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Original article

Spatial mapping of the incidence, case-fatality rate and recovery rate of COVID-19 in West Bengal: An epidemiology study

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ABSTRACT

Information on the spatial and temporal distributions of COVID-19 cases is important for improved control, social distancing strategies and developing targeted prevention strategies. Towards this objective, we analyzed the spatial and temporal growth pattern of COVID-19 incidence and death counts in districts of West Bengal. This paper also analyzes the current trend or pattern of COVID-19 transmission in West Bengal. For this approach, COVID-19 data have been compiled from several sources, including the WHO, Ministry of Health and Family Welfare (MoHFW), and demographic data from Census of India (2011). This analytical study was conducted based on detailed data from 23 districts of West Bengal from May 31, 2020, till December 31, 2021. We used ArcGIS Software for map-making and different formulas to measure Incidence, CFR, and CRR, considering all possible scenarios. Up to December 31, 2021, Kolkata, the origin of the COVID-19 epidemic, had reported 337767 COVID-19 cases, while the confirmed cases in the surrounding districts North 24 Parganas, South 24 Parganas, and Howrah were 337091, 104268, and 102048, respectively. The top five districts with the highest incidence were Kolkata (7.51%), Darjeeling (3.66%), North 24 Parganas (3.36%), Kalimpong (2.85%), and Jalpaiguri (1.79%), had high risks of COVID-19. Therefore, identification of the case fatality, recovery rates, and spatiotemporal trends should be the first step to evaluate disease severity and develop effective policies to manage and control any new epidemic. These results are informative locally and useful for the rest of the world.

Background

The past 20 years have seen several epidemics like the acute respiratory syndrome coronavirus during 2002-2003 and H1N1 influenza during 2009 [1]. In the 21st century, emerging infectious diseases are a major challenge. Ebola and Middle East Respiratory Syndrome coronavirus (MERS-CoV) epidemics have caused massive economic, healthcare systems and resources losses in recent years [2,3]. The ongoing new corona virus disease 2019 (COVID-19) outbreak is becoming a severe disease and global public health problem [4-6].

The coronaviridae family contains large, enveloped, single-stranded RNA viruses [7]. The human coronaviruses (HCoV) are 229E, NL63, HKU1, OC43, Middle East respiratory syndrome coronavirus (MERS-CoV) and severe acute

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respiratory syndrome coronavirus (SARS-CoV). Four HCoVs (HCoV 229E, NL63, OC43, and HKU1) are endemic at a global level and account for 10% to 30% of the upper respiratory tract infections in adults. [8]. Although HCoVs have long been regarded inconsequential pathogens due to their mild clinical manifestations in humans, two large-scale epidemics with alarming morbidity and mortality in the early 21st century – i.e., SARS and MERS - have changed that view.

The COVID-19 has struck fear into populations all over the world and horrified the global medical community. The World Health Organization [9] declaring (On March 11, 2020,) it is a pandemic only two and a half months the outbreak of the disease. The COVID-19 outbreak is similar to the middle east respiratory syndrome coronavirus (MERS-CoV) and severe acute respiratory syndrome coronavirus (SARS-CoV) outbreak that occurred in 2002-2003.

The Wuhan Municipal Health Committee reported 27 cases of pneumonia with unknown etiology in Wuhan city, Hubei province of China, on December 31, 2019[10]. Majority of the cases were linked to the Wuhan Southern China Seafood Market, which was subsequently closed on January 1, 2020 [11]. On January 7, 2020, laboratory tests identified that the previously unexplained pneumonia was a new type of coronavirus; this pneumonia was then officially named novel coronavirus (COVID-19) by the World Health Organization. [12,13] and was later renamed severe acute respiratory syndrome coronavirus (SARS-CoV-2) [14,15]. The COVID-19 outbreak started in Wuhan and spread rapidly to other provinces and countries [16]. In India, the first case of COVID-19 was found in Kerala on January 30, 2020, in a student who had returned home from Wuhan University, China. Soon after, the epidemic spread in the other part of mostly due to the imported cases from outside the country. On March 17, 2020, West Bengal reported the first COVID-19 positive case, after a UK-returned student was tested positive. To tackle the pandemic situation the lockdown(Janta Curfew) in the entire country was announced (Hon'ble Prime Minister of India)on March 24 for a period of 21 days to break the chain of coronavirus transmission or human-to-human transmission and since then Borders were sealed, transportation was ceased, all the industries, shops, restaurants, offices (government and private), businesses and, academic institutions have been temporarily closed, barring only the essential services as per the guidelines of the government.

COVID-19 is defined as a class B infectious disease; however, the Indian government and state governments are treating it as a class A infection disease. Daily case reports are being released, and prohibited government orders are punishable by law. Currently, the number of cases is increasing, and the epidemic has not yet peaked; however, the situation differs from state to state and district to district. Keeping this in mind, in this paper, we analyze the evolution of COVID-19 cases and deaths in various West Bengal Districts. Specifically, we study and model the temporal evolution of infection and death counts for various time intervals and analyze their variations. These updated results of the current situation will provide valuable information for disease prevention at both the individual and organization levels to make decisions based on a dynamic situation analysis.

Objectives

1. To examine the spatial spread of the Incidence of COVID-19 in all districts of West Bengal.
2. To study the case fatality rate and case recovery rate in the West Bengal districts.

Methodology

Materials and Methods

This research was performed by reviewing the available published literature, news articles, and different government and non-government organizations' information from reports and official websites. We also used data from various sources such as WHO, Ministry of Health and Family Welfare (MoHFW) [17], MoEFCC, etc. Scientific literature was collected through electronic means from the database of Springer, Science Direct, PubMed, Taylor and Francis, Research Gate, Google Scholar, and Z-library but not in a systematic manner.

We retrieved data between 31 May 2020 to 31 December 2021 from the Government of West Bengal Health & Family Welfare Department Novel Coronavirus Bulletin portal available in the public domain. It provides data daily up to the district level since the first date, 15 March 2020, a COVID-19 case was found in West Bengal. This dataset includes district-wide details of confirmed cases, recovered cases, and death cases.

Data analysis

The COVID-19 data of West Bengal has been analyzed (**Figure 1** and Supplementary Information: Table: A). Statistical models are essential tools to analyze the real-time data analysis of infectious diseases. Charts and maps have been prepared concerning the data to interpret and explore the results. We analyzed the cumulative number of all reported cases between 31 May 2020 to 31 December 2021 as announced by the Government of West Bengal Health & Family Welfare Department on 31 December 2021 [18], calculating the incidence of COVID-19 in each district according to the following formula:

Formula: I

COVID-19 incidence= Confirmed cases/ Total population (1)

Measuring the case fatality rate and case recovery rate

Case Fatality Rate (CFR) is the proportion of deaths due to a specified health condition compared to total infected cases [19], and Case Recovery Rate (CRR) is the proportion of recovered or discharged individuals with a specified health condition compared to total infected cases [20]. Given the difficulty of calculating CFR and CRR accurately during the ongoing COVID-19 pandemic period, we used two different approaches to estimate CFR and CRR, considering all possible pictures **(Table 2)**.

According to **Battegay et al.,** [21] we estimated CFRs and CRRs using the proportion of total deaths and recovered cases of COVID-19 disease to total cases of disease at districts levels of West Bengal.

Formula: II

CFR= (Total Deaths Attributed to COVID-19/Total Cases of COVID-19) * 100 (2)

CRR= (Total Recovered Individuals Attributed to COVID-19/Total cases of COVID-19) * 100 (3)

Spatial distribution analysis

The spatial distribution analysis was used to analyze the distribution of total COVID-19 cases in all districts. Temporal and spatial distribution of COVID-19 confirmed cases and a total deaths map have been produced for a period of every last day of months using ARC GIS software over the period from May-2020 to December-2021. As an example, 8 maps for each variable (e.g., confirmed cases) have been created on 31 May 2020, 31 July 2020,30 September 2020,30 November 2020,30 February 2021, 31 May 2021,31 August 2021,31December 2021 **(Figure 3)**. The spatial distribution analysis was created by entering the COVID-19 data into each district's shape file's attribute table. Finally, the spatial distribution maps were classified into five classes of the number of COVID-19 cases.

Univariate and local bivariate spatial autocorrelation

Moran's local univariate spatial autocorrelation analysis [22] was used to map the clusters and outliers in the districts that contributed to the spatial autocorrelation of the incidence rate and to analyze the local indicators of spatial association. Using the Local Indicators of Spatial Association (LISA) technique, we identified the local spatial heterogeneity of COVID-19 incidence, i.e., detecting districts with high incidence rate values surrounded by districts with high incidence rate values (H-H clusters) and districts with low incidence rates surrounded by districts with low incidence rates (L-L clusters).

We also used local bivariate autocorrelation analysis or Bivariate Local Moran's I [23] to evaluate the spatial association between the incidence rate in district i and the population calculated in a neighboring districts j. In our study, the value of incidence rate in district i was related to the values of the population measured in an adjacent district j located in direct contact with district i. Through the analysis of local bivariate spatial autocorrelation, maps of clusters formed by districts with high values for the variable incidence were produced, which were surrounded by districts with high values for the variables population. These clusters were represented in the high-high (H-H) class. Moran's I were also calculated, and the other low-low (L-L), low-high L-H), and high-low (H-L) clusters were mapped considering a p-value <0.05 significant. All stages of spatial analysis of this research were performed using the exploratory spatial data analysis software GeoDa [24].

Study area

With 20.4 million inhabitants [25], West Bengal State is one of the most populated states in the India comprising 23 districts, which serve as administrative divisions and covering a total geographical land of around 88,752 km^2 **(Figure 2)**. Known for its geographical variation and cultural diversity, this state is situated in the eastern part of India and well connected via international and domestic flights with a number of destinations. Major airports exist in the districts of Kolkata, Paschim Bardhaman, and Jalpaiguri. These districts

are also well linked with metropolitan cities in the country through rail and road networks.

As per Census 2011, the state population density is 1029 per km^2 with an average decadal growth rate of around 13.84 percent. The state is bounded by the Indian state of Sikkim and the country Bhutan in the north. In the northeast, Assam, the Indian state, and in the east, it is the country Bangladesh sharing its boundary. The Bay of Bengal located in the entire southern part while it is bounded by the Indian state of Odisha in the southwest and Jharkhand and Bihar in the west. The state shares a small portion of its boundary with the country of Nepal in the northwest.

Figure 1. Methodological workflow.

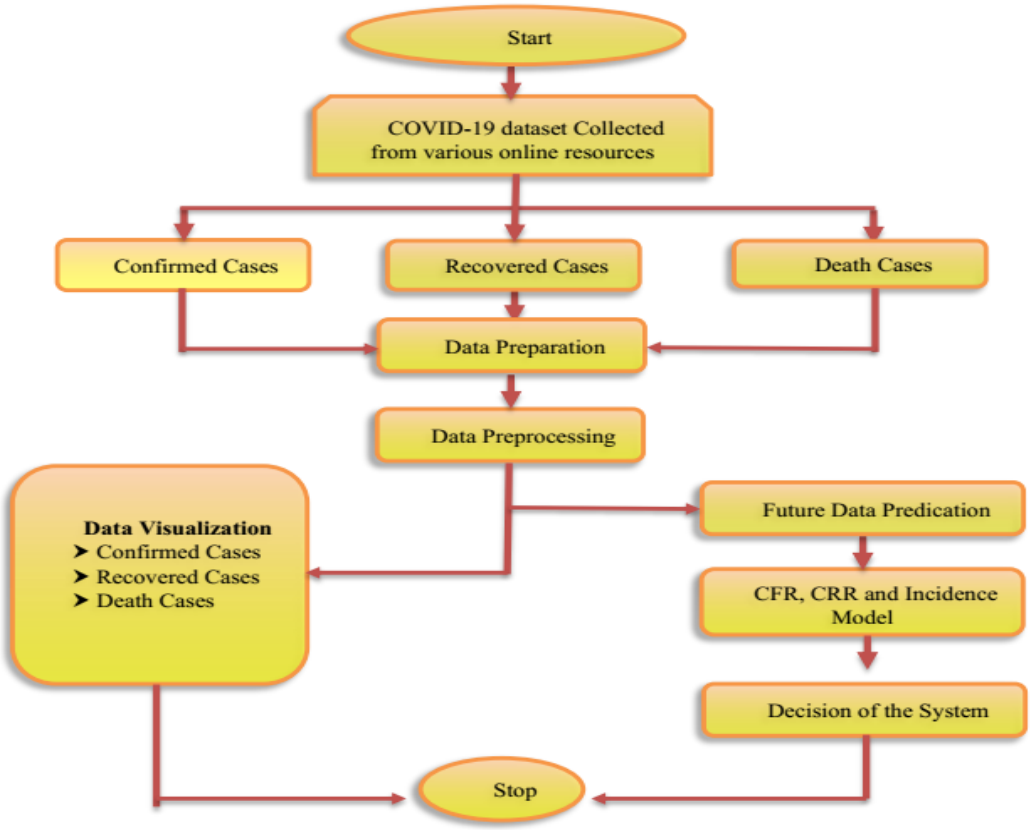
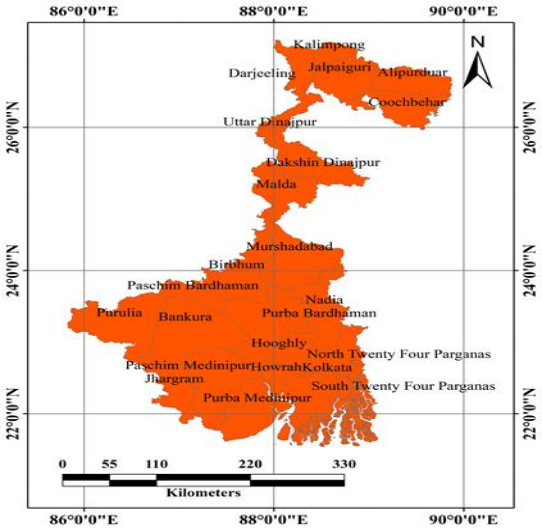


Figure 2. Location of the study area.



Results and Discussion

District level variations in COVID-19:

Figure 3 shows the district-level variations in COVID-19 from May 31, 2020, to October 31, 2020, respectively. The color in the map represents the number of positive COVID-19 cases in these districts during these periods. The deep red color of the map, the higher the number of total cases. A shift in the number of cases could easily be visible in districts ranking till December 31, 2021. Spatial distribution maps in West Bengal showed that most cases (97%) of the disease occurred in the Kolkata district and in the surrounding districts of Kolkata and very few cases (3%) have been reported in the Bankura, Purulia, Kalimpong, Darjeeling, etc. At the end of December 2021, the district of Kolkata has the most cases. By the end of May 2020, three

districts will have approximately 66.97% of the confirmed cases (Kolkata 33.99%, Howrah 18.94%, and North 24 Parganas (14.01%). On October 31, 2020, however, a new pattern was observed, with approximately 50.09 percent of the COVID-19 confirmed cases consisting of four major districts (Kolkata: 18.81%; North 24 Parganas: 18.12 %; South 24 Parganas: 7.43 %; Nadia: 5.73%).

In May 2020, about 11 % of the confirmed cases belonged to another five districts (Coochbehar, Malda, Nadia, Purba Medinipur, and Purba Bardhaman) with at least 50 confirmed cases.

The spatial distribution map showed the areas with a high number of cases (red color) scattered in several districts such as Kolkata, Howrah, and North 24 Parganas. The highest total case of COVID-19 was in Kolkata district with 337767 cases, while the lowest number of cases was found in the Kalimpong district with 7177 cases.

Trend of monthly total confirmed cases, death, and discharged in West Bengal, 31 May 2020 – 31 December 2021

Figure 4 presents the month-wise (last date of the month 30/31) state pattern of total cases, total discharged, and total COVID-19 death, in West Bengal in the study period. In West Bengal, the average monthly total active cases rose 259.03 times (from 2983 to 10710), the average discharged points increased 74862.6% times (from 2145 to 1607948), the average total patients increased 30001.2% times (from 5443 to 1638409). During the study period, in 2020 the COVID-19 cases were in peak August, September, October, November, and then it started declining (December). In 2021 COVID-19 cases were in peak April, May, June, July, August and then again started declining(September, October, November, December). Three-phase were visible during the study period. The first phase is May to July-2020, and second and third are December to March and September to December-2021.In these three-phase COVID -19 cases were low.

The first death was reported on June, and the number of deaths began to increase rapidly from August onwards, with the cumulative number of deaths reaching 209 on December 31, 2021.

The results for this are shown in **figure (5)**. The number of death cases from COVID-19 is predicted to increase around September 2020. Around September 30, 2020, the number of death cases in West Bengal is expected to be around 4955. This number may further increase after September 30, 2020. The overall mortality rate in West Bengal is expected to be lower as compared to the rest of India.

Along the same lines as above, the model is built for predicting the monthly number of recovered cases of COVID-19 in West Bengal, as shown in **figure (6)**. This number is expected to increase after May 2021. As discussed previously, by the end of August 2020, West Bengal may have around 25100 confirmed cases, and there could be a severe shortage of hospital beds by September 2020. This may lead to an increase in case fatality.

The simple linear regression analysis of number of deaths as a function of number of confirmed cases for West Bengal is shown in **figure (7)**. The coefficient of determination (R^2) is calculated to be 0.987, which implies a strong linear correlation between confirmed and death cases reported up to 31 December 2021 from the 31 May 2020 and the simple linear regression analysis of number of discharged cases as a function of number of confirmed cases for West Bengal is shown in **figure (8)**. The calculated R^2 of 1 implies a linear correlation between confirmed and recovered cases (as on 26 May 2020).

General epidemic characteristics of COVID-19

Figure 9 shows the incidence of COVID-19 in the 23 districts in West Bengal **(Table 1)**. As can be seen from **table (1)** and **figure (9)**, depicting the situation as of 31 December 2021, the top five districts with respect to the number of cases of COVID-19 were the following districts: Kolkata (337767) North 24 Parganas (337091), South 24 Parganas (104268), Howrah (102048) and Hooghly (89543). Moreover, the districts with the highest incidence were Kolkata (7.51%), Darjeeling (3.66%), North 24 Parganas (3.36%), Kalimpong (2.85%), and Jalpaiguri (1.79%).

This section analyzed the reported COVID-19 incidence by spatial statistical methods, exploring the geographical distribution of the disease. While local spatial correlation analysis showed Kolkata most of the cases and also the highest incidence. We also noted the lack of hotspots at the end of the time covered (31 December 2021). Answers to the questions whether the disease will stay in the same geographic location or spread to nearby areas. However, the lack of COVID-19 clusters with high or low values is an indication that in West Bengal, the focus area for COVID-19 prevention and control is still in Kolkata.

The total number of reported cases from 31-5-2020 to 31-12-2021 was 163840. Kolkata had the highest number of COVID-19 cases detected. **Table 2** shows districts data on the COVID-19 health-related consequences. West Bengal CFR for COVID-19 estimated by first and second methods were 1.20% and 1.21%, respectively. Similarly, CRR were estimated as 98.14% 98.78%. Considering the 1st method shows that Kolkata (1.57%), Howrah (1.51%), and the North 24 Parganas (1.48%) account for the highest CFR. Given the second estimation model, most districts such as Coochbehar, Jhargram, Purba Bardhaman, and Paschim Bardhaman had CRR above 98% **(Table 2)**.

Though the analysis showed models 1 and 2 potentially provide more accurate estimates of CFR and CRR **(Table 2)**. The WHO reported the CFR for COVID-19 as 2 % [26].

We have shown that the CFR varies greatly geographically. As a clear example of this, CFR of 0.21% was estimated in Jhargram and 1.57% in Kolkata. Other factors that could contribute to varying estimations are the population, number of ICU beds, diagnostics strategies, capability of the healthcare system, and the reporting system etc. Comparison among districts with high, moderate, and low CFR was illustrated in **figure (10)**.

However, if all these possible factors are carefully acknowledged, Case fatality rate (CFR) may help better appreciate the severity of COVID-19 and required mitigation steps. After the end of the pandemic, observing CFR and CRR using this method can be done, but while the pandemic is still ongoing, this method is naive and could be misleading.

Local univariate spatial autocorrelation analysis of the incidence rate

COVID-19 cases have a high spatial autocorrelation. Based on the total number of cases, we calculated the map of the clusters and the Moran's I diagram of West Bengal, shown in **figure (4)**. The analysis of local univariate spatial autocorrelation showed that West Bengal presented positive and statistically significant autocorrelation (I=0.1911; p<0.05). The scores indicate whether the numbers of cases in individual districts correlate with the numbers in surrounding districts. In the map to the left in **figure (11)**, we identified a H-H cluster located in the Northeastern zone that was formed by the following districts: Kolkata, Howrah, North 24 Parganas. We also identified an L-L cluster formed by the districts Malda Dakhin Dinajpur. In the Northeast, L-H cluster also included the districts of South 24 Pargana.

Local bivariate spatial autocorrelation analysis of the population

The map of the clusters and Moran's I diagram of the spatial association between COVID-19 Incidence and Population are shown in **figure (12)**. We found a positive and statistically significant spatial association between these determinants (I=0.266, p<0.05). The H-H cluster (districts with high incidence rates surrounded by districts with high population) was distributed over the southeastern (Kolkata, North 24 Parganas) zones of West Bengal (**Figure 7**). The districts that belonged to the South-eastern zone cluster were Kolkata, North 24 Parganas. The L-H cluster was formed by districts with low incidence rates surrounded by districts with high populations and included the following districts: Hooghly, Nodia, and South 24 Parganas. The map of **Figure 12** also shows an H-L cluster with three districts with high incidence rates surrounding districts with high populations; this cluster included Darjeeling, Kalimpong, and Jalpaiguri.

Figure 3. Changes in infected cases of COVID-19 in West Bengal at districts level (31-5-2020 to 31-12-2021)

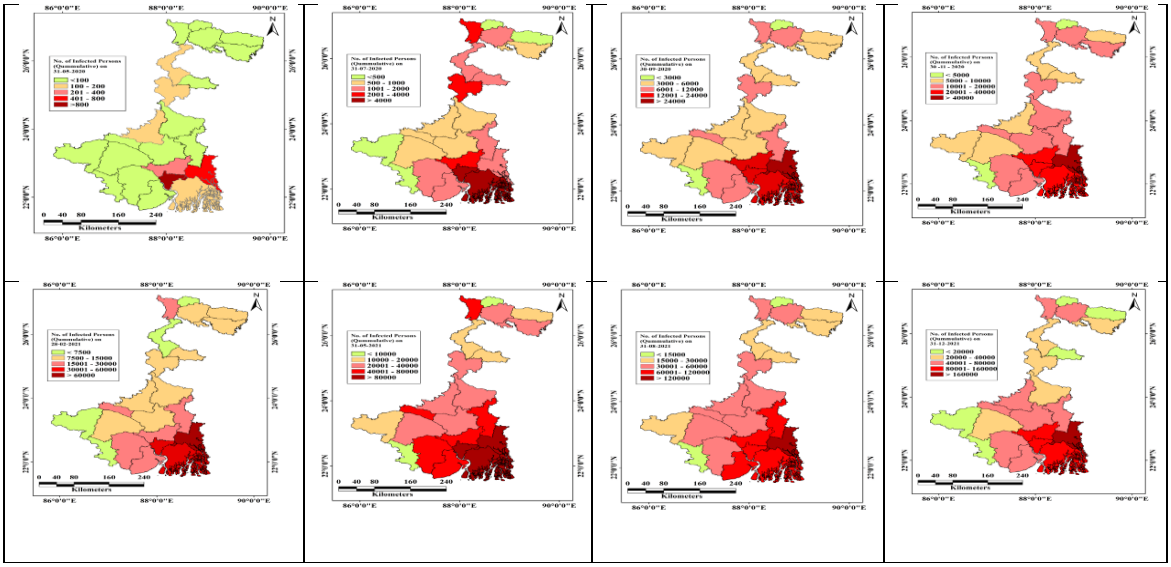


Figure 4. Trend analysis of monthly confirmed cases.

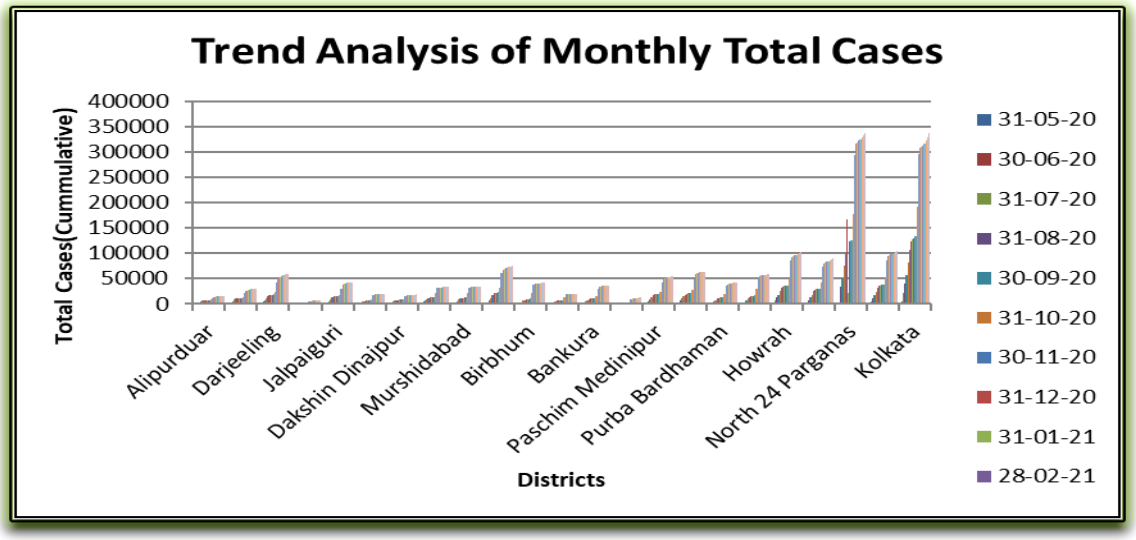


Figure 5. Trend analysis of monthly death cases.

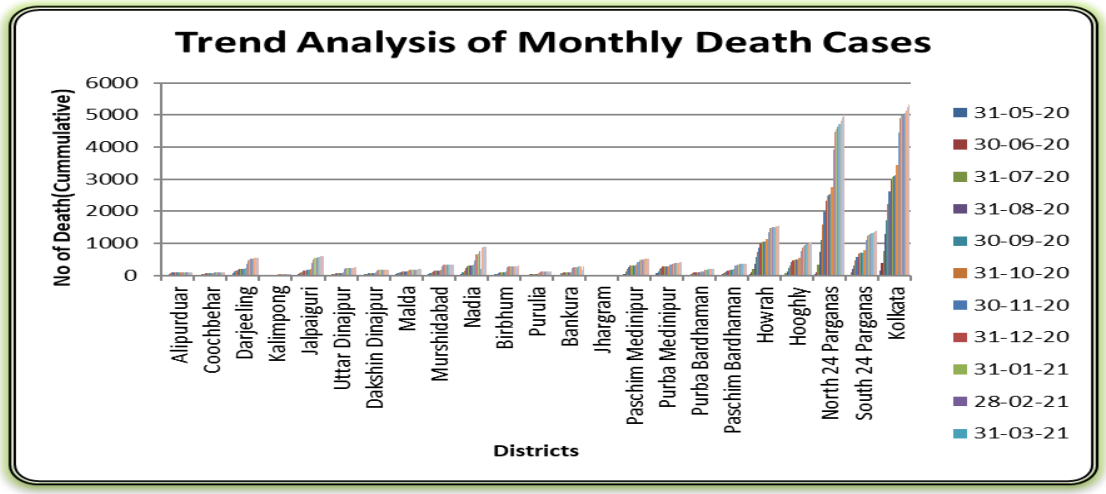


Figure 6. Trend analysis of monthly discharged.

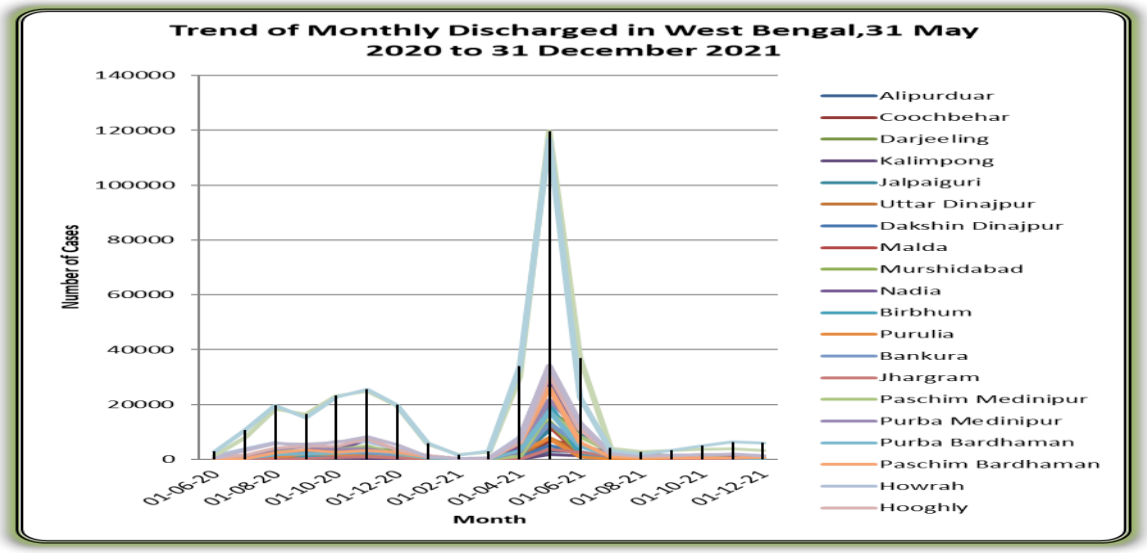


Figure 7. Linear regression model analysis of total number of cases with total number of deaths in West Bengal (data taken up to 31December 2021).

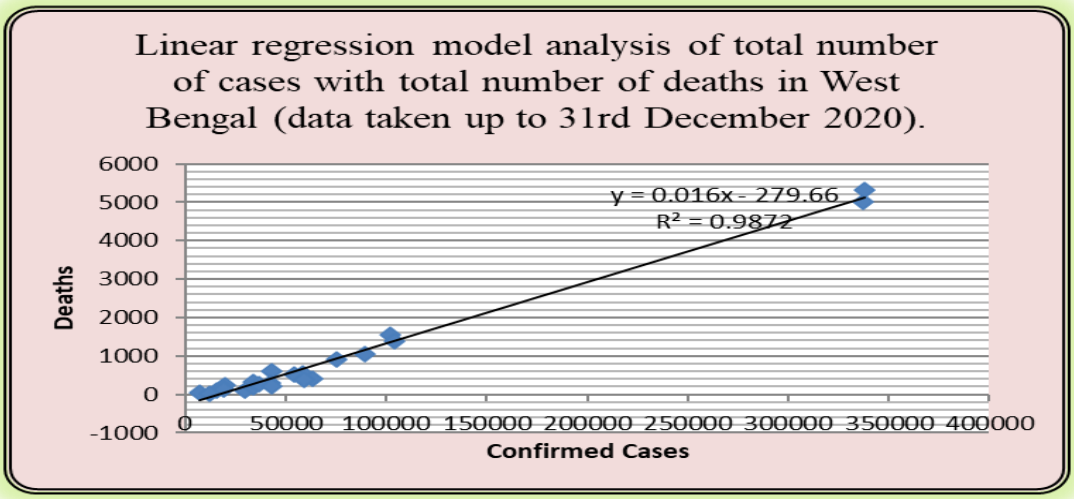


Fig. 8. Linear regression model analysis of total number of cases with total number of recovered cases in West Bengal (data taken up to 31 December 2021).

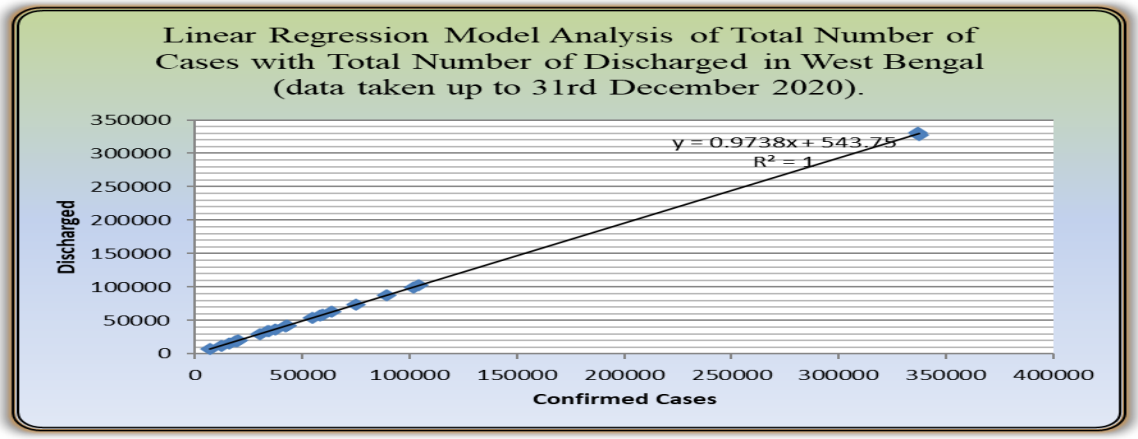


Figure 9. Geographical distribution of COVID-19 incidence.

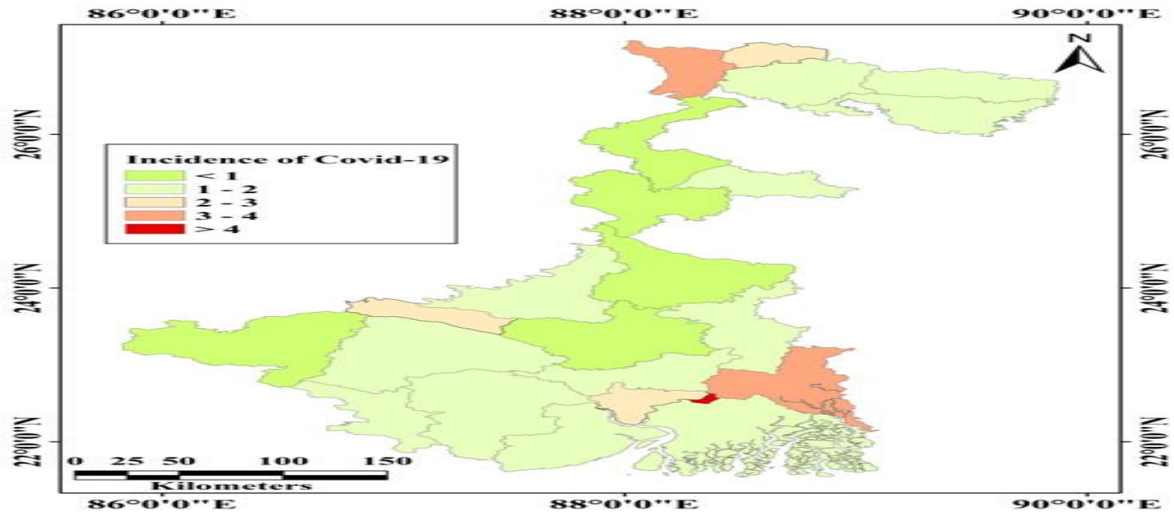


Figure 10. Comparison between districts with low, moderate, and high case fatality ratio.

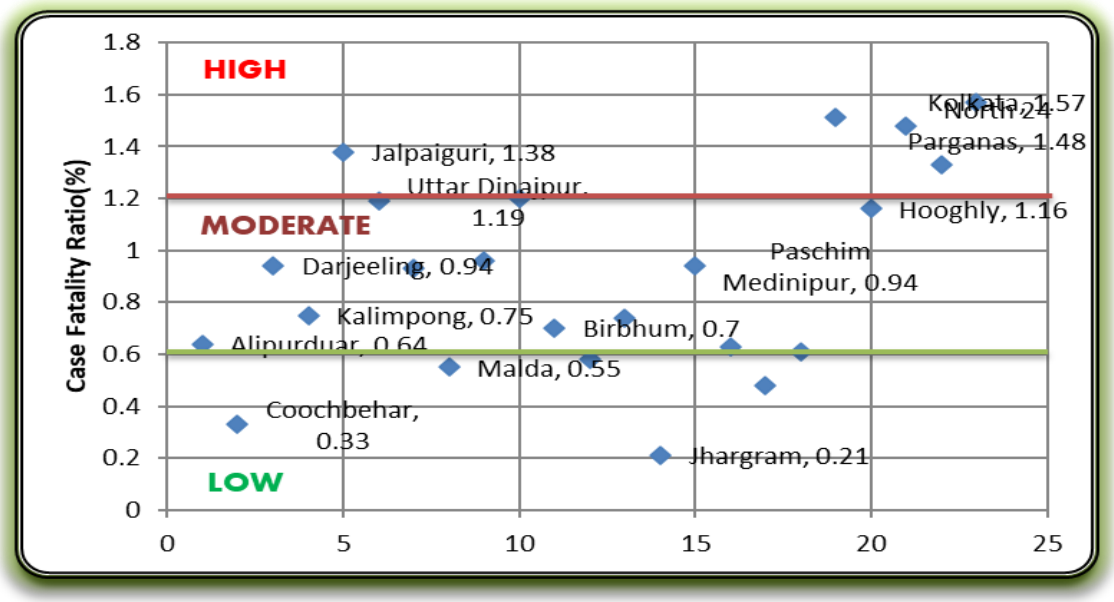


Figure 11. Map and spatial autocorrelation diagram referring to the district clusters in relation to the COVID-19 incidence rate.

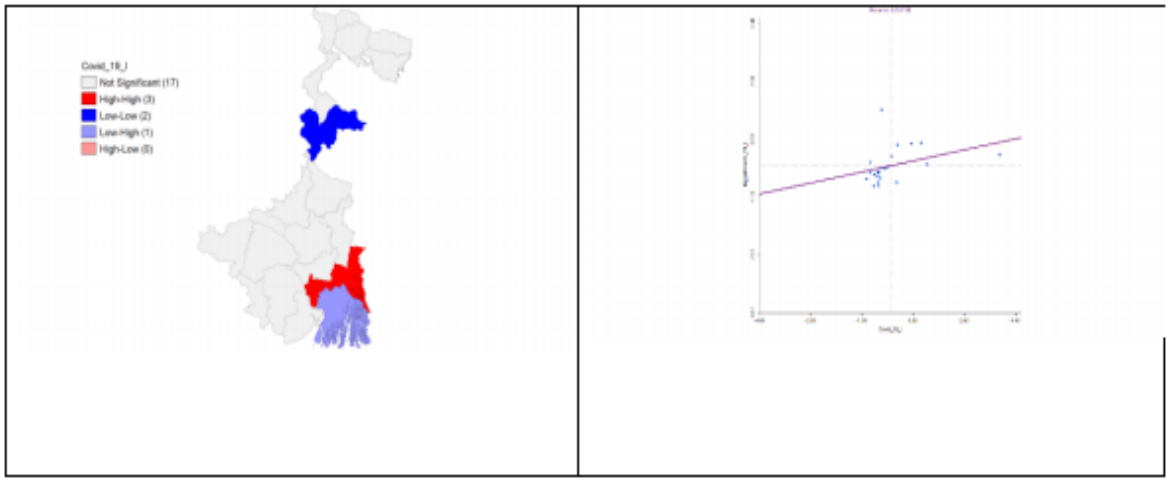


Figure 12. Map and spatial autocorrelation diagram referring to the spatial association clusters between the COVID-19 incidence rate and population.

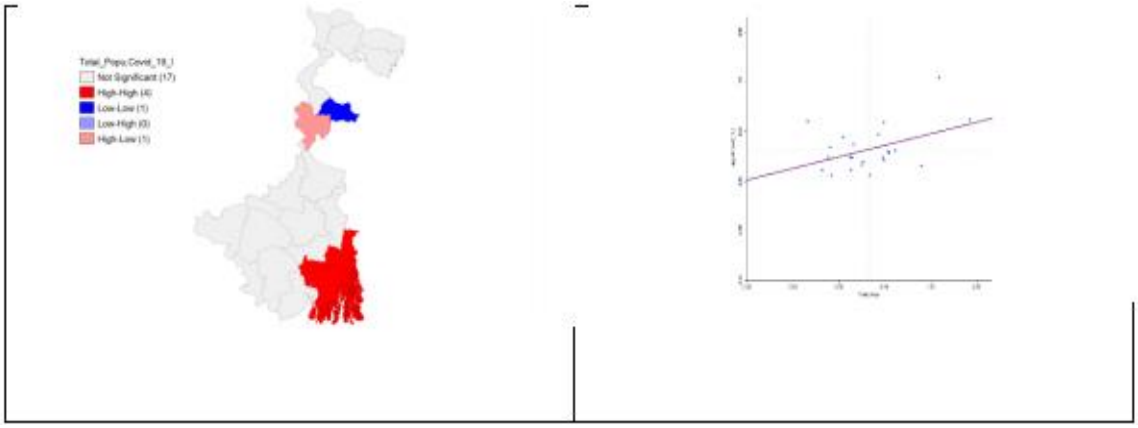


Table 1. Incidence of COVID-19 in all districts of West Bengal.

Districts	Total Cases	Total Population	COVID-19 Incidence
Alipurduar	15778	1491250	1.05
Coochbehar	29915	2819086	1.06
Darjeeling	58487	1595181	3.66
Kalimpong	7177	251642	2.85
Jalpaiguri	42781	2381596	1.79
Uttar Dinajpur	20180	3007134	0.67
Dakshin Dinajpur	18725	1676276	1.11
Malda	33969	3988845	0.85
Murshidabad	34282	7103807	**0.48**
Nadia	75057	5167600	1.45
Birbhum	42133	3502404	1.20
Purulia	19539	2930115	0.66
Bankura	37057	3596674	1.03
Jhargram	12389	1136548	1.09
Paschim Medinipur	54482	4776909	1.14
Purba Medinipur	63614	5095875	1.24
Purba Bardhaman	42845	4835532	0.88
Paschim Bardhaman	59282	2882031	2.05
Howrah	102048	4850029	2.10
Hooghly	89543	5519145	1.62
North 24 Parganas	337091	10009781	3.36
South 24 Parganas	104268	8161961	1.27
Kolkata	337767	4496694	**7.51**

Source: Ministry of Health and Family Welfare and Census of India-2011

Table 2. The Comparison of case fatality rate and case recovery rate by model between 23 districts.

					According to **Battegay et al.**		According to **Ghani et al.**	
Districts	Total cases	Total discharged	Total death	Total active cases	Case fatality rates	case recovery rate	Case fatality rates	Case recovery rate
Alipurduar	15778	15660	102	26	0.64	99.25	0.64	99.35
Coochbehar	29915	29730	99	86	0.33	99.38	0.33	99.66
Darjeeling	58487	57734	553	200	0.94	98.71	0.94	99.05
Kalimpong	7177	7101	54	22	0.75	98.94	0.75	99.24
Jalpaiguri	42781	42058	592	131	1.38	98.30	1.38	98.61
Uttar Dinajpur	20180	19898	241	41	1.19	98.60	1.19	98.80
Dakshin Dinajpur	18725	18469	176	80	0.93	98.63	0.94	99.05
Malda	33969	33651	188	130	0.55	99.06	0.55	99.44
Murshidabad	34282	33898	331	53	0.96	98.87	0.96	99.03
Nadia	75057	73863	903	291	1.20	98.40	1.20	98.79
Birbhum	42133	41655	295	183	0.70	98.86	0.70	99.29
Purulia	19539	19398	114	27	0.58	99.27	0.58	99.41
Bankura	37057	36680	276	101	0.74	98.98	0.74	99.25
Jhargram	12389	12323	27	39	**0.21**	99.46	**0.21**	99.78
Paschim Medinipur	54482	53801	513	168	0.94	98.75	0.94	99.05
Purba Medinipur	63614	63125	404	85	0.63	99.23	0.63	99.36
Purba Bardhaman	42845	42522	209	114	0.48	99.24	0.48	99.51
Paschim Bardhaman	59282	58480	366	436	0.61	98.64	0.62	99.37
Howrah	102048	99713	1548	787	1.51	97.71	1.52	98.47
Hooghly	89543	87942	1039	562	1.16	98.21	1.16	98.83
North 24 Parganas	337091	330428	5016	1647	1.48	98.02	1.49	98.50
South 24 Parganas	104268	102298	1396	574	1.33	98.11	1.34	98.65
Kolkata	337767	327521	5319	4927	**1.57**	96.96	**1.59**	98.40
Total	**1638409**	**1607948**	**19761**	**10710**	**1.20**	**98.14**	**1.21**	**98.78**
Data retrieved 1st January 2022.								

Conclusions

The coronavirus pandemic is currently causing the disruption daily life of human around the world, and it is necessary to address this health issue and study it in terms of geographical features [27]. In this study, COVID-19 outbreaks exhibited distinct spatiotemporal clustering patterns at the districts' levels in West Bengal State. In conclusion, the Kolkata,Howrah,Hooghly,South 24 Parganas are at risk. Moreover, the results have shown maximum infections in the surrounding districts of Kolkata. The risk of COVID-19 for major cities and the surrounding areas was high compared to the rural districts and over time, the risk for rural areas remained relatively lower than in cities.

The monthly incidence of COVID-19 disease in West Bengal State showed that the frequency of cases was increasing from August to November-2020, after the reduction of the disease in a period of four months, the cases have increased again in the following months-April, May, June, July and August-2021 and started to decline thereafter. It seems that the observance of health protocols such as social distancing, regular hand washing, the use of masks and gloves, disinfection of fruits and vegetables, disinfection of surfaces, and personal hygiene by the people has reduced the incidence of disease in September and December. Based on spatial distribution maps of COVID -19 diseases in West Bengal, most cases of the disease occurred in the city of Kolkata in comparison of rural districts. The result of this study indicates that

the pattern of spatial distribution of the prevalence of COVID-19 disease in West Bengal was clustered and based on model we have shown that the case CFR varies greatly geographically. As a clear example of this, a CFR of 0.33% was estimated in Coochbehar and 1.57% in Kolkata.

The implications of the study are that future interventions to halt the disease transmission, should target the major highly density districts like Kolkata, Hooghly, Howrah, and that by time, attention should be paid to the month of November, December and partly January, when it is very cold.

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