Spatial distribution and mapping of COVID-19 pandemic in Afghanistan using GIS technique

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Abstract

Geographic information science (GIS) has emerged as a unique tool that is extremely valuable in various research which involves spatial–temporal aspects. The geographical distribution of the epidemic is considered a significant characteristic that can be analyzed using GIS and spatial statistics. Proper knowledge can assist in controlling, mitigating, and mapping factors for detecting the transmission as well as the disease dynamics, and it provides geographical information of the outbreak and it can also give a glimpse of the disease trend and hotspots as well as provide ways to further evaluate the associated risk. This study analyzed the countries’ total confirmed cases, total death cases, and the total recovered cases using an (IDW) geospatial technique which is an inherent tool used in ArcMap for spatial analysis. In order to identify the hotspots for COVID-19 cases, the Getis-Ord Gi* statistic method was applied with a confidence level of 95% in Herat and 90% for Kabul, Kapisa, and Logar provinces. The data considered in this research ranged from the period of 23rd July 2020 to 24th February 2021. All the COVID-19 confirmed, recovered, and death cases were correlated with provincial population density using the Pearson Correlation coefficient. Among the total cases 54,487, 32% cases were reported in the capital of the country (Kabul), and the mortality rate was 31% followed by Herat (18% deaths), Balkh (7% deaths), and Nangarhar (6% deaths). Most of the recoveries were observed in Kabul with (30%) followed by Herat (16%), Bamyan (10%), Balkh (5%), and Kandahar (5%). The results for Global Moran’s I showed that the incidence rate of the total COVID-19 cases was in the random pattern, with the Moran Index of −0.14. Given the z-score of −1.62, the pattern does not appear to be significantly different than random. There was a strong correlation between the COVID-19 variables and population density \[r(33) = 0.827\], \[r(33) = 0.819\] and \[r(33) = 0.817\] for the total cases, death cases, and recovered cases, respectively. Even though GIS has limited applicability in detecting the type and its spatial pattern of the epidemic, there is a high potential to use these tools in managing and controlling the pandemic. Moreover, GIS helps us better in comprehending the

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epidemic and assists us in addressing those fractions of the population and communities which are underserved during the disease outbreak.

**Keywords** COVID-19 · Interpolation · Spatial analysis · Public health · Afghanistan

**Introduction**

The coronavirus 2019 has risked the lives of humanity around the globe (Mondal and Ghosh 2020; S. N. Journal of Ongoing Chemical Research 2020) because of its rapid transmission and infection rate, this contagious disease has initiated a global challenge to the healthcare system (Clara-Rahola 2020). COVID-19 has a 5-to 6-day incubation period, but it can take up to 14 days for symptoms to develop (Gupta et al. 2020; Member and Bhatnagar n.d.). During this time, COVID-19-infected patients can spread the virus to those in their immediate vicinity without displaying any symptoms (Koubaa 2020). Currently, 11 countries account for more than 70% of all COVID-19 cases worldwide: The United States, Brazil, India, Russia, South Africa, Peru, Mexico, Colombia, Chile, Iran, and Spain. According to the World Health Organization (WHO), the virus has been transmitted to more than 213 nations and worldwide by direct communication with infected individuals. The scale of the casualty rate varies greatly across landmasses and is largely dependent on population demographic profile and health services (Ranjan 2020) and also the government’s successful behavior promptly (Bedford et al. 2020; Wang et al. 2020).

Furthermore, over the last two decades, the prevalence of these infectious diseases has risen dramatically. Infectious disease rates are rising as a result of unsanitary environmental conditions. COVID-19, in the case of Wuhan, China, has been discovered to propagate via social interactions, with the active facilitation of unauthorized animal markets (Shereen et al. 2020). However, the level of understanding is growing about the infectious diseases that they are geographically specific; as a result, it is even becoming more crucial to investigate the different aspects of health-related data within a given region.

Geographic information systems (GIS) provide an excellent medium for integrating specific health data and its understanding with relation to population habitus, including healthcare services, and the environment (Wang et al. 2020). A geographic analysis of the virus, on the other hand, is based on the issue of “Where is the outbreak focusing and spreading?” In epidemic studies, GIS is used to determine where more individuals are impacted, as well as to examine disease concentrations in great detail. This phenomenon has been described clearly by spatial autocorrelation, which is extensively applicable in the context of COVID-19 propagation in any nation.

To combat the outbreak of SARS pandemics, several researchers have used a variety of tools and tactics (Conhecimento 2020; Gatto et al. 2020). A variety of research studies have been conducted in this area, taking into account different variables like the provision of adequate healthcare services, metrics to keep up with the infected ones’ requirements like isolation procedures, and the constantly emerging
distribution. To forecast and approximate the temporal analysis of the Corona spread, along with all the variables, there is a need for analyzing overt geographic distribution models. As a result, Geographical Information systems and spatial maps are becoming increasingly popular globally (Bergquist 2010). The results from this study will be helpful for researchers in understanding the various GIS tools used for mapping any contagious disease.

Geospatial methods can be very useful for understanding, treating, tracking, and mitigating a certain disease. Using this approach will provide a visual representation of disease distribution, risk factors, and possible treatment facilities. As a result, these techniques can be applied to the preparation, configuration, and delivery of global health assistance for care and prevention (Murugesan et al. 2020). The aim of this study is to provide visualization about the occurrence and spread of COVID-19 in any geographical area as well as show the relationship between the population density and the COVID-19 variables. Another significance of conducting this study is to know the severity of the pandemic in a particular area, and consequently, establish temporary a health facility. Such maps are very trendy for the person to avoid going to highly affected areas of COVID-19. In this study, we have utilized the application of the GIS tools in the field of public health care. GIS can be utilized to map the distribution of disease and its connection with treatment resources and prevention. It is unique in terms of it gives the geographical information of the outbreak and it can also give a glimpse of the disease trend, hotspots, and to further evaluate associated risks.

Materials and methods

Study area

Afghanistan is a landlocked country covering an area of 652,000 km². To the east and south, it is bordered by Pakistan, Iran lies to the west, Tajikistan, Uzbekistan, and Turkmenistan on the north, and China lies in the northeastern part of Afghanistan. The capital is Kabul city which is home to almost 4,860,880 people and is the most populous in the country, and it is followed by Herat, Nangarhar, and Balkh provinces, respectively. The population of Afghanistan is 30,075,018 according to a 2019 estimate, and the population density is 46/km² (Fig. 1). Nooristan ranks last in the population statistics (Table 1).

The total distribution of COVID-19 cases in Afghanistan is depicted in Fig. 2. A total of 54,487 cases of the novel coronavirus have been presented from the 23rd of June 2020 till February 24th 2021. However, able to be noted is that from the total 54,487 cases, 48% of the infected patients recovered in the fight against coronavirus, 2% of people died (Fig. 2).

Data for the COVID-19 in Afghanistan came from different sources (Afghanistan Ministry of Health, HDX 2021; NSIA 2019; OCHA Afghanistan 2019). We have selected three types of cases in our study because only the total confirmed cases, death cases, and recovery cases are published daily on the Humanitarian Data Exchange site for Afghanistan and the periods under investigation were
Fig. 1  Population density of Afghanistan

Table 1  Provincial Population of Afghanistan (NSIA 2019)

| No  | Province      | Population | Are/km² | People/km² | No  | Province      | Population | Are/km² |
|-----|---------------|------------|---------|------------|-----|---------------|------------|---------|
| 1   | Badakhshan    | 1,017,499  | 43,460  | 23.41      | 18  | Kunar         | 482,115    | 4848    |
| 2   | Badghis       | 530,574    | 20,709  | 25.62      | 19  | Kunduz        | 1,091,116  | 7904    |
| 3   | Baghlan       | 977,297    | 17,803  | 54.90      | 20  | Laghman       | 476,537    | 3836    |
| 4   | Balkh         | 1,442,847  | 16,769  | 86.04      | 21  | Logar         | 419,377    | 4395    |
| 5   | Bamyan        | 478,424    | 17,892  | 26.74      | 22  | Wardak        | 637,634    | 10,580  |
| 6   | Daykundi      | 498,840    | 15,779  | 31.62      | 23  | Nangarhar     | 1,635,872  | 7397    |
| 7   | Farah         | 543,237    | 49,591  | 10.95      | 24  | Nimroz        | 176,898    | 41,039  |
| 8   | Faryab        | 1,069,540  | 20,718  | 51.62      | 25  | Nooristan     | 158,211    | 8987    |
| 9   | Ghazni        | 1,315,041  | 21,668  | 60.69      | 26  | Paktika       | 748,910    | 19,067  |
| 10  | Ghor          | 738,224    | 37,131  | 19.88      | 27  | Paktya        | 590,668    | 5275    |
| 11  | Helmand       | 1,395,514  | 60,009  | 23.25      | 28  | Panjsher      | 164,115    | 3730    |
| 12  | Herat         | 2,050,514  | 54,938  | 37.32      | 29  | Parwan        | 711,621    | 5590    |
| 13  | Jawzjan       | 579,833    | 11,120  | 52.14      | 30  | Samangan      | 415,343    | 12,913  |
| 14  | Kabul         | 4,860,880  | 4655    | 1044.23    | 31  | Sar-e-Pul     | 599,137    | 15,268  |
| 15  | Kandahar      | 1,337,183  | 54,165  | 24.69      | 32  | Takhar        | 1,053,852  | 12,319  |
| 16  | Kapisa        | 471,574    | 1882    | 250.57     | 33  | Uruzgan       | 420,964    | 10,862  |
| 17  | Khost         | 614,584    | 4284    | 143.46     | 34  | Zabul         | 371,043    | 17,350  |
from late June 2020 till the 24th of February 2021. To show the trend and spread of COVID-19, a GIS tool known as the Inverse Distance Weighted (IDW) was used for visualization.

The data were downloaded from different available sources and were modified in accordance with the objective of this study. Data were in the form of excel sheets with latitude and longitude information for all provinces of the country (Afghanistan). The shapefile of the study area was downloaded from the (DIVA-GIS) website. The shapefile and excel sheets were imported in ArcGIS software. The excel data were converted into point data and eventually, the IDW technique was applied to it to create the maps of total cases, total deaths, and total recovered cases in the country.

**Spatial analysis of COVID-19**

**Spatial autocorrelation**

Spatial and autocorrelation are important in geographic modeling. Since then various methods and techniques for testing and evaluating spatial autocorrelation have been developed, many geographers are interested in using Moran’s I statistic, which is regarded as one of the most famous types of spatial autocorrelation (Bivand et al. 2005). The value of Global Moran’s I falls between −1.0 and +1.0. The spatial pattern demonstration is characterized as follows: > 0: Clustered, = 0: Scattered, and < 0: random distribution (Bivand et al. 2005). In our study, the spatial distribution pattern of the total confirmed cases for each region was investigated using Global Moran’s I.

**Hot spot analysis**

Once the clustered pattern is obtained, the areas with the greatest incidence known as the high-risk spots were studied. Using the hotspot analysis tool (Getis-Ord Gi*). 

![Corona Statistics of Afghanistan (24th February 2021)](Image)
in GIS ArcMap software, the statistics for Getis-Ord Gi* are derived. It derives values by examining each feature with the surrounding neighboring features. Features with high values can be interesting, but they might not be a statistically significant one, it should also be surrounded by features with high values, thus, making a significant hotspot (Kim and Choi 2017). Z-score can be extracted from Gi*statistic; values with high Z-scores show the intensity of the high clustering values, while negative values for the Z-score depict high intense values of low clustering values or known as cold spots (Peeters et al. 2015).

**Interpolation IDW**

In Afghanistan, the incidence of COVID-19 cases has been published for each province; however, the actual geographical location of the incidents has not been specified. So with the help of GIS Software, we predicted the spread of the incidents across the country using the IDW spatial interpolation technique as proposed by Murugesan et al. (2020). This method of interpolating the expected zone of the neighboring regions to compute the values of any uncertain area (Childs 2004). Inverse Distance Weighted technique is built upon Tobler’s first law of geography which says “everything is related to everything else, but near things are more related than distant things.” This technique was invented in 1972 by the United States National Weather Service and was listed among the deterministic method. This approach requires less computation for achieving statistical assumptions as compared to other stochastic methods like Kriging, TRA, etc. (Chen and Liu 2012).

IDW is built upon the function of inverse distances, in which the weightage increases with the decrease in distance and vice versa. It implies that known-value points were used to approximate the values of uncertain points. The need for known point values distinguishes spatial interpolation from other techniques such as isololeth mapping, which interpolates with the use of assigned points like polygon centroids. The fundamental theorem of spatial interpolation states that values that need to be assessed at a particular point are more affected by those points that are near than those located farther. A stochastic approach would normally make the inference of a random operation. IDW interpolation (inverse distance weighted) is an exact procedure for estimating the value of a point that is affected by adjacent known points rather than those farther apart. The IDW method’s general equation is

$$K_{xy} = \frac{\sum_{i=1}^{N} K_i W_i}{\sum_{i=1}^{N} W_i}.$$ 

$K_i$ denotes the sample point control value, $W$ signifies the weight responsible for showing the relative significance of each $K_i$ in the interpolation process, the value that needs prediction is denoted by $K$ and $N$ signifies the total whole sample points under consideration (Bartier and Keller 1996). However, IDW has certain limitations, i.e., the quality of interpolation can defer whenever the measured values are inconsistent. Moreover, the high and low values in the area under interpolation can...
only emerge near the sample datasets. This would result in minor spikes and troughs around the sample datasets (Setianto and Triandini 2015; Zhu 2016).

Results

The COVID-19 virus has made its way through the whole country. From the 24th of June 2020 to February 24th 2021, a total of 54,487 cases have been registered (Fig. 3). In our research study, data of the provincial cases were linked to the COVID-19 cases in the form of point data. The data from 34 provinces of Afghanistan have been studied to determine the spatial variation. Using ArcGIS 10.4.1 IDW tool was used to visualize the current state and severity of the infectious disease outbreak.

To estimate the spread of the cases in Afghanistan, the IDW interpolation technique has been adopted in ArcGIS 10.4.1. As of February 24th 2021, in Afghanistan, a total of 54,487 cases of the disease were reported. Using the IDW interpolation tool, the maps of the study area were generated, and based on the natural break classification, the values were classified as eight classes ranging in order from 100–1000, 1000–1700, 1700–3000, 3000–4800, 4800–6700, 6700–9300, 9300–13,000, and 13,000 to 17,200 as shown Fig. 4. The provincial cases are risked based on the density of the population which is one of the crucial factors in the disease spread also reported by Kadi and Khelfaoui (2020), Bhadra et al. (2021), and Coşkun et al. (2021). More than 31% of the cases were discovered in the capital
Kabul Province which is the most populous city in Afghanistan. As the capital city of the country around 17% of the population is living there with 1044 people/km². Due to densely populated COVID cases spread rapidly. We can observe from Fig. 4 that Kabul is in the South-East of the country and Herat which ranks second in the number of COVID incidents is located in the North-West near the border of Iran that has 9168 cases from June 2020 to February 2021 and most of the cases in this province came across because of the people returned to their homes due to closure of their workspace in Iran. Kabul and Herat are the main epicenters within the country for the spread of COVID cases. Balkh and Nangarhar provinces have 6.19% and 4.70% of confirmed cases, respectively. A strong positive correlation was found between the population density and the total confirmed cases using the Pearson correlation coefficient with the COVID-19 data [where $r(33) = 0.827$] (Table 2).

As of February 24th 2021, a total of 2417 deaths have been officially confirmed according to the health ministry of Afghanistan. The capital Kabul alone reported

![Fig. 4](total_covid_cases_distribution_in_afghanistan.png)

**Fig. 4** Total COVID-19 cases distribution in Afghanistan (24th February 2021)

| Table 2 | Pearson Correlation between COVID-19 variables and population density |
|---------|---------------------------------------------------------------|
| Variables | T test | DF | Significance value | Pearson’s coefficient |
| Confirmed cases | 2.926 | 33 | 0.006 | 0.828 |
| Death cases | 2.866 | 33 | 0.007 | 0.821 |
| Recoveries cases | 2.970 | 33 | 0.006 | 0.782 |
763 deaths which account for 31.56% which is because most of the COVID cases have been observed in the capital city. Nearly 431 (17.83%), 180 (7.45%), and 154 (6.37%) have been reported from Herat, Balkh, and Nangarhar provinces, respectively. Table 2 presents the relationship between the population density and the death rates due to Coronavirus \( [\text{where } r(33)=0.819] \) which means that population has a positive relationship with the number of deaths reported (Fig. 5).

The number of total recoveries from this infectious disease was 48,163 cases as of February 2021 which is 88% of the confirmed cases. Kabul has witnessed the highest number of recoveries which was 15,907 cases of the total 17,251 confirmed cases. Kabul alone has a 33% percent recovery rate followed by Herat, Balkh, and Kandahar provinces with 8653 (18%), 2852 (6%), and 2424 (5%), respectively. The strength of the correlation between the recoveries and population density can be observed in (Table 2) \( [\text{where } r(33)=0.817] \) (Fig. 6).

The first case of the Corona Virus in Afghanistan was found on 24th February 2020 in a 35-year-old man, who was one of the three people from Herat who recently came from the neighboring country Iran (Storai and Sediqi 2020). This led to an increase in three more cases on March 7 becoming a total of four cases (Sediqi 2020).

It was on 10th March, when a new confirmed case was reported in Samangan province, the infected person too was reported to have come from neighboring Iran (Ministry of Health 2020a). The number spiked to 607 cases on April 11 which were reported in Kabul, Herat, Kandahar, Balkh, Bamiyan, Helmand, Nangarhar, and Paktya provinces (Ministry of Health 2020b).
There is a strong correlation between population density and all the COVID-19 cases including the total cases, total deaths, and the total recoveries (Table 2).

**Evaluating Global Moran’s I**

For Moran’s I calculation, Inverse distance was selected as the Conceptualization of Spatial relationship field and Euclidean Distance as the distancing measure. Euclidean Distance is the most commonly used method and it is derived by calculating the shortest straight line between two points. Mathematically, it can be expressed as follows:

$$E(P_1, P_2) = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}.$$

The results for Global Moran’s I showed that the incidence rate of the Total COVID-19 cases was in the Random pattern, with the Moran Index of $-0.14$. Given the $z$-score of $-1.62$, the pattern does not appear to be significantly different than random. These statistics are evident in Fig. 7.

**Hotspot analysis**

To identify the hotspots for COVID-19 cases, the Getis-Ord Gi* statistic method was applied, and the result is illustrated in Fig. 8 with a confidence level of 95% in Herat and 90% for Kabul, Kapisa, and Logar provinces.

From June 2020 to February 2021, the study of hotspots to identify Hot and Cold spots is shown in Fig. 8. Herat was considered the disease’s hotspot with a 95%
degree of certainty at the end of February 2021, and it had the most unfavorable location for eight months. Officials from the Ministry of Health in Herat have verified the first case of COVID-19, which was contracted by a person who had purportedly been to Iran. This is also visible in Fig. 3, which shows Herat as the province with the second-highest number of overall COVID-19 cases. Kabul province, with a 90% confidence level as the hotspot is Afghanistan’s capital and largest city, and home to over 4.5 million people and serves as the country’s political, cultural, and economic hub. The disease has spread throughout the nation, with the bulk of cases occurring in the nearby provinces of Kapisa and Logar with a degree of 90% confidence.

Discussion

The COVID-19 virus has caused widespread health problems across the country. This study has applied various spatial techniques ranging from Spatial autocorrelation using Global Moran’s I, Hotspot analysis using Getis-Ord Gi* statistics, and correlations between the population and COVID-19 variables from the month of February 2021.
June 2020 to February 2021. In Afghanistan, a total of 54,487 cases have been registered as of February 24th 2021. Kabul city ranks at the top in the total COVID cases trailed by Balkh, Kandahar, and Nangarhar provinces, respectively. Nooristan province ranks the lowest in the number of active infections but again Kabul stands at the top in the number of mortalities which accounts for the highest death rate in the country. The correlation between population and number of cases, deaths, and recoveries has a positive relationship which is also observed in another study (Ganasegeran et al. 2021a, b; Moazzam et al. 2021). A very strong correlation was found between the population density and the COVID-19 variables which is very necessary for officials in establishing new healthcare centers and providing guidelines to the community based on the density of the disease-prone areas. Thus, for controlling the COVID-19 spread, it is of significance to weigh the population density with other factors.

For identifying the spatial patterns in Afghanistan, Moran’s I was used to find the spatial autocorrelation, but the results showed no significance with a random pattern of −0.14 as depicted in Fig. 7. Moreover, hot and cold spots were identified using Getis-ord- Gi* statistics with Herat at 95% confidence level and Kabul, Logar, and Kapisa provinces at 90% confidence level. This showed that how GIS tools could be helpful in identifying hot spots for the disease so that the health authorities are informed and proper decisions could be made in time.

Despite the increased burden on the healthcare sector and increased demand for its services because of the COVID-19 pandemic, health facilities and staff continue to be attacked and intimidated by conflict groups. Specific assaults on clinics,
abductions of healthcare staff, acts of coercion, abuse, and interference, looting of medical equipment, and indirect damage from the current military struggle have all occurred since the onset of the pandemic.

Examining the potential reasons of COVID and its associated risk i.e., occupations and businesses, as well as the concentration of living situations (not only population density). Safety supervisors can use the number of COVID-19 cases to decide where to focus their attention. By using GIS techniques to handle temporal evaluations of pandemic illnesses like COVID-19, this study can greatly aid in the development of country-specific healthcare policy. As a result, wise medical-care policies are necessary for Afghanistan to offer developed COVID-19 surveillance as well as more effective control of the new coronavirus.

Conclusion

In this study, regional distribution of the COVID illness in Afghanistan was visualized using geospatial technology. Spatial Autocorrelation techniques including global Moran’s I and Getis-Ord G* techniques were applied to visualize the spatial pattern of the study area. The findings demonstrated that spatial distribution of the disease in Afghanistan is of heterogeneous nature, particularly the cases are concentrated in the central and western provinces of the nation. The resultant hotspots of COVID-19 in Afghanistan (Kabul, Logar, Kapisa, and Herat) will assist provincial health officers in improving their corrective action and developing possible disease control plans. Moreover, a GIS-based approach known as IDW was utilized to find the potential virus-affected regions in Afghanistan. The study also showed a strong correlation between the total, recovered, and death cases, and the population density. It should be noted that after adhering to strict COVID-19 measures, within this seven months’ data, there are a large number of recoveries and reduced deaths from mid-September.

Moreover, our research shows that geographical and temporal analyses of population-based surveillance data for illnesses will be beneficial in the management of viral infections like COVID-19 by targeting the right places for providing public health resources.

Besides, this strategy not just takes into account the determination of various zones all through the country; however, it additionally considers the exhibit of the level of impossibility in the expectation, which might be helpful in different countries.

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