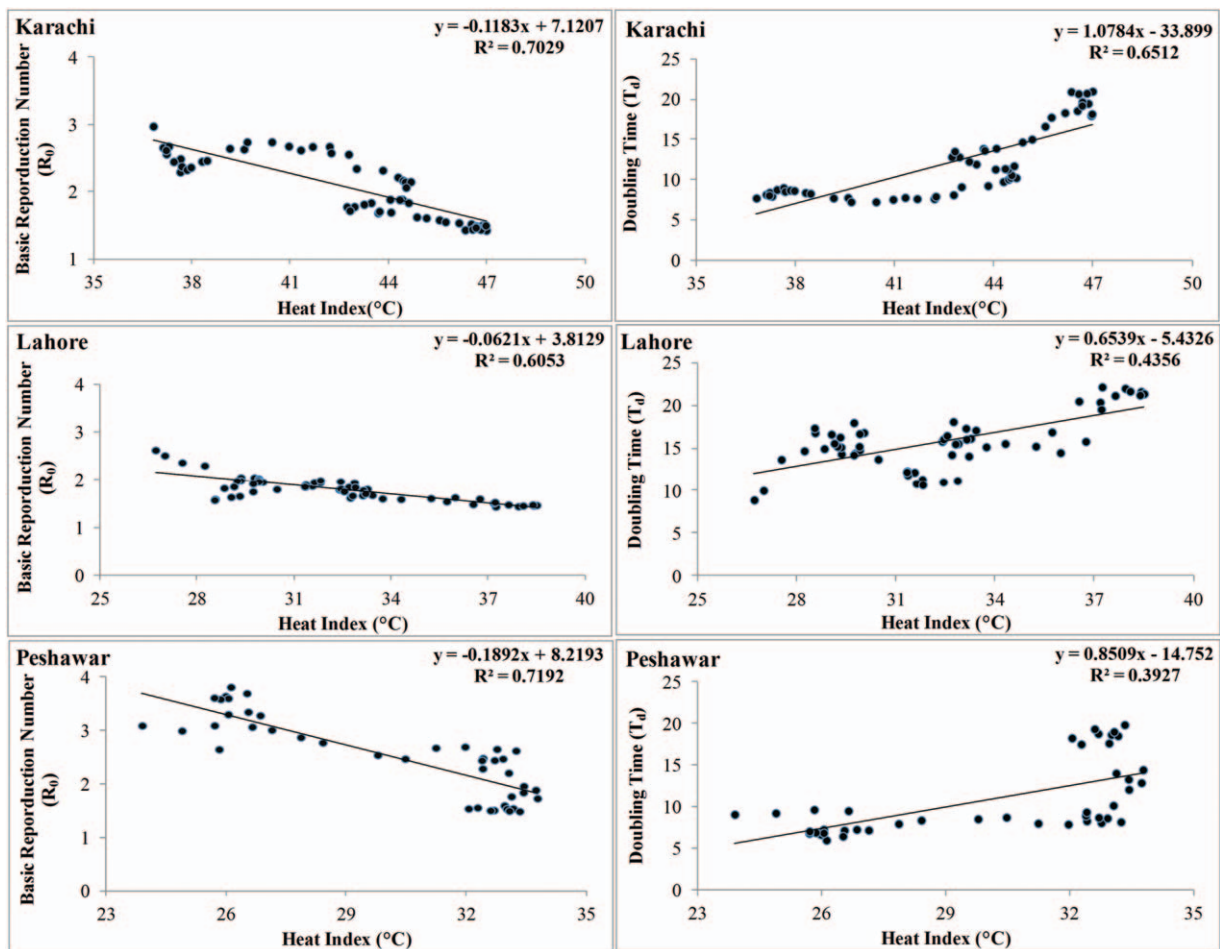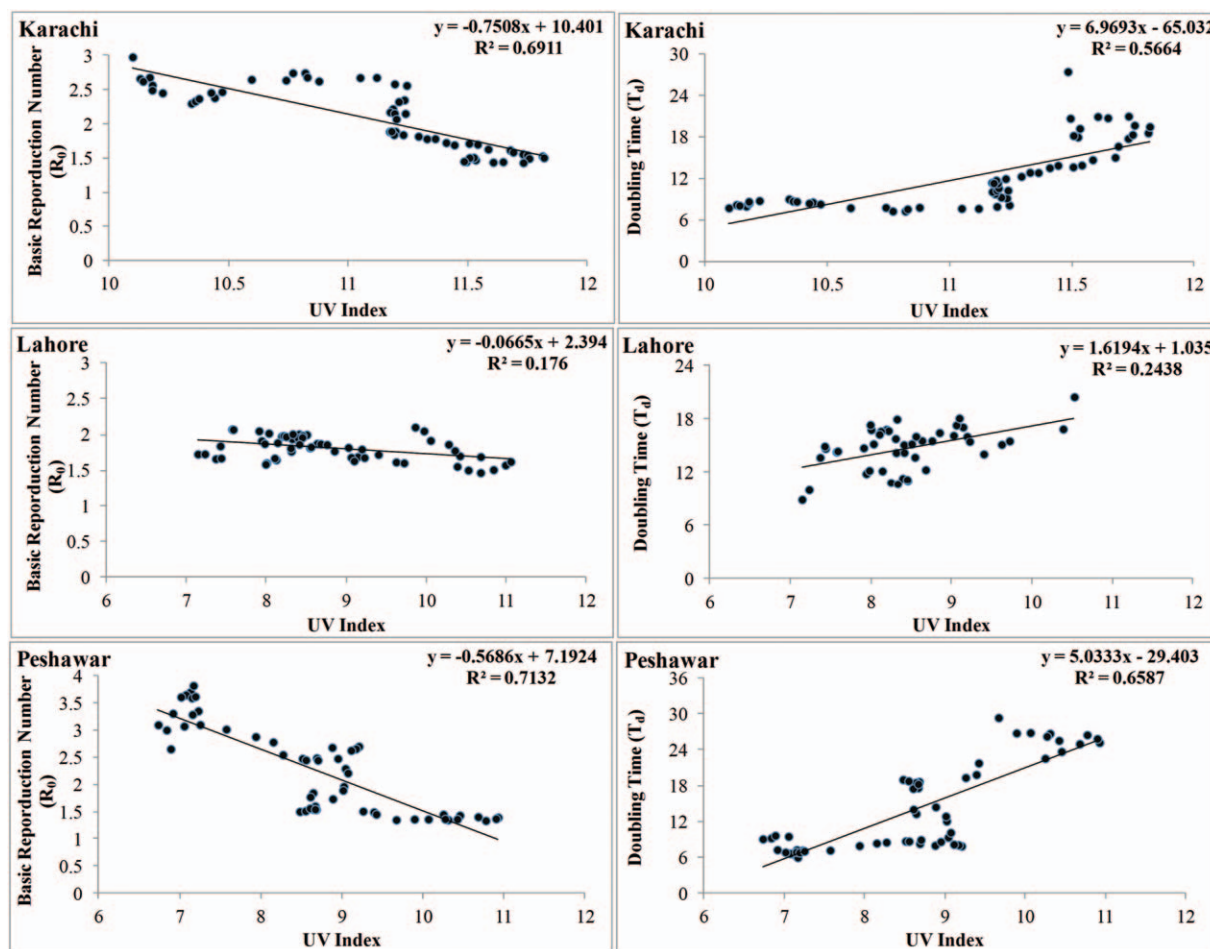

FIGURE 2. Relationship between basic reproductive number (R_0) and doubling time (T_d) versus heat index (°C) at Karachi, Lahore, and Peshawar.

FIGURE 3. Relationship between basic reproductive number (R_0) and doubling time (T_d) versus UVI at Karachi, Lahore, and Peshawar.

respectively. The significant decrease in R_0 and increase in T_d were observed when UVI values remain above 11 for Karachi and 8 for both Lahore and Peshawar at 5% significance level. Similarly, the relationship between HI and UVI to growth rate has been identified (Fig. 4). The temperature change impacted the growth rate of COVID-19 cases in China.[26] The results show the highest value of R^2 between HI and UVI to growth rate at Peshawar (0.47 and 0.48) respectively. However, it was lowest at Lahore (Fig. 4). The significant decrease in growth rate was observed when HI remains above 42 °C for Karachi, 31 °C for Lahore, and 32 °C for Peshawar, whereas UVI remains above 11 for Karachi and 8 for both Lahore and Peshawar, respectively at 5% significance level.

The inverse correlation (negative) between R_0 and heat index (°C) is observed over Peshawar (−0.85), Karachi (−0.77), and Lahore (−0.67) at 5% significant level. Moreover, a significant negative correlation between R_0 and UVI is observed over Peshawar (−0.84), Karachi (−0.76), and Lahore (−0.46). The doubling days has significant positive correlation to HI as well as UVI over all the three cities. Growth rate of COVID-19 is inversely proportional to T_d which depicts that, an increase in doubling days reduces the growth rate.

The respiration infection spread more vigorously during cold and dry conditions, which indicates low humidity is an important risk factor to increase the respiratory disease.[27,28] The results of our study show that the increase in temperature and humidity, will result in decrease the COVID-19 transmission significantly, which are

consistent with several other studies.[29–31] The MERS-CoV out broke during summer in Riyadh with low humidity and wind speed with high temperature and (UVI).[32] The respiratory droplets settles rapidly in high humidity and it is difficult for influenza virus to spread.[33] The results show that heat index (temperature, humidity) and UVI play a vital role to reduce the transmission and spread of COVID-19.

The climatology of Karachi, Lahore, and Peshawar cities shows that temperature and humidity and UVI remain high during June to September, resulting low transmission of COVID-19 over these region. Based on the climatology of Pakistan, it is predicted that COVID-19 cases may increase after the retreat of summer monsoon and second spike may be observed during in pre winter, that is, October to December, as UVI, temperature, and humidity remains very low during these months.

The weekly analysis suggests that transmission rate will decline (50% to 75%) with an increase of 3 °C to 5 °C mean temperature and 10% to 15% of relative humidity (RH). The results suggest that hot and humid climate reduces COVID-19 transmission over Pakistan. The mean temperature (more than or equal to 30 °C) and mean relative humidity (RH) above 55% slow down the COVID-19 spread in Pakistan. The climatology of these three cities indicates that the HI and UVI remains high during June to September which will suppress COVID-19 spread and increase the doubling days of the disease. This positive impact of the both indices indicates that COVID-19 transmission will likely to reduce in other areas of
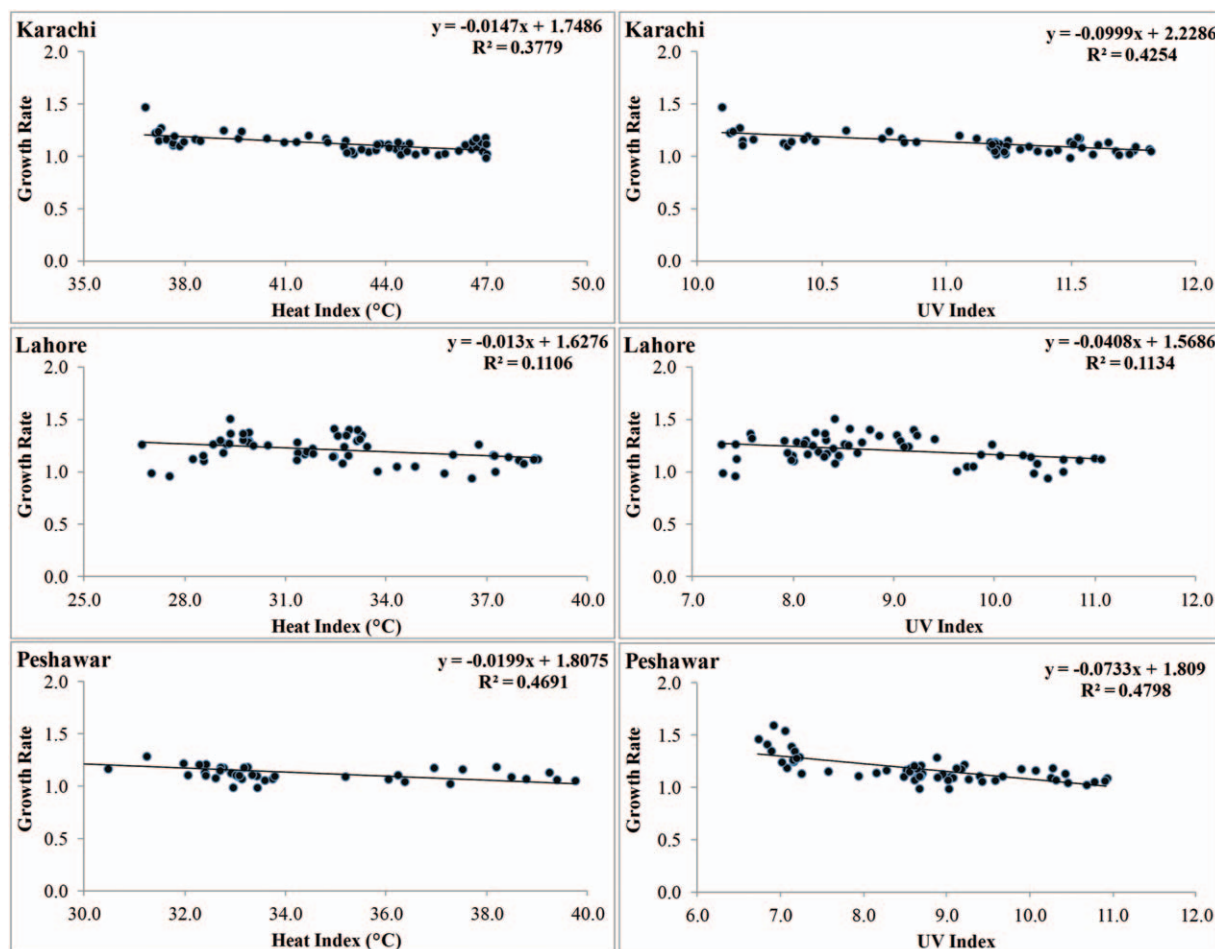
FIGURE 4. Relationship of heat index (°C) and UVI versus growth rate at Karachi, Lahore, and Peshawar.

Pakistan. In the light of above results, we may conclude that those countries including Pakistan, India, Bangladesh, and Sri Lanka having long, hot, and humid summer, the impact of COVID-19 is likely to decrease as the summer progress provided the smart lock-down approach and COVID-19 standard operating procedures are followed.

The weather (HI and UVI) has played a significant role to prevent the COVID-19 outbreak. Moreover, the smart lockdown approach was implemented by the administration that affectively played an important role to reduce the COVID-19 transmission. The both indices (HI and UVI) may tend to decrease during pre-winter which may help to increase the COVID-19 transmission. So, proper intervention is needed to minimize it transmission rate. The lockdown and social distancing could reduce the COVID-19 transmission and help to fight the future outbreak.[34,35] This pandemic has strongly affected industrial and economic growth around the world and financial assistance packages are provided to resume normal operation.[36]

CONCLUSION

Based on the results, it is concluded that HI and UVI play a very significant role to reduce the COVID-19 propagation. Our results provide clear indication that hot and humid weather suppress the COVID-19 transmission and countries in south Asia such as India, Pakistan, Bangladesh, Sri Lanka, Myanmar, etc, where monsoon has already commenced, the COVID-19 new cases is likely to decline as HI (above 40 °C) and UVI (above 10) strengthens during July to September. The mean temperature (more than or

equal to 30 °C) and relative humidity (more than or equal to 50%) significantly impact on peak and propagation of new cases of COVID-19. This study suggests that government intervention of awareness, smart lock down, and general public ownership to keep social distancing, use of sanitizers, mask and proper hand washing may slow down the COVID-19 transmission. This study provides the useful insight to policy makers and health departments to develop better understanding to reduce its fast transmission and defeat this disease.

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