SPATIAL AUTOCORRELATION OF COVID-19 INCIDENCE DATA IN PUNJAB, PAKISTAN

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Abstract. To devise an effective control strategy for the COVID-19 epidemic, an extensive knowledge of spatiotemporal patterns and contributing factors is needed. We conducted the current study to enhance our understanding about the spatiotemporal trends and contributing factors associated with the COVID-19 pandemic in Punjab, Pakistan. A descriptive observational design was used to conduct study. The data about confirmed cases of COVID-19 was extracted from 2nd July to 10th August 2020 and analyzed to calculate the Cumulative Incidence (CI), Case Fatality Rate (CFR) and Mortality Rate. The spatial autocorrelation and spatio-temporal trends of COVID-19 cases were determined. The CI and CFR of COVID-19 in Punjab were 153 per million and 2.14% respectively for the study period. There was significant positive spatial autocorrelation between COVID-19 cases and various districts of Punjab. Lahore district was identified as a highly significant hotspot for COVID-19 ($p < 0.05$). The findings of the current study could be used to devise effective mitigation strategies to control future epidemics of COVID-19 and other contagious diseases like influenza by the health authorities.
Keywords: *case fatality rate, temporal, spatial, hotspot, pandemic*

Introduction

Coronaviruses belonging to alpha and beta genera affect human beings. From 1966 to 2019 different strains of coronaviruses e.g. HCo-229E, HCo-OC43, SARS-CoV, HCoV-NL63, HCoV-HKUI, MERS-CoV and SARS-CoV-2 were present in the environment. The first case of SARS-CoV-2 was reported in Wuhan City, China in December 2019 (Liu et al., 2020). It was declared as an international public health emergency on 30th January 2020 by the WHO and renamed as COVID-19 on 12th February 2020 (Zu et al., 2020). By 10th August 2020, confirmed cases were 20,065,647 and death toll was 801,907 worldwide. In Pakistan, the first case was reported in Karachi on 26th February 2020 (Khan et al., 2020). From May 2020 to April 2022, Pakistan experienced three waves of pandemic, with the third wave having the highest positivity rate (20%). The Government of Pakistan (GoP) implemented smart lockdown to control the hotspots. Various field hospitals were established in the country to reduce the burden on tertiary care hospitals.

The geographical identification of disease has crucial role during an epidemic. Timely hitting the identified spots and clusters by appropriate measures can reduce the spread of disease. Similarly, Geographic Information System (GIS) can provide visual information to determine disease distribution, pattern and high-risk areas (Jaber et al., 2022).

The COVID-19 pandemic significantly overburdened the Pakistan's healthcare system resulting in a surge of new positive cases and fatalities. Nevertheless, the implementation of smart lockdowns reduced the daily cases, and the spatial analysis of hotspots of disease played a crucial role in preventing and controlling the spread of the disease. The main objectives of this study were to identify the spatio-temporal trends of the confirmed cases of COVID-19 at district level and influencing factors impacting the COVID-19 epidemic in Punjab province of Pakistan, using spatial statistics tools and Spearman's rank correlation methods.

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Materials and methods

Study area

Punjab is the most populated province of Pakistan, consisting of 36 districts (*Fig. 1*). According to 2017 census, the population of Punjab was 109,989,655. The population density of Punjab is 535.63 per square kilometer and household size is 6.38. The Punjab province is situated between 31.17040° N and 72.70970° E and has a land area of 205,345 square kilometer (Nawaz et al., 2019).

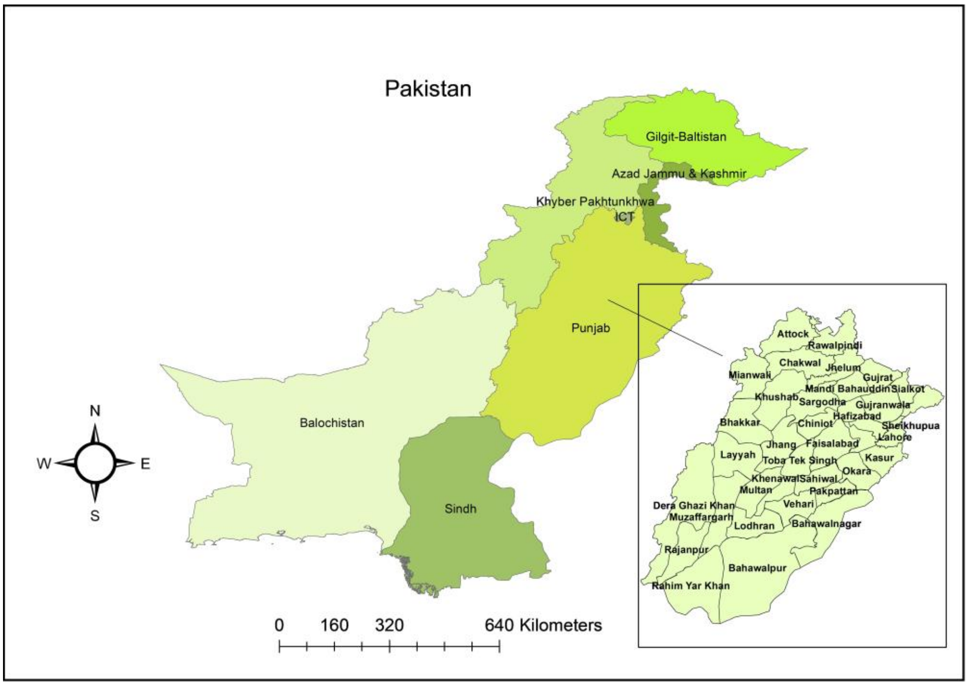

Figure 1. *Location of 36 districts of Punjab Province, Pakistan (study area)*

Study design

The current study was a descriptive observational study. The daily cases and deaths of COVID-19 patients were extracted from dashboards of Provincial Disaster Management Authority (PDMA) Punjab, COVID-19 Health Advisory Platform by Ministry of National Health Services and Coordination, Pakistan and WHO COVID-19 global dashboard. Data about land area, population, and number of persons per square kilometer of districts of Punjab were acquired from the Bureau of Statistics, Government of Punjab.

Data analysis

Cumulative incidence (CI) and case fatality rate (CFR)

The cumulative confirmed cases of COVID-19 were defined as incident counts of SARS-CoV-2 infection positive by RT-PCR. The epiR package in R Software (version 2.0.36; Stevenson and Sergeant, 2021) was used for analysis. The number of confirmed cases of COVID-19 was used as the numerator and the total population of district as the denominator (Gordis, 2014). The CI at district level was calculated by dividing the

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number of confirmed cases of COVID-19 reported from a specific district divided by the total population of that district. CFR of COVID-19 was calculated as the number of total deaths due to COVID-19 divided by the total number of confirmed cases of COVID-19 multiplied by 100. All statistical analyses were conducted in RStudio (Team, 2020).

Global and local spatial autocorrelation

Spatial autocorrelation was performed using spatial statistics and modelling tools of ArcGIS 10.8. The global Moran's I was used to determine the spatial autocorrelation of cumulative confirmed cases of COVID-19 within Punjab. Positive Moran's I index value (+I) indicate positive spatial association or clustering of similar value and a negative Moran's I index value (-1) indicated inverse spatial association (clustering of dissimilar value). The Moran's I index with zero value indicated no spatial autocorrelation. Larger values of Moran's I index indicated that there was strong spatial autocorrelation,

$$I = \frac{\sum_{i=1}^{n} \quad \sum_{j=1}^{n} wij(x_i - \bar{x})\ (x_j - \bar{x})\ \ \mathrm{n}}{\sum_{i=1}^{n} \quad (x_i - \bar{x})^2 \qquad \sum_{j=1}^{n} wij \sum_{i=1}^{n}} \tag{Eq.1}$$

where I = Moran's index, x_i = observation values at location I, x_j = observation values at location j, w_{ij} = spatial weighted matrix between I and j, $\bar{x}$ = average number of variables and n = total numbers of (area) observations.

Local spatial autocorrelation is commonly characterized by Local Moran's I and Getis-Ord Gi*. Local Moran's I is the decomposition of global Moran's I into various sub-regional units, also known as Local Indicators of Spatial Association (LISA) (Anselin, 1995). Local spatial autocorrelation determined the spatial clustering of local features. Getis-Ord Gi* was used to analyze hotspots and cold spots of confirmed cases of COVID-19 with statistical significance. Higher and lower values of z-score indicated the hotspots and cold spots respectively. The increase in z-score reflected the intensity of clustering. Positive z-score reflected more intensity of clustering of high values while negative z-score determined clustering of low values (Fatima et al., 2021). The spatial analysis was conducted in ArcGIS version 10.8 (ESRI, 2020).

Influencing factors of COVID-19 in Punjab

The data was analyzed to evaluate the relationship between cumulative confirmed cases of COVID-19 and influencing factors at district level by using Spearman's Rank Correlation test in RStudio (Team, 2020). Twelve variables namely land area, population size, household size, growth rate, number of persons per square kilometer, number of hospitals, number of beds, number of gowns provided, number of masks provided, number of gloves provided, number of goggles provided and number of hand sanitizers bottles provided were included in the analysis. Spearman's rank correlation coefficient (ρ) varies between +1 and -1 reflecting correlation between the two variables. The values between 0.2 ~ 0.4 were interpreted as weak positive correlation, whereas 0.4 ~ 0.6 and 0.6 ~ 0.8 reflected moderate and strong positive correlation between the variables respectively (Xiong et al., 2020).

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Results

From 2nd July to 10th August 2020, a total of 16,843 cumulative confirmed COVID-19 cases and 358 deaths were reported from all districts of Punjab. The highest number of cases were reported on 3rd July 2020 (n = 1341) from all over Punjab (*Fig. 2*). The highest number of confirmed cases (n = 7448) and deaths (n = 137) were recorded in Lahore district as compared to other districts of Punjab (*Table 1*; *Fig. 3*). The overall CFR for Punjab was 2.12% (95% CI: 1.91-2.35). The highest CFR was recorded in Khushab district (9.21%), and Rahimyar Khan (7.88%) as compared to other districts of Punjab. The CI in overall Punjab was 153.10 per million (95% CI: 150.80 – 155.43) and mortality rate was 3.25 (95%CI: 2.92 - 3.61) per million population. The incidence rate was highest in Lahore district (669.43/1,000,000) and mortality rate was highest in Rawalpindi district (8.32/1,000,000) among all districts of Punjab (*Table 1*).

Table 1. *Burden of COVID-19 in 36 districts of Punjab from 2nd July to 10th August 2020*

District name	District population	Confirmed cases	Deaths	Case fatality rate (CFR) %	Incidence rate/M	Mortality rate/M
Attock	1883000	172	2	1.16	91.3436	1.06
Bahawalnagar	2982000	128	2	1.56	42.92421	0.67
Bahawalpur	3668000	475	7	1.47	129.4984	1.91
Bhakkar	1650000	123	2	1.63	74.54545	1.21
Chakwal	1496000	93	0	0	62.16578	0.00
Chiniot	1370000	43	1	2.33	31.38686	0.73
Dera Ghazi Khan	2872000	361	9	2.49	125.6964	3.13
Faisalabad	7874000	836	36	4.31	106.1722	4.57
Gujranwala	5014000	627	7	1.12	125.0499	1.40
Gujrat	2756000	780	7	0.9	283.0189	2.54
Hafizabad	1157000	65	1	1.54	56.17978	0.86
Jhang	2743000	80	2	2.5	29.16515	0.73
Jhelum	1223000	135	1	0.74	110.3843	0.82
Kasur	3455000	144	0	0	41.67873	0.00
Khanewal	2922000	79	0	0	27.03628	0.00
Khushab	1281000	76	7	9.21	59.32865	5.46
Lahore	11126000	7448	137	1.84	669.423	12.31
Layyah	1824000	61	0	0	33.44298	0.00
Lodhran	1701000	94	1	1.06	55.26161	0.59
Mandibahuddin	1593000	170	0	0	106.7169	0.00
Mianwali	1546000	97	2	2.06	62.74256	1.29
Multan	4745000	649	22	3.39	136.7756	4.64
Muzaffargarh	4322000	154	15	9.74	35.63165	3.47
Nankana Sahib	1356000	91	1	1.1	67.10914	0.74
Narowal	1710000	67	0	0	39.18129	0.00
Okara	3039000	127	3	2.36	41.79006	0.99
Pakpattan	1824000	142	0	0	77.85088	0.00
Rahimyar Khan	4814000	241	19	7.88	50.06232	3.95
Rajanpur	1996000	119	0	0	59.61924	0.00
Rawalpindi	5406000	1580	45	3.03	292.2679	8.32
Sahiwal	2518000	154	5	3.25	61.15965	1.99
Sargodha	3704000	364	8	2.2	98.27214	2.16
Sheikhupura	3460000	223	2	0.9	64.45087	0.58
Sialkot	3894000	378	12	3.17	97.07242	3.08
Toba Tek Singh	2190000	222	2	0.9	101.3699	0.91
Vehari	2897000	245	0	0	84.57025	0.00
Overall Punjab	110011000	16843	358	2.14	153.1029	3.25

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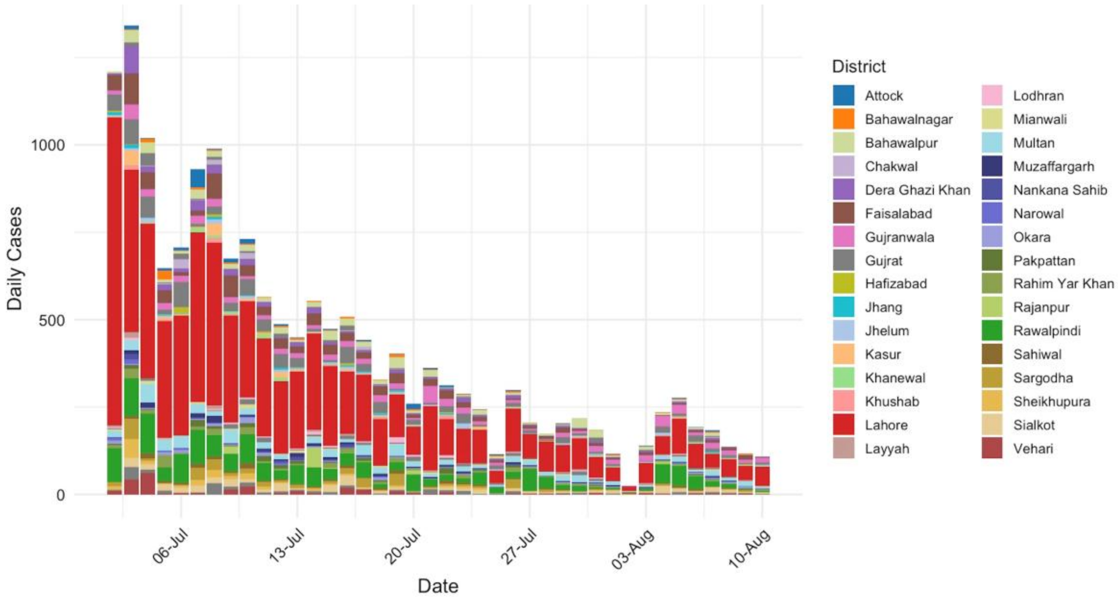

Figure 2. *Epidemic curve of COVID-19 confirmed cases per district from July to August 2020*

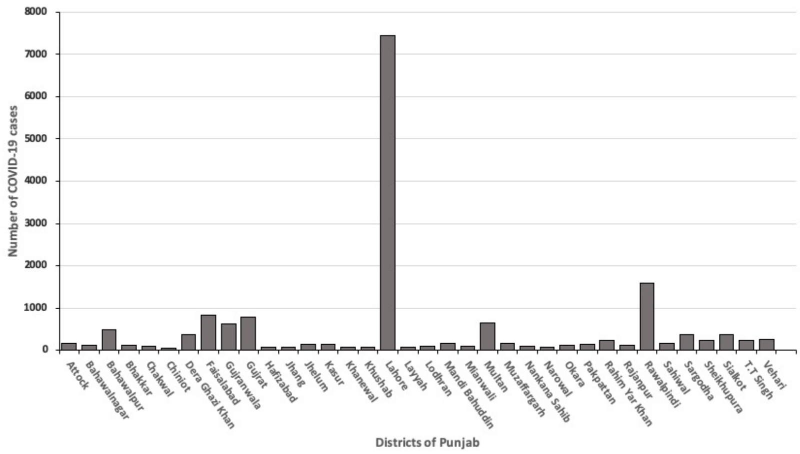

Figure 3. *Number of COVID-19 confirmed cases in various districts of Punjab*

Smart lockdown was implemented from 2nd July to 10th August 2020 in different districts of Punjab to halt the infection. The smart lockdown was initially introduced in Lahore, Rawalpindi, Faisalabad, Sialkot, Gujranwala, Gujrat, Vehari, Multan, Khanewal, and Dera Ghazi Khan. The number of confirmed cases and deaths due to COVID-19 were initially high but gradually decreased during the lockdown period, however, the CFR increased in the last 10 days of lockdown (1st to 10th August 2020) (*Fig. 4*).

During the study period, the Government of Punjab supplied PPE (gowns = 2,055,277, surgical masks = 4,838,309, gloves = 4,576,700, goggles = 1,553,800 and N95 face masks = 302,950 and hand sanitizers = 379,126) to all districts of Punjab to enhance the preventive measures in healthcare facilities for reduction of SARS-CoV-2 transmission among patients, attendants, healthcare providers and administration staff. The government of Punjab also provided food items to the needy persons during that period consisting of food hampers (n = 1,501,000), water bottles (n = 817,000) and flour bags (n = 286,800).

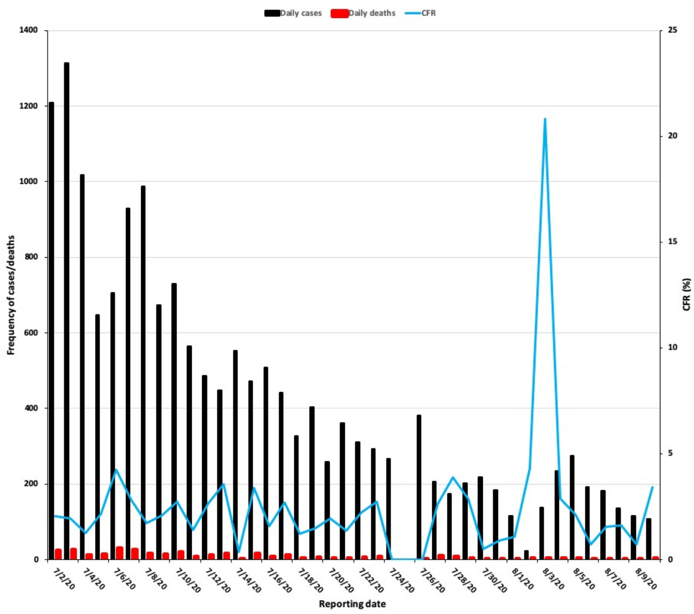

Figure 4. *Daily morbidity, mortality and CFR of COVID-19 during the study period*

The total number of suspected COVID-19 cases were 705,489 in Punjab. The daily average stable patients, patients on low oxygen flow, patients on high oxygen flow and patients on ventilators were 549, 216, 275 and 129 respectively in healthcare facilities of Punjab. The daily average positivity rate was 6% in the province. The mean and median age of people who died of COVID-19 was 62.25 and 60 years respectively during that period and the highly vulnerable age groups were 41-60 years (45.89%) and 61-80 years (33.99%). The number of males amongst those who died was 97 (66.44%) and that of females was 49 (33.56%).

The Government of Punjab took enormous steps to control the spread of virus by allocating 42,646 hospital beds, 3364 high dependency unit beds (HDUs) and 567 intensive care unit beds (ICUs) (equipped with ventilators) to COVID-19 patients in various private and public sectors hospitals to reduce the severity of the disease. The daily average patients in HDUs were 349 and on ventilators were 104 with occupancy rate of 10.58% and 67.17% respectively.

Spatial statistics of the COVID-19 pandemic in Punjab

The z-score and Moran's I index values indicated that the incidence of COVID-19 was positively and spatially correlated between districts of Punjab. Local Moran's I index showed that cumulative confirmed cases of COVID-19 were spatially clustered in different districts of Punjab (*Fig. 5*). Positive values of Local Moran's I reflected similar features and negative value showed dissimilarity of features. Within LISA, five different groupings were identified (high–high, low–low, high–low, low–high, and not significant). HL values were red-colored, LH blue-colored, LL light blue-colored and HH light red-colored.

Global spatial autocorrelation of confirmed cases of COVID-19 at district level

The global spatial autocorrelation results illustrated that number of cumulative confirmed cases of COVID-19 at district level in Punjab, had a highly significant positive autocorrelation (Global Moran's I = 0.958887, p-value < 0.0001 and z-core = 7.954438) (*Fig. 6*).

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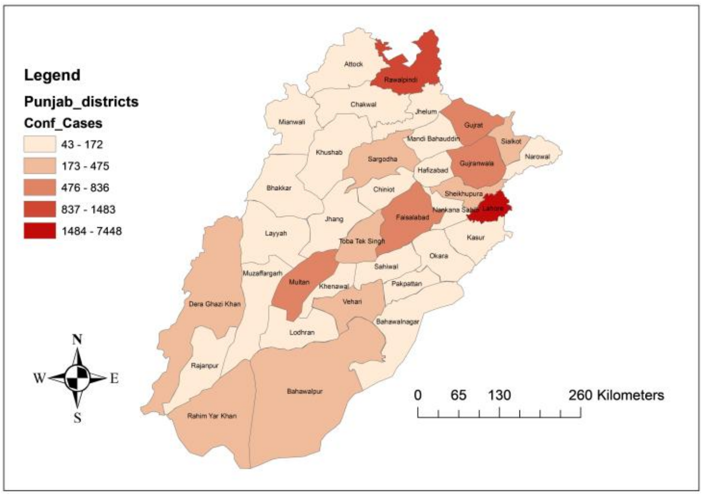

Figure 5. *Spatial distribution of confirmed cases of COVID-19 at district level of Punjab*

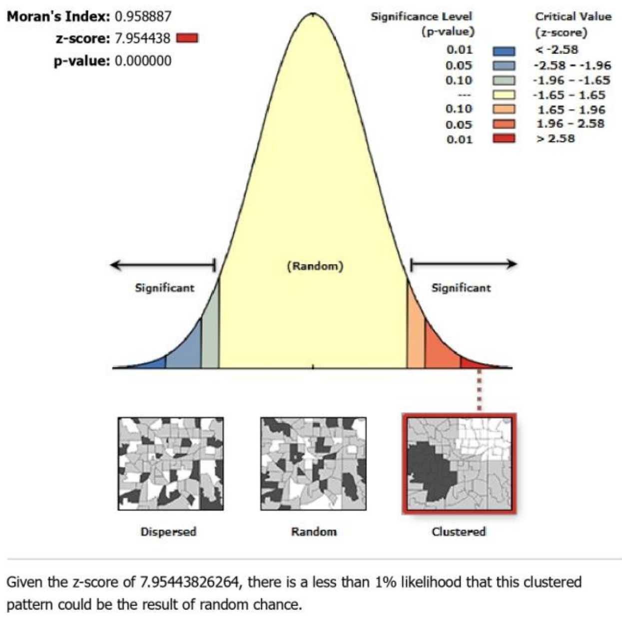

Figure 6. *Global Moran's I analysis of confirmed cases of COVID-19 at district level of Punjab*

Cluster and hotspot analysis of confirmed cases of COVID-19 at district level

The Local Moran's I analysis showed statistically significant locations. District Sargodha and Bhakkar were identified as low-low (LL) category clusters for the cumulative confirmed cases of COVID-19, where an area with low index value was surrounded by other low index value area. Sargodha had six neighboring districts with low index value, whereas Bhakkar was surrounded by four low index value neighbors. In contrast, Faisalabad and Multan districts were categorized as high-low (HL) outliers, where high value areas were surrounded by low value areas (*Fig. 7*) indicating that cumulative confirmed cases of COVID-19 in these districts were significantly ($p < 0.05$) higher than the neighboring districts and depicting both districts as high-risk areas of COVID-19 pandemic in the province (*Table 2*).

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Table 2. *Cluster and outlier analysis (Anselin Local Moran's I)*

District	Cluster type	Z-score	Neighbor	p-Value	Interpretation
Sargodha	LL	0.8316	6	0.014	A low value area surrounding by low valve areas
Bhakkar	LL	0.7269	4	0.012	A low value area surrounding by low valve areas
Faisalabad	HL	0.7031	6	0.036	Complete spatial random, high value area surrounding by low value areas
Multan	HL	-0.7092	6	0.042	Complete spatial random, high value area surrounding by low value areas

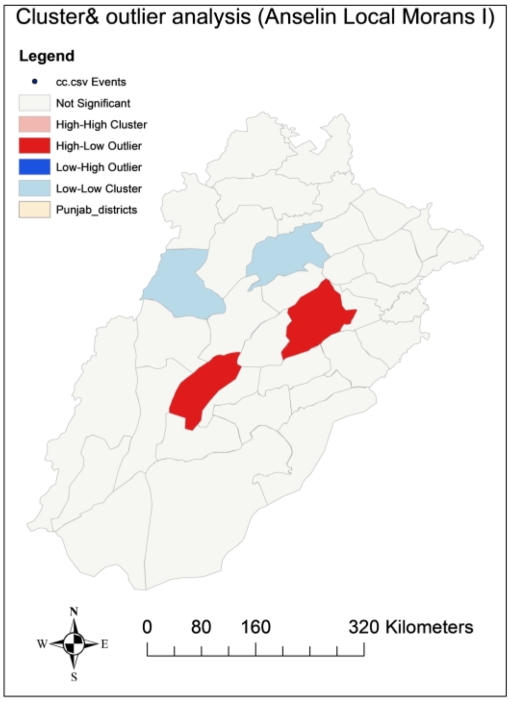

Figure 7. *High-low cluster analysis of COVID-19 confirmed cases at district level of Punjab*

The hotspots analysis (Getis-Ord Gi*) identified strong clustering of cumulative confirmed cases of COVID-19 at district level, where higher concentration of events was found in Punjab. District Lahore was identified as highly significant hotspot of COVID-19 (99% confidence level), while Kasur district and Sheikhupura district were identified as significant hotspots (95% confidence level). However, Nankana Sahib district was shown as a moderate hotspot (90% confidence level) in Punjab province (*Fig. 8*).

Influencing factors of COVID-19 in Punjab

The results demonstrated strong, positive and highly significant correlation between cumulative confirmed cases of COVID-19 and district population ($\rho > 0.76$; $p < 0.001$), number of hospitals ($\rho > 0.71$; $p < 0.001$) and number of beds in hospitals ($\rho > 0.82$; $p < 0.001$). A moderate, positive and significant correlation was shown with population

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density (persons per square Km) ($\rho > 0.50$; $p < 0.05$), and moderate, positive and highly significant correlation with number of gowns provided ($\rho > 0.53$; $p < 0.001$). However, number of surgical masks, number of gloves, and number of goggles showed a weak, positive and significant correlation with the cumulative confirmed cases of COVID-19 at the district level ($\rho > 0.4$; $p < 0.05$) (*Fig. 9*).

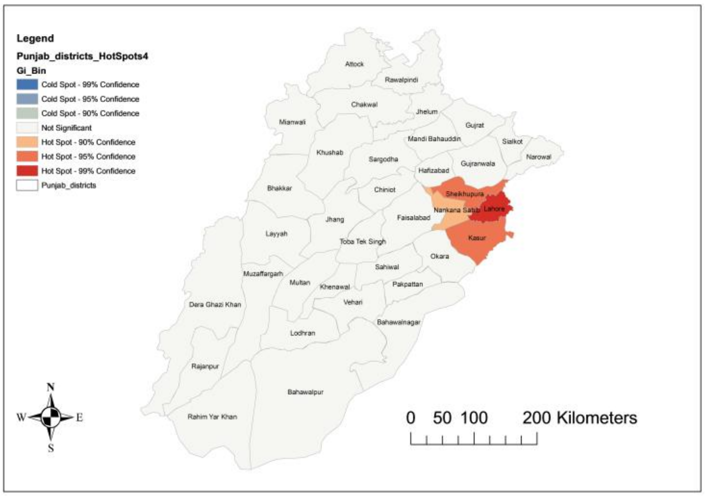

Figure 8. *Hotspots of COVID-19 confirmed cases at district level of Punjab*

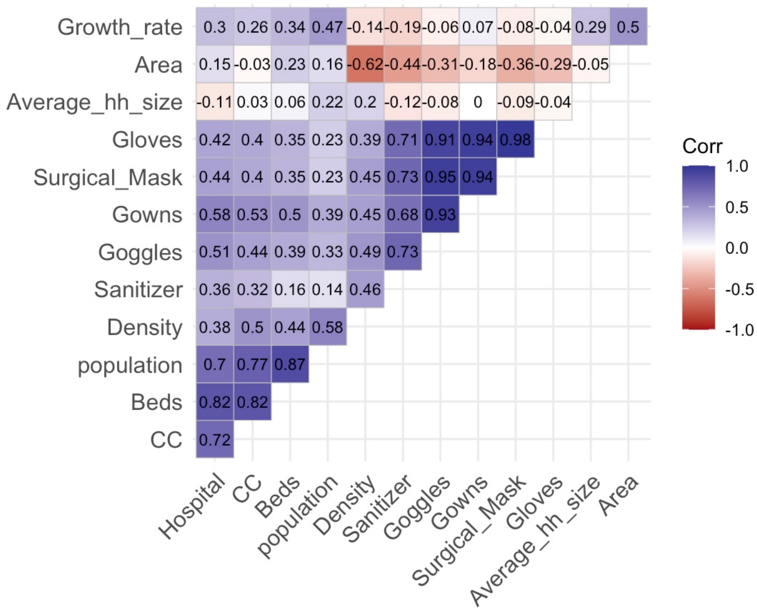

Figure 9. *Correlation matrix of influencing factors of COVID-19 in Punjab*

Discussion

The COVID-19 pandemic disrupted the world in every aspect of life and overwhelmed the healthcare system globally (Vilinová and Petrikovičová, 2023). Pakistan was also affected by the COVID pandemic like other regions of the world. In the current study, spatial patterns of cumulative confirmed cases of COVID-19 at district level in Punjab,

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Pakistan were described. The incidence rate was 153 per million, CFR was 2.14% and mortality rate was 3.25 per million. In India, the CFR was 1.42% and 2.97% on 27th July, 2020 (Singh et al., 2021). The worldwide median CFR was reported to be 2.19 on 2nd July, 2020. CFR reflects disease severity, as well as the efficiency of treatment and healthcare response and strain (Cao et al., 2020). The data from Qom Province of neighboring country Iran, showed increased monthly incidence of COVID-19 from February to April which also corroborates with the findings of the current study (Jesri et al., 2021). In Punjab, smart lockdown was implemented in different districts to mitigate the virus transmission from 2nd July to 10th August, 2020. A "smart lockdown" was referred to a localized approach to controlling the spread of COVID-19. Instead of restricting movement for everyone, specific neighborhoods, streets, or districts with high infection rates were sealed off temporarily. Movement in these areas was restricted, while businesses and markets in low-risk areas remained open under standard health protocols. During that period, infection rate slowed down indicating it as a successful strategy. Smart lockdown has been reported as a preventive measure to minimize the virus transmission (Wang et al., 2021). The efforts made by the Government of Pakistan to reduce the spread of COVID-19 were recognized at global level and Pakistan was among the top three countries, who had handled COVID-19 pandemic with a successful strategy of smart lockdown along with the Hong Kong and New Zealand (Dawn, 2021). Implementation of policies at the right times particularly the smart lockdown minimized the spread of COVID-19 in Pakistan and remained under control compared to neighboring and even some developed countries (Abbas and Mannan, 2022).

Spatial statistics analysis has been used as a tool to identify geographic and environmental risks (Kang et al., 2020; Xiong et al., 2020). In the current study, global spatial autocorrelation analysis identified positive spatial association between COVID-19 confirmed cases and various districts. It depicted that the COVID-19 pandemic in Punjab had a significant and strong spatial dependence between the neighboring districts. The Local Moran's I analysis identified Faisalabad and Multan districts as HL outlier. District Lahore was identified as a highly significant hotspot for COVID-19 surrounded by Kasur and Sheikhupura districts. These districts also have higher population density (persons per square kilometer) (Anonymous, 2022). These significant clusters showed that the risk of COVID-19 infection in these districts is much higher compared to the other districts. Punjab and Sindh were the most affected provinces of Pakistan and Lahore district was identified as highly significant hotspot of COVID-19 previously (Arif and Mahmood, 2023; Mahmood, 2022). High concentration of population was also identified as risk factor of coronavirus in China (Yang et al., 2020).

Influencing factors of COVID-19 epidemic had important role to understand spread of infection and its control measures. A strong, positive and highly significant correlation between number of COVID-19 confirmed cases and district population was identified ($\rho > 0.7$; $p < 0.001$). It has been established that risk of COVID-19 is significantly higher in densely populated areas due to high proliferation rate and contiguous nature of the pathogen (Aw et al., 2021; Md Iderus et al., 2022; Tammes, 2020). The PPE supply during that period also showed a significantly positive correlation with the COVID-19 confirmed cases at the district level, interpreting that with the increasing number of cases, the use of PPE also increased. Evidence based data demonstrate that mask wearing and social distancing are effective nonpharmaceutical interventions to reduce the spread of any virus and during the COVID-19 pandemic, the scientific evidences to support this hypothesis has increased (Aw et al., 2021; Brooks and Butler, 2021; Jesri et al., 2021). The current

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study showed high correlation between COVID-19 confirmed cases and number of hospitals and number of beds in hospital. Higher number of hospitals and beds indicates an efficient healthcare system to deal health emergencies and pandemics in urban areas. Data indicated that urban areas with high population density (Lahore and Rawalpindi districts) have higher number of COVID-19 confirmed cases compared to lower population density districts. The urban areas with higher population density usually tend to have higher positivity rate for COVID-19 due to better healthcare facilities and reporting system because these areas had more hospital and ICU beds, which may serve as referral centers for patients with more severe forms of COVID-19 therefore resulting in a higher death rate (Saffary et al., 2020).

The major limitation of the current study is that data was incorporated from a specific time period, when there was lockdown in all the major districts of Punjab. There may be underreporting of cases due to movement restrictions and shutdowns of all major business and transportation facilities. The high number of undetected or asymptomatic COVID-19 cases may also have impacted the results (İçöz and Yenilmez, 2023).

Conclusions

The current study provides a comprehensive understanding of the spatial clustering and association of COVID-19 confirmed cases in Punjab, Pakistan. Geo-visualizing the hotspot can help the healthcare authorities of Punjab, Pakistan to initiate public health interventions to halt the spread of virus to neighboring districts in future epidemics. The Global Moran's I could be used by the health authorities to identify small epidemics of COVID-19 and similar infections to initiate control strategies.

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