Journal of Geographical Research and Area Studies (JGRAS)
January-June, 2025 [Vol.1, Issue 1]

Vulnerability Assessment and Spatio-Temporal Pattern of COVID-19 outbreak in West Bengal using GIS

Dr. Kundan Kumar Das[1,*]
Corresponding Author's email id. kundan.das20@gmail.com

Cite as: Das, K., (2025), Vulnerability Assessment and Spatio-Temporal Pattern of COVID-19 outbreak in West Bengal using GIS, Journal of Geographical Research and Area Studies, 1(1), pg. 13- 23.

Abstract
A number of sources, including the COVID-19 data from Health and Family Welfare, Govt. of West Bengal and demographic data from the Census of India (2011) etc., have been used for this analysis. Two time period from May 2, 2021, to March 6, 2022, comprehensive COVID-19-related data for 23 districts of West Bengal served as the basis for this analytical investigation. Maps are created using ArcGIS software, and COVID-19 incidence rate, mortality rate etc. are calculated using several methods while taking into account all potential outcomes. Three indicators i.e. population density, urban population and distance from Kolkata, are used to create a composite index of vulnerability at the district level. The vulnerability index was calculated using a geographically weighted regression index. The majority of the southern districts, including South 24 Paragana, Kolkata, and North 24 Paragana, are deemed to be extremely vulnerable. In contrast, it is discovered that the majority of the northern and western districts are less vulnerable. This disparity in vulnerability can be attributed to various factors, including socioeconomic conditions, infrastructure resilience, and access to resources. The investigation of the concentration point of any geographical phenomenon is known as the spatial mean centre. This study implies that there was minimal temporal fluctuation between May 2, 2021, to March 6, 2022, and the mean centre of COVID-19 cases was situated quite near the southern region of West Bengal. Spatial mean centre and directional distribution clearly indicates nearness to Kolkata exacerbates the COVID-19 incidence rate. Consequently, targeted interventions may be necessary in the more affected areas to enhance their adaptive capacity and reduce risks.

Keywords: COVID-19, West Bengal, Urbanisation, Population Density, Geographically Weighted Regression (GWR), Spatial Mean Centre

Introduction
India reported its first case of COVID-19 in Kerala on January 30, 2020. When a student returned from the United Kingdom on March 17, 2020, the first positive case of coronavirus infection was discovered in West Bengal, India (Hembrem, Pal, & N.C.Jana, 2023). West Bengal had 564,032 COVID-19 cases as of January 15, 2021, and 10,023 deaths as a result (Biswas, Roy, Roy, Chowdhury, Dhara, & Mistry, 2021). Numerous studies have examined various elements of the situation in West Bengal, India, as a result of the COVID-19 epidemic. The region has been significantly impacted.

[1] Assistant Professor, Department of Geography, Khalisani Mahavidyalaya, University of Burdwan, Hoogly, West Bengal, India

A geographic distribution and trend analysis of the coronavirus pandemic in West Bengal was carried out (Mandal, Bose, Das, & Basak, 2020), demonstrating the virus's spread throughout the state. (Biswas, Roy, Roy, Chowdhury, Dhara, & Mistry, 2021) looked into the geographical distribution of COVID-19 cases and fatalities in West Bengal and proposed Kolkata as the state's disease source. At a macro level, the study found differences in COVID-19 cases, deaths, and recoveries. This study reveals that COVID-19 cases are positively correlated with population density and urban population. (Malakar, 2021) assessed the COVID-19 vulnerability in West Bengal using a geographic modelling approach, identifying varying degrees of susceptibility throughout the state. (Das et al., 2021) took comorbidity and immunisation into account when developing a fractional ordered COVID-19 model to investigate West Bengal's transmission patterns. During the first wave of the COVID-19 pandemic in West Bengal, (Mondal, Sahoo, Paria, Chakraborty, & Alamri, 2021) carried out a multi-sectoral impact assessment, concentrating on some areas including the environment, employment, health, education, and economics. (Majumder, 2021) assessed how the COVID-19 shutdown affected West Bengal's urban ambient air quality, emphasising how the pandemic had changed the quality of the air. (Hembrem, Pal, & N.C.Jana, 2023) assessed and mapped the incidence, case-fatality ratio, and recovery rate of COVID-19 in West Bengal. This study helps in targeted interventions and resource allocation. In this study, it was found that there was a high risk of COVID-19 in the top five districts with the greatest incidence: Kolkata, Darjeeling, North 24 Parganas, Kalimpong, and Jalpaiguri. Thus, the first step in assessing the severity of the disease and creating efficient management and control strategies for any emerging epidemic should be the identification of case fatality, recovery rates, and spatiotemporal trends. WHO and UNICEF claim that the lack of safe water, sanitation, and hygiene (WASH) facilities in households, schools, and other public places exacerbates the COVID-19 mitigation concerns (Das, 2024). WASH (safe water, sanitation, and hygiene) conditions are essential to protecting public health during infectious disease epidemics, as they were with COVID-19. By stopping the spread of bacteria and viruses that cause the flu, common colds, and other illnesses, it lowers the total burden of disease.

The terms vulnerability and susceptibility are sometimes used interchangeably. Regarding COVID-19, Acharya & Parwal suggested that susceptibility refers to the likelihood of contracting the virus, which is influenced by a number of epidemiological factors, personal cleanliness habits, and the capacity to keep oneself physically apart from other people. They said vulnerability, on the other hand, refers to the possibility of infection-related outcomes, such as transmission, morbidity and mortality, and social and financial repercussions (Acharya & Parwal, September 2020). For instance, older residents of densely populated urban areas are at high risk of serious mortality and morbidity, even if these areas are susceptible to COVID-19 infection. Their study reveals that West Bengal is one of the nine states among the thirty major states—have districts with high overall vulnerability.

(Sarkar & Chouhan, 2021) assessed the district-level COVID-19 vulnerability in India. Their analysis shows that socio-economic factors are an inseparable part of addressing the COVID-19 pandemic. Vulnerability assessment using a composite index can provide an understanding of real-world situations. The vulnerability index has highlighted the districts which are backward environmentally and socio-economically. These areas will suffer more critical problems due to the COVID-19 pandemic, for their socio-environmental problem (Sarkar & Chouhan, 2021). In the study (Kanga, Meraj, Sudhanshu, Farroq, & Singh, 2020) provide a methodology for risk assessment that analyses COVID-19 risk to regions by utilising the pandemic's combined hazard and vulnerability components for efficient risk reduction.

In light of this, the main goal of this paper is to study the spatial pattern of COVID-19 incidence, COVID-19-related death, mortality rate, spatial centre, and directional distribution of COVID-19, and finally prepare a vulnerability index based on the geographically weighted regression index.

Although the index is helpful, it has certain drawbacks. Calculating the index at the sub-district level would be ideal. Nevertheless, many crucial factors that were utilised to identify susceptibility were unavailable at the sub-district level. As a result, this analysis is limited to the district level.

All things considered, these studies offer insightful information on every facet of the COVID-19 scenario in West Bengal.

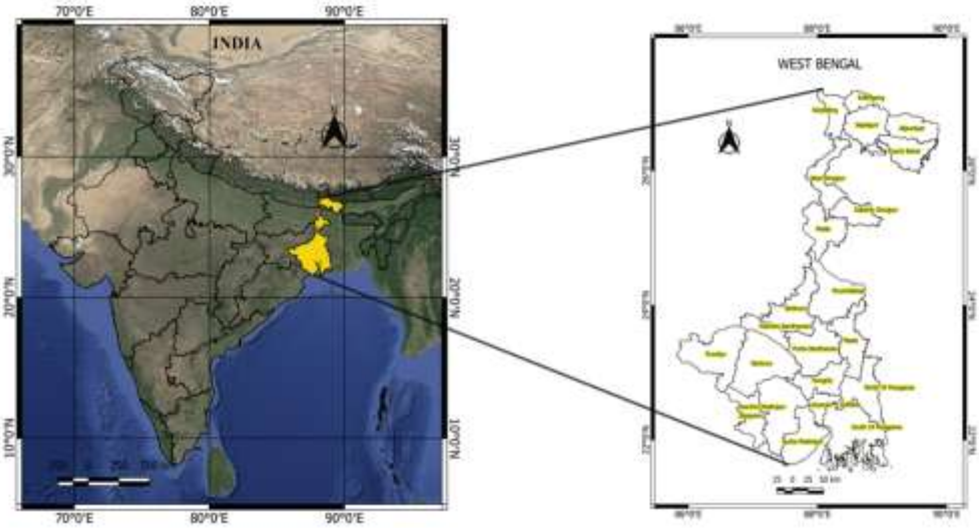

Fig. 1, Location Map of West Bengal

Study Area

The eastern Indian state of West Bengal has been selected for the current study. Beginning on February 5, 2020, the West Bengal government kept on posting daily COVID-19-related bulletins and data for public use and research on its official portal (https://www.wbhealth.gov.in/pages/corona/bulletin). According to the 2011 Indian Census, West Bengal has a total population of 91,347,736 and an area of about 88,752 square kilometres. Its population is growing at an average decadal rate of 13.84 per cent. With 950 people per square kilometre in 2011, the state ranks fourth in terms of population density among Indian states. The degree of urbanisation in West Bengal varies greatly. The average level of urbanisation is 28.78%, with variations ranging from 100% urban (Kolkata) to just 8.30% (Bankura). In a similar vein, the state's population density varies from 468 people per square kilometre in Purulia to 24,306 people per square kilometre in Kolkata. In 2011, the state's total literacy rate was 74.04 per cent, while the sex ratio was 934. Many West Bengal workers, especially migrant labourers, are employed throughout India and other nations. During the epidemic, the majority of them had returned to the state. There is ample documentation of people returning from other states and nations. It might be viewed as a geographical and economic stand-in for India. Any significant conclusions drawn from this study could be deemed appropriate or pertinent for all of India.

Objectives

1. To study the spatio-temporal pattern of COVID-19 spread in West Bengal between May 2, 2021, and March 6, 2022, using spatial mean centre and directional distribution of COVID-19 cases.
2. Depicting district-wise vulnerability during the COVID-19 outbreak using a geographical weighted regression model.

Materials and Methods

Database

The data for this study was collected from Health and Family Welfare, Govt. of West Bengal, which provided COVID-19 data regularly at the local level. The spatial unit of this analysis is the district. Demography is incorporated into this study since the core of the COVID-19 outbreak is that population dynamics determine both the rate of transmission and infection-related mortality. Since Kolkata was the epicentre of COVID-19 in West Bengal, the distance of districts from Kolkata is also taken into consideration in this study. Data on population, population density, urban population, and distance from Kolkata are taken from the Census of India 2011, Alipurduar Zila Parisad website (http://alipurduarzp.org/), Kalimpong district official website (https://kalimpong.gov.in/), Jhargram District Website (https://jhargram.gov.in/), Purba Bardhaman Zilla Parisad website (https://www.burdwanzp.org/), and Paschim Bardhaman official website (https://paschimbardhaman.gov.in/).

Methodology

An analysis has been conducted on West Bengal's COVID-19 data. Maps and charts pertaining to the data have been created in order to analyse and investigate the findings. In order to determine the Incidence rate of COVID-19 in each district, the following formula has been used:

$$\text{COVID-19 Incidence Rate} = \frac{\text{Confirmed Cases of COVID}-19}{\text{Total Population}} \times 1000$$

To determine the Death rate of COVID-19 in each district, the following formula has been used:

$$\text{COVID-19 Death Rate} = \frac{\text{Deaths related to COVID}-19}{\text{Confirmed Cases of COVID}-19} \times 100$$

ArcGIS Desktop was used to associate the COVID case data with a shapefile that was created in the GIS environment. An administrative boundary map of the districts of West Bengal in shapefile format was created and updated using the most recent databases from the global administrative regions database.

The distribution of all COVID-19 cases across all districts was examined using the spatial distribution methodology. By inserting the COVID-19 data into the attribute table of each district's shape file, the spatial distribution analysis was produced. The spatial distribution maps were then categorised into groups.

The spatial features of COVID-19 dispersion and directional trends are displayed by the standard deviational ellipses. The most popular method for forecasting a disease epidemic over time is the standard deviation ellipse. The following is the standard deviational ellipse formula:

$$SDE_X = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

$$SDE_Y = \sum_{i=1}^{n}(y_i - \bar{y})^2$$

Where n is the total number of features, x and y are the coordinates for feature i which is the mean centre for the features.

To comprehend the spatial prediction of diseases and vulnerability assessment of different districts of West Bengal during the COVID-19 outbreak, geographically weighted regression, or GWR, has been used. GWR analytical framework is as follows;

$$y_{dcc=}\ \beta_{0(u_i v_{i)}} + \beta_1 T_{p(u_i v_{i)}} + \ \beta_2 P_{d(u_i v_{i)}} + \beta_3 U_{P(u_i v_{i)}} + \beta_4 D_{K(u_i v_{i)}} + \ \varepsilon_l$$

Where, $\boldsymbol{\beta_{0(u_i v_{i)}}}$ is the geographical coordinate of the point i. $\boldsymbol{T_p}$ is the total population, $\boldsymbol{P_d}$ is the population density, $\boldsymbol{U_P}$is the urban population, $\boldsymbol{D_K}$ is the distance from Kolkata, $\boldsymbol{P_{hc}}$ is the primary health centre, and $\boldsymbol{C_{hc}}$ is the community health centre of the ith district. The regression coefficient is estimated at each data location.

The weight of each point is calculated as;
$\beta^{\wedge}{}_{(u_i v_{i)}} = (x^t w((u_i v_{i)} x^{-1} x^t w\ (u_i v_{i)} y$

In GWR, the weight assigned to each observation is based on a distance decay function centred on observation i. GWR places more weight on locations that are closer to Kolkata compared to the location than those that are more distant in space.

Result
Figure 2.a) shows the incidence rate of COVID-19 per 1000 population in different districts of West Bengal on 2nd May, 2021. Kolkata (44.32 ‰), North-24-Paragana (18.54 ‰), Darjeeling (13.37 ‰), Kalimpong (11.22 ‰), Howrah (10.94 ‰) and Paschim Bardhaman (10.74 ‰) are the top six districts with respect to the number of Covid-19 cases on 2nd May, 2021.

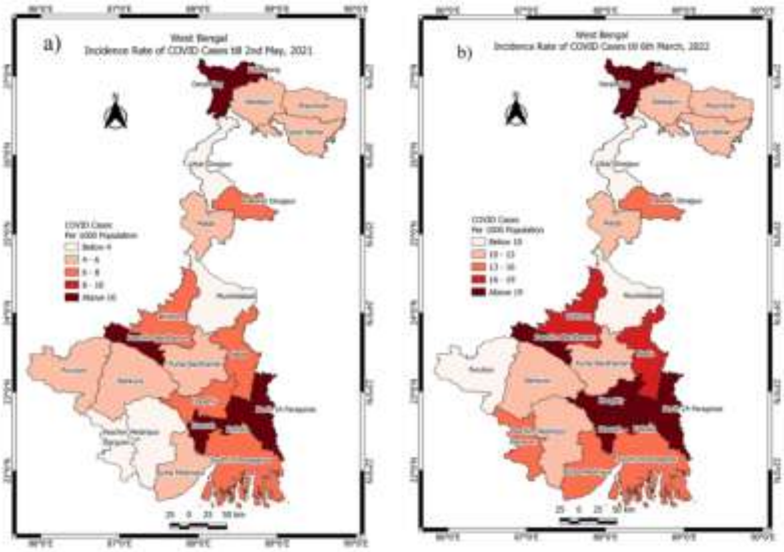

Fig.2, The incidence rate of COVID-19 per 1000 population in West Bengal

Figure 2.b) shows the incidence rate of COVID-19 per 1000 population in different districts of West Bengal on 6th March, 2022. Kolkata (99.45 ‰), North-24-Paragana (40.27 ‰), Darjeeling (37.39 ‰), Kalimpong (33.85 ‰), Howrah (25.79 ‰), Paschim Bardhaman (26.25 ‰) and Hooghly (19.56 ‰) are the top seven districts with respect to the number of Covid-19 cases on 6th March, 2022.

Figure 3.a) displays the proportion of COVID-19-related deaths to all COVID-19 cases in each West Bengal district as of May 2, 2021. The southern areas of West Bengal, particularly those surrounding Kolkata, have a significant number of fatality cases due to COVID-19. On May 2, 2021, the top three districts for COVID-19-related fatality cases were Howrah (2.13%), Kolkata (1.75%), and North-24-Paragana (1.52%). Later on, however, the situation has somewhat changed (Figure 3.b). According to the number of Covid-19-related fatality cases on March 6, 2022, North-24-Paragana (1.32%), Howrah (1.31%), Jalpaiguri (1.31%), Kolkata (1.26%), and South-24-Paragana (1.19%) are among the top districts. It clearly demonstrates that COVID-19-related mortality rates are generally greater in areas with dense populations and those near large cities.

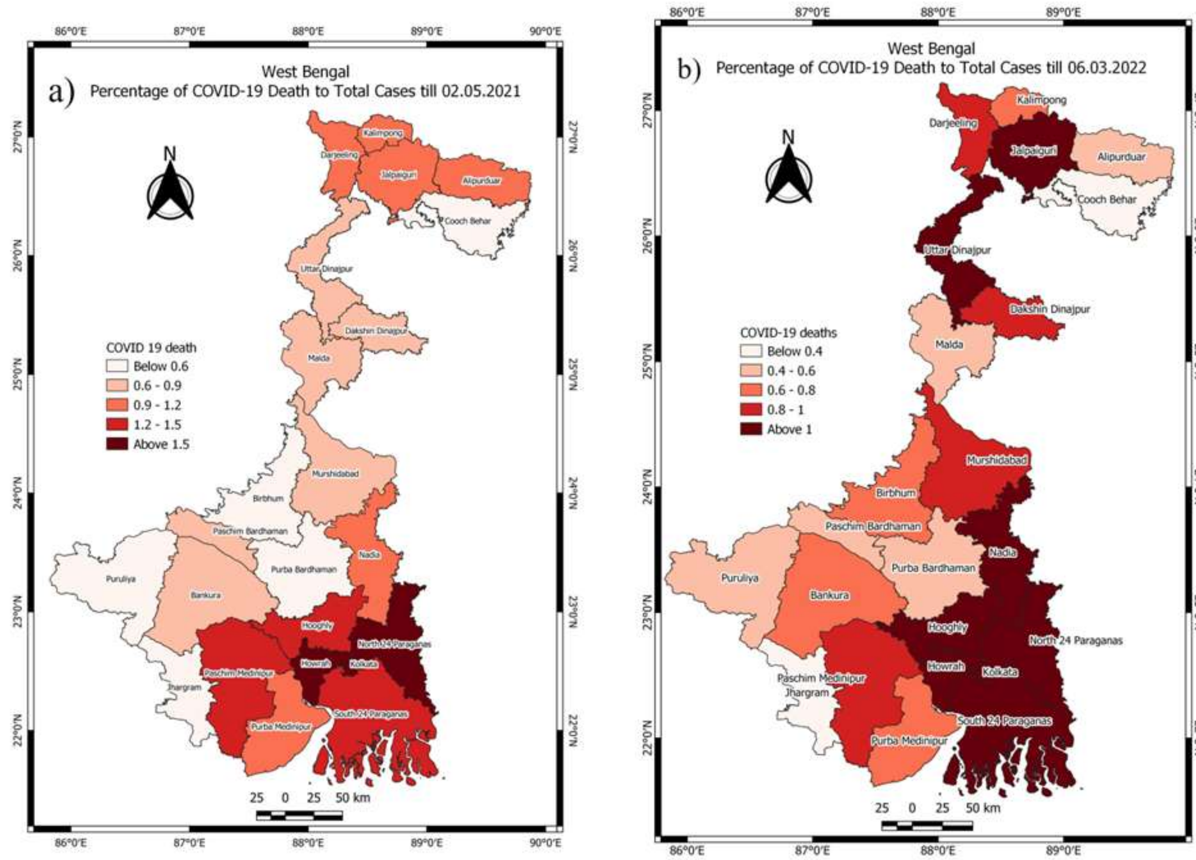

Fig. 3, Percentage of COVID-19 Deaths to Total Cases in West Bengal

The geographic mean centres of COVID-19 and the directional distribution of COVID-19 cases for May 2, 2021, and March 6, 2022, are displayed in Figure 4. The analysis of the concentration point of any geographical phenomenon is known as the spatial mean centre. It implies that there was minimal temporal fluctuation and that the mean centre of COVID-19 cases was situated relatively near the southern region of West Bengal. According to the elliptical polygon's directional distribution, COVID-19 propagated in a north-south direction in West Bengal.

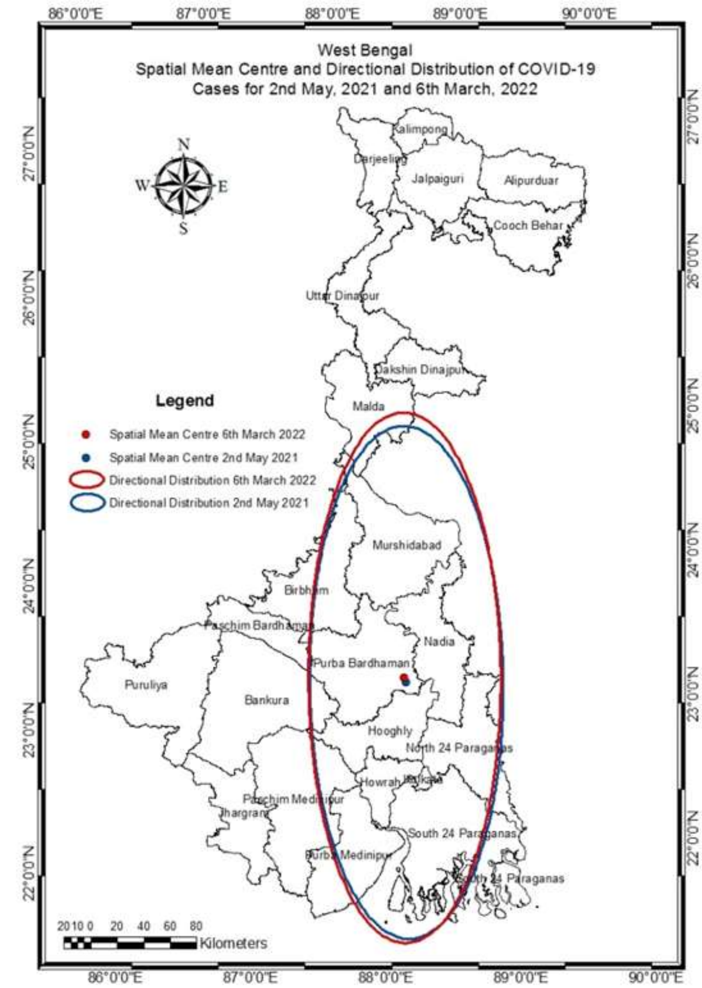

Fig. 4, Spatial Mean Centre and Directional Distribution of COVID-19 in West Bengal

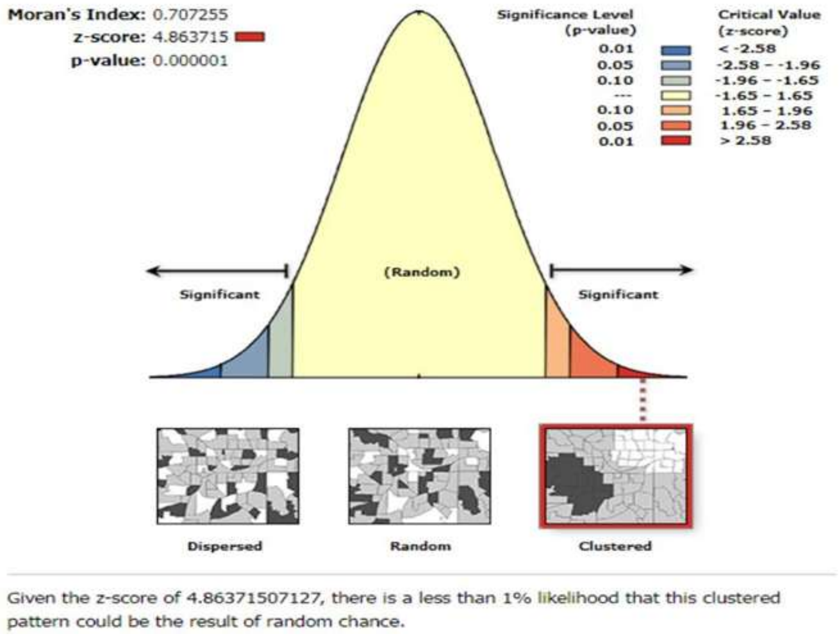

Fig. 5, Moran's Index

According to Moran's I-based spatial autocorrelation values, COVID-19 cases across West Bengal exhibit positive spatial autocorrelation. For COVID-19 cases, the Moran's I value is 0.707 (p=0.000), and the Z-score is 4.863, indicating statistical significance in the data and clustering of COVID-19 cases in West Bengal during 2022.

Vulnerability index for different districts of West Bengal has been calculated on the basis of the Geographically Weighted Regression (GWR) in Figure 6. Density of Population, level of urbanisation, and distance from Kolkata are taken as explanatory variables, and the occurrence of COVID-19 cases is taken as a predictive variable.

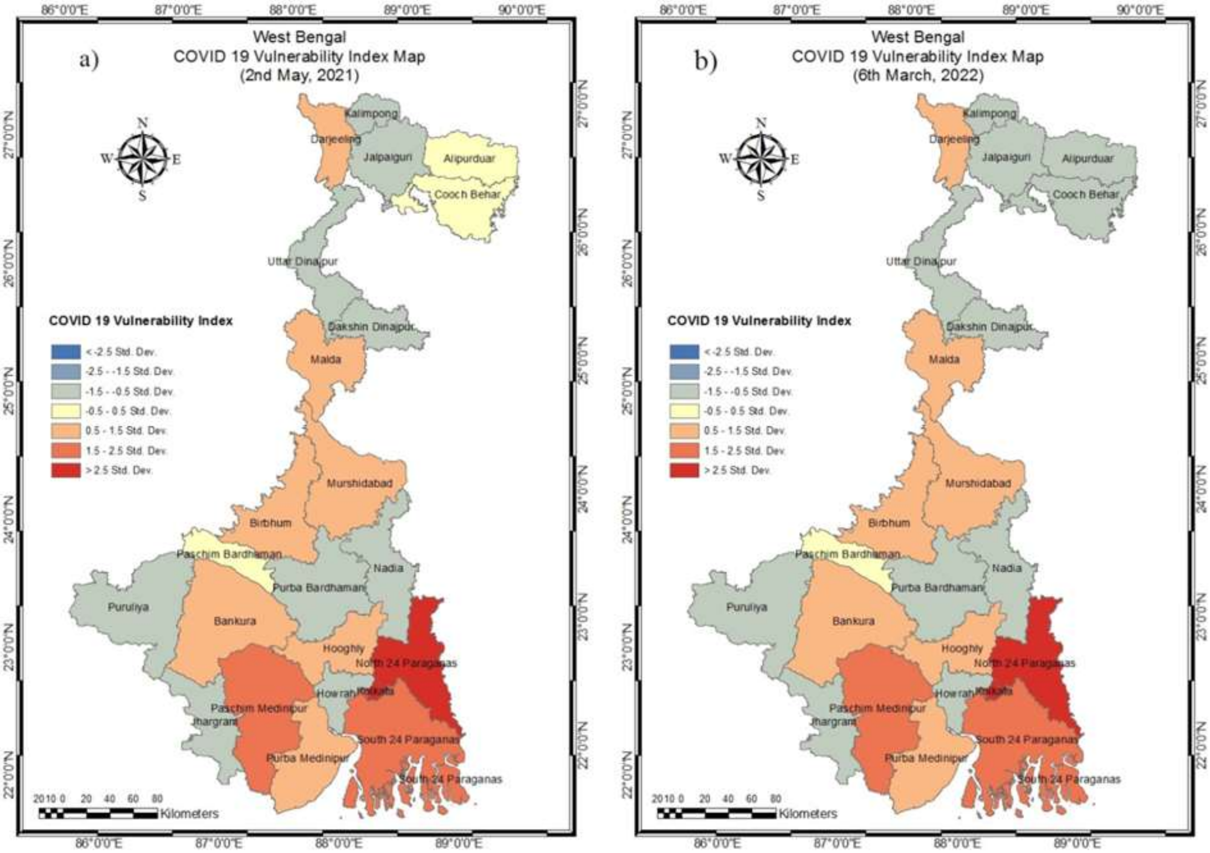

Fig. 6, Vulnerability Index on the basis of the Geographically Weighted Regression (GWR)

The result of GWR indicates that North-24-Paragana and Kolkata are very- high vulnerable districts. Paschim Medinipur, South-24-Paragana, Hooghly, Bankura, Birbhum, Maldah, Purba Medinipur, Murshidabad, and Darjeeling are considered highly vulnerable districts. Paschim Bardhaman, Alipurduar and Cooch Behar are considered medium vulnerable districts. Puruliya, Jhargram, Kalimpong, Jalpaiguri, Purba Bardhaman, Uttar Dinajpur, and Dakshin Dinajpur are considered low-vulnerable Districts.

Discussion

Vulnerability of a geographical region to COVID-19 has been a topic of interest, particularly in low-income and middle-income countries like India to assess its multifactorial impact on incidence, prevalence or mortality. A statistical analysis is used to compute such vulnerability indices and investigate their association with metrics of the pandemic growth (Bhattacharyya, et al., 2023). This study validates the finding that during second wave, the pandemic made greater inroads from major cities or source region to peripheral and hinterlands. The knowledge, healthcare, and provisioning deprivation indices for the vulnerable districts are all low in West Bengal (Bhunia, 2022). This study further validates the findings of this paper. Furthermore, the COVID-19 Risk Assessment and Mapping framework (CRAM) indicates that lower population density lowers the COVID-19 risk due to less hazard probability (Kanga, S. et al. 2021). The level of urbanisation, population density, and distance from big urban centres are important factors in the nature and extent of COVID-19 cases and related deaths (Biswas, Roy, Roy, Chowdhury, Dhara, & Mistry, 2021). At the district level, maps were made of the population distribution, density, COVID-19 cases, population under 19, area within 1 km of a road, hospitals, and oxygen plants. The biggest number of COVID-19 cases is validated by both population distribution and density maps (Khan, Ali, Mohsin, & Parvin, 2022). A key factor in the spatiotemporal distribution of COVID-19 is the population's rural-urban split. Because of its closeness to Kolkata City both geographically and economically, the western boundary of the North 24 Parganas records a higher distribution of COVID-19 cases (Routh, Rai, & Bhunia, 2023). It further validates the claim that the greater population densities brought about by urbanisation make people more susceptible to pandemic disease if they use outdoor restrooms and consume contaminated water.

West Bengal is home to many low-wage workers who move throughout the nation. Millions of these migrant workers are returning to their areas of origin in the state when lockdown rules are loosened because almost all commercial operations were halted during the national lockdown (Acharya and Porwal 2020). Additionally, during the lockdown, the government of West Bengal improved its e-governance, developed the Integrated Covid Management System (WB-ICMS), and released the "Sandhane" (Search) app to help community health workers, such as Accredited Social Health Activists (ASHA), track down COVID-19 suspects in remote and rural areas (Mondal, Sahoo, Paria, Chakraborty, & Alamri, 2021). Given that respiratory illness is one such comorbidity and is affected by hand hygiene, it is plausible that improving access to handwashing could lower the risk of severe COVID-19 among the population as a preventive measure (Das, 2024).

Efforts to stop the COVID-19 outbreak and manage its far-reaching repercussions will require effective techniques and the right data. The District Vulnerability Index in this paper is meant to support government efforts to successfully address the future outbreak of COVID-19 in West Bengal. Planners will utilise this information to pinpoint underserved communities and provide support for preparing for, as well as minimising, the socioeconomic and health effects of COVID-19, as well as other forms of similar diseases.

Taking the index's usefulness into account, there are certain disadvantages. It would be ideal if it were possible to measure the index at the block or village level. Nevertheless, a number of important factors that are used to characterize vulnerability were unavailable at the micro level. However, this research is limited to the district level. Other demographic traits and environmental factors must be added to the map in order to make it better. Last but not least, the data utilized in this analysis is only two years old.

Conclusion

GIS is sometimes a useful tool for making decisions. Vulnerability evaluation with GWR can give insight into real-world conditions. Vulnerability ranking provides an overview of backward districts in terms of socio-cultural and demographic factors. Vulnerable districts will face more serious problems if a COVID-19 outbreak-like situation arises in the future.

In terms of its physical environment, people, occupations, and culture, as well as its economic diversity and proximity to both domestic and international borders, West Bengal is often regarded as a diverse state. West Bengal is well-known for its tourism industry as well. West Bengal is particularly affected by the COVID-19 pandemic because of its large population and excessive reliance on Kolkata for a number of functions. Therefore, in order to instil appropriate management and planning, a suitable database for in-depth assessment must be prepared. The study's findings can be used to pinpoint the thrust region that needs reinforcement and to ascertain potential planning and management strategies.

In contrast to the southern district of West Bengal, the majority of the districts in the north and west are deemed to be less vulnerable. Numerous factors, such as availability of resources, infrastructure resilience, and socioeconomic situations, can be blamed for this gap. Lastly, additional susceptible components should be taken into account for a more thorough outcome.

References

- Acharya, R., & Parwal, A. (September 2020). A vulnerability index for the management of and response to the COVID-19 epidemic in India: an ecological study. Lancet Global Health, Vol 8, Issue 9, e1142-e1151.
- Bhattacharyya, R., Burman, A., Singh, K., Banerjee, S., Maity, S., Auddy, A., et al. (2023). Role of multiresolution vulnerability indices in COVID-19 spread in India: a Bayesian model-based analysis. BMJ Open, 1-12.
- Bhunia, G. S. (2022). Vulnerability Assessment of COVID Epidemic for Management and Strategic Plan: A Geospatial-Based Solution. In H. Sajjad, L. Siddiqui, Atiqur Rahman, Mary Tahir, & M. A. Siddiqui, Challenges of Disasters in Asia: Vulnerability, Adaptation and Resilience (pp. 209-218). Singapore: Springer Natural Hazards, Springer Nature Singapore Pte Ltd.
- Biswas, B., Roy, R., Roy, T., Chowdhury, S., Dhara, A., & Mistry, K. (2021). Geographical Appraisal of COVID-19 in West Bengal, India. Geo-journal, 2641-2662.
- Das, K. K. (2024, June). Spatial Pattern and Hotspot Analysis of COVID-19 during the Second Wave in India using Geographical Information System (GIS). (A. Sarkar, Ed.) Indian Journal of Spatial Science, 15(2), 1-7.
- Hembrem, B., Pal, R., & N.C. Jana (2023). Spatial Mapping of the Incidence, Case-fatality Ratio, and Recovery Rate of COVID-19 in West Bengal: A Situational Analysis. Microbes and Infectious Diseases, 357-369.
- Kanga, S., Meraj, G., Sudhanshu, Farroq, M., & Singh, M. S. (2020). Risk assessment to curb COVID-19 contagion: A preliminary study using remote sensing and GIS. Research Square, 1-19.
- Khan, Z., Ali, S. A., Mohsin, M., & Parvin, F. (2022). A district-level vulnerability assessment of the next COVID-19 variant (Omicron BA. 2) in Uttarakhand using quantitative SWAT analysis. Environment Development and Sustainability.
- Majumder, R. (2021). Impacts of COVID-19 lockdown on ambient air quality: Statistical analyses of available data on urban West Bengal (India). Advances in Environmental Research, Vol. 10, No. 2, 133-145.
- Malakar, S. (2021). Geospatial Modelling of COVID-19 Vulnerability using an Integrated Fuzzy MCDM Approach: A Case Study of West Bengal, India. Modelling Earth System and Environment, Vol 8, 3103-3116.
- Mandal, G., Bose, A., Das, B., & Basak, D. (2020). Geospatial Distribution and Trend Analysis of Corona Pandemic (COVID-19) in West Bengal, India. Research Review Journal, Vol 5, Issue 6, 149-156.
- Mondal, B. K., Sahoo, S., Paria, P., Chakraborty, S., & Alamri, A. M. (2021). Multi-sectoral impact assessment during the 1st wave of the COVID-19 pandemic in West

- Bengal (India) for sustainable planning and management. Arabian Journal of Geosciences, Volume 14, 2448, 1-26.
- Routh, D., Rai, A., & Bhunia, G. S. (2023). Post-lockdown spatiotemporal pattern of COVID clustering in North 24 Parganas, West Bengal, India. Spatial Information Research, 101-112.
- Sarkar, A., & Chouhan, P. (2021). COVID-19: District-level vulnerability assessment in India. Clinical Epidemiology and Global Health 9, 204-215.