



Geographical Appraisal of COVID-19 in West Bengal, India

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Abstract Study shows that COVID-19 cases, deaths and recoveries vary in macro level. Geographical phenomena may act as potential controlling factor. The present paper investigates spatial pattern of COVID-19 cases and deaths in West Bengal (WB), India and assumes Kolkata is the source region of this disease in WB. Thematic maps on COVID related issues are prepared with the help of QGIS 3.10 software. As on 15th January 2021, WB has 564032 number of COVID-19 cases which is 0.618% to the total population of the state. However, the COVID-19 case for India is 0.843% and for world is 1.341% to its total population. Lorenz Curve shows skewed

distribution of the COVID-19 cases in WB. 17 (90%) districts hold 84.11% of the total population and carry 56.30% of the total COVID-19 cases. However, the remaining two districts—Kolkata and North 24 Parganas—hold remaining 43.70% COVID-19 cases. Correlation coefficient with COVID-19 cases and Population Density, Urban Population and Concrete Roof of their house are significant at 1% level of significance.

Keywords COVID-19 · West bengal · Geographical factor · Urbanization · Population density · Nonworking population · Forest

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Introduction

Novel coronavirus (2019-nCov) is wreaking havoc worldwide. As on 15th January 2021, the virus-related disease COVID-19, killed about 2,009,092 human lives, spreading over 273 countries. However, in the macro (even in micro) level, there are spatial variations on its cases and deaths. Data from published epidemiology and virology studies provide evidence of 2019-nCov transmission from infected peoples to others who are in direct contact or close contact through respiratory droplets, or by contact with contaminated objects and surfaces. A recent study shows that the novel coronavirus disease can spread

through aerosols and thus the inhalation of particles is a common way to spread the virus (The Hindu, 22nd September, 2020). For the last 12 months, the disease has been spreading at an exponential rate. On 30th January 2020, India reported its first case of COVID-19 in Kerala, which rose to three cases by 3rd February 2020. All the cases were students returning from Wuhan, China. Apart from these, no significant rise in transmission was observed in February. On 4th March 2020, 22 new cases were reported, including 14 infected members of an Italian tourist group. While in West Bengal, India first positive case of coronavirus infection was detected on 17th March 2020 when a student returned from United Kingdom (Anandabazar Patrika, 17th March 2020). As on 15th January 2021, West Bengal has 564,032 number of COVID-19 cases and 10,023 deaths due to it. COVID-19 cases and deaths are highly skewed in the spatial distribution in West Bengal, India. Many researchers have suggested spatial variations of COVID-19 cases and deaths occur due to population density, climate, exposure to malaria, and a weaker strain of the SARS-CoV 2 virus (El-Gendy et al. 2020).

The present paper attempts to investigate the spatial pattern of COVID-19 cases and deaths in the state West Bengal, India with geographical perspective. The paper starts with literature review which shows the gap in the existing COVID-19 (Geographical) studies. A brief comparison with the world as well as India has been made with the study area to understand prevailing burden of COVID-19. Attempt has been made to understand the nature of spatial variations and possible underlying factors therein.

Literature Review

A brief literature review has been made to identify the existing gap in the studies (up to 10th December 2020). The database used for the literature review is PubMed using Endnote X7. The primary 'keyword' for the review was "COVID" and the associated terms were 'India', 'West Bengal' and 'Factors'. The latest search confirms 76,441 publications with the keyword COVID. 4809 research papers were found using "COVID + India"; 221 with "COVID + India + West Bengal"; and finally, 22 with the key words "COVID + India + West Bengal + Factors".

All these papers have been published in 2020 (Table 1).

We can broadly classify these 22 papers on eight different thematic aspects (Table 2). For example,

- (i) RNA structure of the Corona virus (Biswas and Majumder 2020);
- (ii) 'Antimicrobial Resistance' due to use of excessive sanitizers (Bandyopadhyay and Samanta 2020);
- (iii) Co-Morbidity and its role on COVID-19 fatality; (Das et al. 2020a, b; Saha and Chouhan 2020);
- (iv) Status on learning system etc. due to lockdown related closure of the educational institutes (Kapasia et al. 2020);
- (v) Impact of lockdown on reducing pollution load with special emphasis on air and water (Acharya et al. 2020; Bera et al. 2020; Mahato and Ghosh 2020; Mahato et al. 2020; Patel et al. 2020);
- (vi) Vulnerability, public health including mental health, health risk assessment of the common people, health workers including doctors (Ankita Zaveri and Chouhan 2020; Arora et al. 2020; Chatterjee et al. 2020a, 2020b; Das et al. 2020a, b; Dubey et al. 2020; Ghosh and Sarkar 2020; Ghosh et al. 2020a, b; Kam et al. 2020; Mishra et al. 2020a, b; Murhekar et al. 2020; Podder et al. 2020; Rajarshi et al. 2020; Suri et al. 2020);
- (vii) Spatial pattern, prediction and Modelling; and
- (viii) Factors for COVID-19.

The present study would like to exclude the first six themes, as it is beyond the scope of the present study and we could find a few relevant papers in the final two categories. In these two thematic categories spatial pattern, prediction, modelling, and some identified factors of COVID-19 cases and deaths are available, which are related to the present study.

Spatial pattern, prediction and modelling of COVID-19 in India and West Bengal have been investigated by a few researchers. To investigate the COVID-19 and urban vulnerability, urban to rural transmission processes in India in national level and also at sub-city level vulnerability have been

Table 1 COVID-19 Literature search

Database	Number of publications (2020)	Keyword(s)	Regional extent
PubMed	76,441	COVID	Global
	4809	COVID; India	India
	221	COVID; West Bengal	West Bengal
	22	COVID; West Bengal, Factors	West Bengal

Source: Authors' Calculation using PubMed-Literature Survey (dated:07.12.2020)

investigated. Vulnerability zones were prepared with the help of Analytical Hierarchical Process. This has helped to categorise the city into low to very high vulnerable zone (Mishra et al. 2020a, b). Resultant lockdown due to COVID-19 and its impact on community mobility in India has been analysed in the COVID-19 Community Mobility Report, 2020. Study figures out mobility trends over time during pre-lockdown and after lockdown periods across different categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces, and residential areas (Saha et al. 2020). Population mobility has also been investigated using dynamic model of infected population, considering both intra and inter zone mobilization factors with rate of detection (Ghosh et al. 2020a, b). Use of mathematical model, prediction of COVID-19 infection in India, and correlation analysis of the virus transmission with socio-economic factors have also been investigated. The important socio-economic factors considered in this study are state-wise total population, gender ratio, rural urban ratio, literacy, and GDP. A long-term prediction of cumulative cases, spreadability rate, and pandemic peak of COVID-19 was made for India (Kumar et al. 2020).

Various factors of Corona virus infection, incidence and severity, and transmission have been estimated (Arif and Sengupta 2020; Chakrabarti et al. 2020a, b; Pramanik et al. 2020). Biological and environmental factors helping Corona Virus to stem the incidence and severity—was the key question of the research by Chakrabarti et al. (2020a). They tried cross-immunity, innate immune responses, ACE polymorphism, and viral genetic mutations as important factors of COVID diseases (Chakrabarti et al. 2020a). Chakraborti et al. (2020b) have used machine learning in exploring determinant factors of present pandemic situation. It concluded that the air pollution, migration, economy, and demography were most significant controlling

factors (Chakraborti et al. 2020b). Geo-statistical approach has been employed to evaluate the importance of population density on Coronavirus pandemic in the south Indian states (Kerala, Tamil Nadu, Karnataka and Telangana) (Arif and Sengupta 2020). Climatic factors have influences on the magnitude of COVID-19 outbreak. A stochastic model—Tree algorithm shows that average temperature and average relative humidity explain significant variations in COVID-19 transmission across temperate and subtropical regions, whereas in the tropical region, the average diurnal temperature range and temperature seasonality significantly predict the infection outbreak (Pramanik et al. 2020).

We commonly understand that COVID-19 have originated in urban areas and every first case of COVID-19 in any country is found in the city (urban areas). Urbanization determines the population density, and both have relationship with COVID-19 cases. Preventive measures from the Corona virus infection are use of masks, soaps, sanitizers, and proper personal health care. Economic empowerment is directly related to use of these preventive measures. We can understand the economically weaker section or non-working population would be more vulnerable to this disease. Poor housing structures would make the residents more vulnerable to this disease. We understand that forest supplies fresh air and reduces the burden of air pollution. Fresh air may reduce the burden of COVID-19 cases as well.

However, none of these above-mentioned papers have discussed or analysed any possible geographical factors like level of urbanization, presence of forest, poor housing and distance from the urban centre for spatial variations, and modelling of COVID-19 cases. This gives rise to an opportunity to offer a research to fill the gap in considering the geographical factors for the nature and intensity of COVID-19 and its spatial extent.

Table 2 COVID-19 Literature review

Aspect or major issues in the paper	Author(s) and Date	Major findings
RNA structure of the virus	Biswas and Majumder (2020)	This paper has analysed RNA sequences of 3636 SARS-CoV-2 collected from 55 countries reveals selective sweep of one virus type. This paper is beyond the scope for the present study
Antimicrobial resistance (AMR)	Bandyopadhyay and Samanta (2020)	This paper, 'Antimicrobial Resistance in Agri-Food Chain and Companion Animals as a Re-emerging Menace in Post-COVID Epoch: Low-and Middle-Income Countries Perspective and Mitigation Strategies' could find frequent use of hand sanitizer trigger AMR due to the presence of cross-resistance with disinfectants
Co-morbidity	Das et al. (2020a, b)	The paper 'Impact of nutritional status and anaemia on COVID-19: Is it a public health concern? Evidence from National Family Health Survey-4 (2015–2016), India' could find that the percentage of adults with below normal BMI, overweight or obese and anaemia are the most vulnerable to COVID-19
	Saha and Chouhan (2020)	Indoor air pollution (IAP) and pre-existing morbidities among under-5 children in India: are risk factors of coronavirus disease (COVID-19)? This study used NFHS and MoHFW datasets to correlated the Indian states and UTs for COVID vulnerability with Air pollution and co-morbidity. The study classified the Indian states and UTS among (i) very higher, (ii) higher risk, and (iii) very low-risk zones of Corona virus infection
Status on learning system etc	Kapasia et al. (2020)	This paper tried to show the need and importance of setting up proper strategies for effecting learning system in this pandemic related lockdown conditions
Impact on Environment	Acharya et al. (2020)	The study to investigate the impact of lockdown on air pollution level was done using Aerosol Optical Depth in south-southeast Asia, Europe and USA amid the COVID-19 pandemic using satellite observations. It revealed significant reduction of AOD (-20%) was obtained for majority of the areas in SSEA, Europe and USA during the lockdown period. Yet, the clusters of increased AOD (30–60%) was obtained in the south-east part of SSEA, the western part of Europe and US regions. NO ₂ reductions were measured up to 20–40%, while SO ₂ emission increased up to 30% for a majority of areas in these regions
	Bera et al. (2020)	Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health has been estimated. It was found that the pollutants like CO, NO ₂ and SO ₂ are significantly decreased, while the average level of O ₃ has been slightly increased in 2020 during the lockdown
	Mahato and Ghosh (2020)	Short-term exposure to ambient air quality of the most polluted Indian cities due to lockdown amid SARS-CoV-2 has been investigated in this research. It was found that PM ₁₀ and PM _{2.5} concentrations have suppressed below the permissible limit in all cities. CO and NO ₂ have reduced to about -30% and -57% respectively during the lockdown period. Diurnal concentrations of PM ₁₀ and PM _{2.5} have dropped drastically on the very 4th day of lockdown and become consistent with minor hourly vacillation
	Mahato et al. (2020)	The effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India has been estimated. The research shows concentrations of PM ₁₀ and PM _{2.5} have witnessed maximum reduction (> 50%) in compare to the pre-lockdown phase
	Patel et al. (2020)	This paper investigated the impact of lockdown on the river Yamuna's water quality at Delhi. It shows that Biological Oxygen Demand and Chemical Oxygen Demand values reduced by 42.83% and 39.25%, respectively, compared to the pre-lockdown phase

Table 2 continued

Aspect or major issues in the paper	Author(s) and Date	Major findings
Vulnerability, Public health including mental health	Ghosh and Sarkar (2020)	The coronavirus (COVID-19) pandemic's impact on maternal mental health and questionable healthcare services in rural India has been evaluated in this paper. It finds that Child birth is taking place at rural home
	Arora et al. (2020)	The paper entitled, 'Understanding coronaphobia' says COVID -19 has created huge phobia (coronaphobia). Unforeseen reality, unending uncertainties, need of acquiring new practices and avoidance behaviour, loss of faith in health infrastructure, contraction of COVID-19 by head of states, cautionary statements from international bodies, and infodemia etc. are assumed to cause interference with routine life, catastrophizing interpretation of benign symptoms, and social amplification of risk which lead to coronaphobia
	Ankita Zaveri and Chouhan (2020)	"Are Child and Youth Population at Lower Risk of COVID-19 Fatalities? Evidences from South-East Asian and European Countries', this paper highlighted the higher percentage of child and youth population could affect the lower Crude Fatality Rate from COVID-19 in SE Asian countries
	Mishra et al. (2020a)	The paper COVID-19 and urban vulnerability in India has developed COVID Vulnerability Index using Analytical Hierarchical Process
	Chatterjee et al. (2020a)	In this Healthcare workers & SARS-CoV-2 infection in India study, the focus was to map the vulnerability of the health care workers to COVID 19
	Chatterjee et al. (2020b)	Attitude, practice, behaviour, and mental health impact of COVID-19 on doctors has been studied in this paper. The paper tried to explore the knowledge, attitude, and behavior of doctors regarding this pandemic and how it influences their depression, anxiety, and stress level. It was concluded that the Doctors who were working during COVID pandemic have a high prevalence of psychiatric morbidity
	Das et al. (2020a, b)	A Study to Evaluate Depression and Perceived Stress Among Frontline Indian Doctors Combating the COVID-19 Pandemic
	Murhekar et al. (2020)	The study Prevalence of SARS-CoV-2 infection in India: Findings from the national serosurvey, May–June 2020 finds adults are less vulnerable to COVID but put a line of cautious to be careful about this findings
	Ghosh et al. (2020a, b)	This paper tried to evaluate the perspective of Oncology Patients During COVID-19 Pandemic. The study revealed that oncology patients in our country were more worried about their disease progression than the SARS-CoV-2
	Podder et al. (2020)	Comparative analysis of perceived stress in dermatologists and other physicians during national lock-down and COVID-19 pandemic with exploration of possible risk factors: A web-based cross-sectional study from Eastern India finds that higher stress was significantly associated with females and unmarried individuals in both groups. Risk of infecting self or colleagues or family members and lack of protective gear at work place were top causes of stress
	Kam et al. (2020)	Systematic analysis of disease-specific immunological signatures in patients with febrile illness from Saudi Arabia
	Rajarshi et al. (2020)	The research on Essential functional molecules associated with SARS-CoV-2 infection: Potential therapeutic targets for COVID-19 tried to evaluate the beneficial functions of proteins to fight COVID-19
	Suri et al. (2020)	COVID-19 pathways for brain and heart injury in comorbidity patients: A role of medical imaging and artificial intelligence-based COVID severity classification: A review. This paper begins by presenting the four pathways that can lead to heart and brain injuries following a COVID-19 infection. Myocardial injury, hypoxia, plaque rupture, arrhythmias, venous thromboembolism, coronary thrombosis, encephalitis, ischemia, inflammation, and lung injury are some of the symptoms related to COVID-19 disease

Table 2 continued

Aspect or major issues in the paper	Author(s) and Date	Major findings
Spatial pattern, prediction and Modelling	Dubey et al. (2020)	Psychosocial impact of COVID-19 was the central focus of this study and it tried to do the investigation with the help of literature survey
	Mishra et al. (2020a, b)	To investigate the COVID-19 and urban vulnerability in India, this paper tried to study sub-city level vulnerability zone with the help of Analytical Hierarchical Process and categorised the city into Low to very high vulnerable zone
	Saha et al. (2020)	To resultant Lockdown due to COVID-19 and its impact on community mobility in India has been analysed in the COVID-19 Community Mobility Reports, 2020. Study figures out mobility trends over time during pre-lockdown and after lockdown period across different categories of places such as retail and recreation, groceries and pharmacies, parks, transit stations, workplaces, and residential areas
	Mishra et al. (2020a, b)	COVID-19 in India transmits from the urban to the rural
	Roy et al. (2020)	The paper entitled, 'Spatial prediction of COVID-19 epidemic using ARIMA techniques in India' tries to use GIS for spatial modelling using Weighted Overlay Method and Autoregressive Integrated Moving Average (ARIMA). Results shows west and south of Indian district are highly vulnerable for COVID-2019
	Ghosh et al. (2020a, b)	This paper tried to prepare dynamic model of infected population due to spreading of pandemic COVID-19 considering both intra and inter zone mobilization factors with rate of detection
	Kumar et al. (2020)	The paper tried to use mathematical model and predict COVID-19 infection in India and correlation analysis of the virus transmission with socio-economic factors. The important socio-economic factors considered in this study are state-wise total population, Gender ratio, Rural urban ratio, literacy, GDP. A long-term prediction of cumulative cases, spreadability rate, pandemic peak of COVID-19 was made for India
Factors	Chakrabarti et al. (2020)	Biological and Environmental Factors Helping to Stem the Incidence and Severity—was the key question of the research by Chakrabarti et al. (2020a). They tried cross-immunity, innate immune responses, ACE polymorphism, and viral genetic mutations as important factors of COVID diseases
	Chakraborti et al. (2020)	Chakraborti et al. (2020b) used machine learning in exploring determinant factors of present pandemic. It concluded that the air pollution, migration, economy, and demographic factor were most significant controlling factors
	Pramanik et al. (2020)	The paper tried to find the Climatic influence on the magnitude of COVID-19 outbreak: a stochastic model-based global analysis. Tree algorithm method, show that average temperature and average relative humidity explain significant variations in COVID-19 transmission across temperate and subtropical regions, whereas in the tropical region, the average diurnal temperature range and temperature seasonality significantly predict the infection outbreak
	Arif and Sengupta (2020)	This paper finds the nexus between population density and novel coronavirus (COVID-19) pandemic in the south Indian states. It has used geo-statistical approach. Thiessen polygon method (has been applied and found that COVID-19 transmission in four states (Kerala, Tamil Nadu, Karnataka and Telangana) strongly hinges upon the spatial distribution of population density

Source: Authors' Calculation using PubMed (EndNote X7) Literature Survey (Up to 10.12.2020)



Fig. 1 Location of the Study area. Source: Authors' Calculation and Superimposed on Open Street Map (OSM)

Hypothesis and Research Questions

It is a general observation that the disease has travelled from Wuhan, China to all over the globe and that every 1st case of COVID-19 infection in any country is found in a city. Similarly, for West Bengal, the first

COVID-19 case was recorded in the state capital Kolkata. Therefore, this paper would like to set its hypothesis as the following.

- Kolkata (big city) is the main source point of the disease. We can assume that with increasing

distance from Kolkata, the burden of the disease will be reduced.

- Population density plays an important role in localization of COVID-19 patients. We understand that the disease is (highly) infectious. It was thought that higher population density would increase the risk of transmission. This is also true that the population density is directly related with the level of urbanization. So, population density and level of urbanization have direct relationship with COVID-19 cases and death.
- Forest cover influences number of COVID-19 cases—is another hypothesis of the present study. We all know that the presence of a forest always supplies fresh air and reduces the burden of air pollution. Fresh air may reduce the burden of COVID-19 cases as well.
- Non-working population is at a much higher risk of contacting Corona virus infection. It is well known that the COVID-19 related lockdown jeopardises the livelihood of millions. The non-working population would be at the higher level of vulnerability to Corona virus infection as they would prefer to get food than get the objects necessary for prevention measures (sanitiser, soap, mask etc.). The non-working population may be considered as proxy to economically poor people.
- People having concrete households would have lower COVID-19 cases. The fundamental assumption is that the people living in the concrete households are richer. They would have higher purchasing power and would be able to take better prevention measures from Corona virus.

Study Area

The state West Bengal situated in the eastern part of the India (Fig. 1) has been selected for the present study. The Government of West Bengal is publishing daily COVID-19 related bulletin and data in its official portal from 5th February 2020 for public use and researches (<https://www.wbhealth.gov.in/pages/corona/bulletin>). There are large numbers of people (including migrants labours) from West Bengal working all over India and other countries. Most of them have returned to the state during the pandemic period. The returning of the people from other states

and countries are well-recorded. The state has recorded a definite starting date of the COVID-19 infection. Geographically and economically, it may be considered as a proxy to India. Any major findings through this research may be considered fit or relevant for the entirety of India.

West Bengal covers an area around 88,752 sq. km, with a total population by 91,347,736 according to 2011 Census of India. It has an average decadal population growth rate of 13.84 per cent. The state is extended from the foot of Darjeeling Himalayas in the North to the Bay of Bengal in the South, and from edge of Chhotanagpur high lands in the west to the border of Bangladesh and Assam in the east. Tropical, hot, humid, monsoon type climate prevails in West Bengal. Natural vegetation covers 13.93% of total area of West Bengal. Agriculture is the leading occupation of the people of West Bengal. West Bengal is the land of complex blending of religion, cultures, caste, and languages.

The state is the fourth largest state according to population density of the states of India with 950 persons per sq. km in 2011. West Bengal has very diverse level of urbanization. It varies from 100% urban (Kolkata) to only 8.30% (Bankura) with an average urbanization level at 28.78%. Similarly, population density of the state also varies from 468 persons per sq. km (Purulia) to 24,306 persons per sq. km (Kolkata). Sex ratio of the state is 934 and the overall literacy rate in 2011 is 74.04 per cent.

The state of housing is not very good in West Bengal. Only 28.38% of the total households have concrete roof structure. Gross State Domestic Product for the year 2011–2012(P) is Rs. 323,419.50 Crore with an annual growth during the year 2011–2012(P) being 4.72%. Per Capita Income of the state in 2011–2012 is Rs. 32,164.00, which is lower than the national (India) average of Rs. 38,048.00 (State Domestic Product and District Domestic Product of West Bengal 2013–2014).

Database and Methodology

This paper would like to use only the secondary data. In this new-normal situation, primary survey is not feasible and is not done here. This is important to mention that the COVID-19 related data has been published by Health & Family welfare Department,

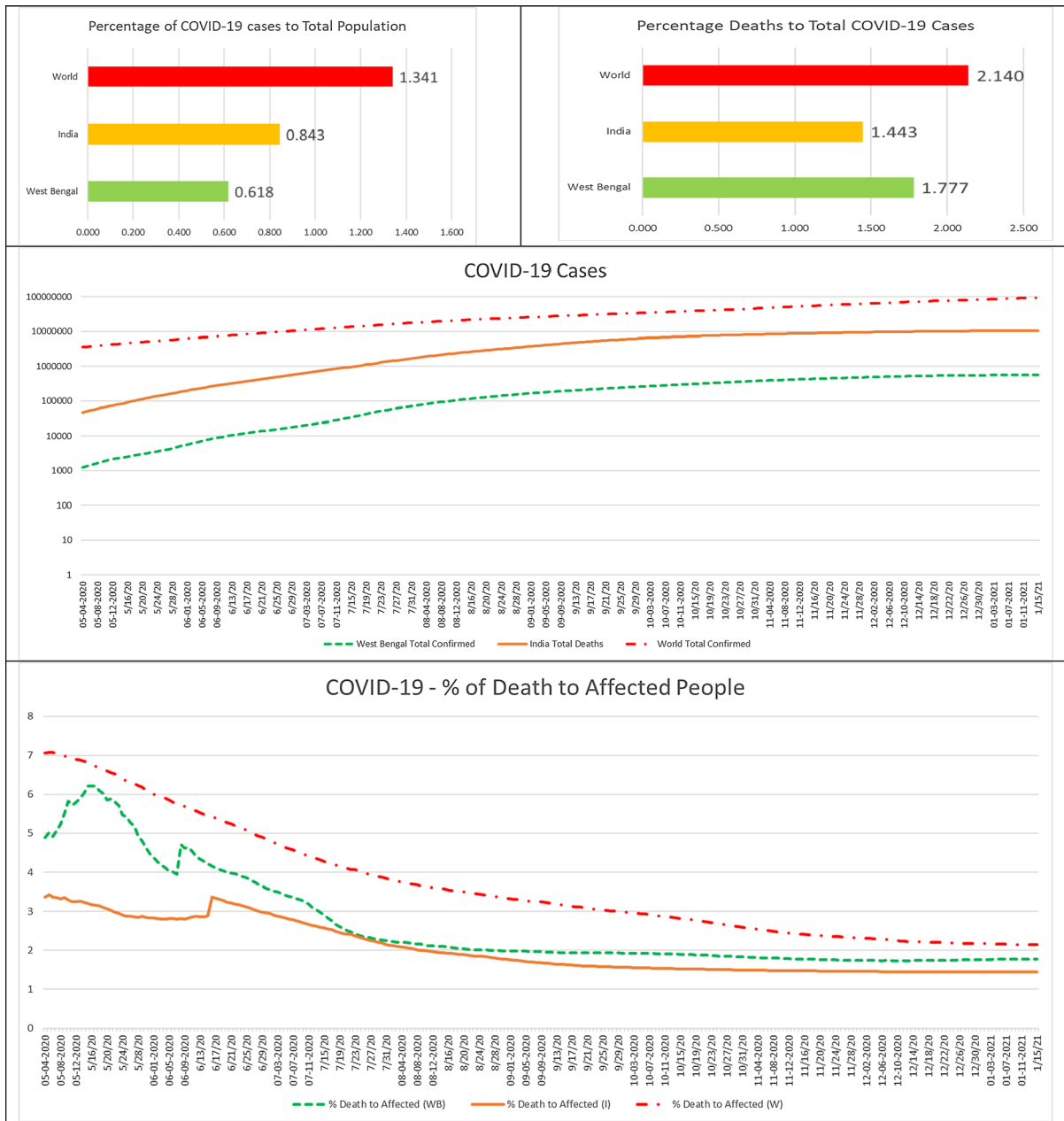


Fig. 2 Comparative chart of COVID-19 Cases and Deaths (04.05.2020 to 15.01.2021) (WB = West Bengal; I = India and W = World). Source: WHO and Govt. of West Bengal Data; and Authors' Calculation

Government of West Bengal from 4th May 2020. All the analysis on the COVID-19 data were done from 4th May to 15th January 2021.

COVID-19 related data has been collected from websites:

- Health & Family welfare Department, Government of West Bengal: <https://www.wbhealth.gov.in/pages/corona/bulletin>
- Ministry of Health and Family Welfare, Government of India: <https://www.mohfw.gov.in/>
- World Health Organization: <https://www.who.int/emergencies/diseases/novel-coronavirus-2019>

Table 3 COVID-19 in West Bengal and its comparison with India and World (31.08.2020)

	Total population- 2011	COVID_ Cases_ 15,012,021	COVID_ Deaths_ 15,012,021	% COVID cases to total population	Total COVID Cases per one million population	% Death to total COVID cases
West Bengal	91,276,115	564,032	10,023	0.618	6179	1.777
India	1,250,300,000	10,543,663	152,130	0.843	8433	1.443
World	7,004,000,000	93,901,504	2,009,092	1.341	13,407	2.140

Source: Global—WHO; West Bengal – Govt. of West Bengal; Till:—15.01.2021; and Census of India, 2011

Data on population of India and West Bengal has been collected from—

- Census of India, 2011, Primary Census Handbook https://censusindia.gov.in/2011-prov-results/prov_data_products_wb.html
- Census of India, 2011, Condition of Census Houses occupied; <http://dataforall.org/dashboard/censusinfo/>
- Census of India, 2011, Construction Material of roof, <http://dataforall.org/dashboard/censusinfo/>

The COVID-19 data of West Bengal has been compared with the India and World data. A few charts and map have been prepared with respect to the data to interpret and explore the results. This is important to mention that presently there are 23 districts in West Bengal and initially there were few patients from ‘other state’ and a few patients could not tell the name of their place of residence. For the present comparative study, we are using Census of India—2011 data. A few new districts of West Bengal have been created through bifurcation of some existing districts of West Bengal after 2011. For example, the district Burdwan has been bifurcated into Purba Bardhaman and Paschim Bardhaman Districts. To make the data comparable, we merged the bifurcated districts at the 2011 level. As a result, there are 19 districts in total for further analysis.

The processed data has been brought in the Geographical Information System (GIS) for preparation of thematic maps and to have visual impact on the nature and extent of distribution of COVID-19 cases and deaths. QGIS 3.10 has been used in this regard.

Spatial distribution and its variations were estimated using Lorenz Curve. Gini Coefficient has been

estimated to show the spatial disparity in COVID-19 distribution in West Bengal.

The paper has considered ‘level of urbanization’, ‘population density’, ‘% of forest cover’, ‘non-working population’, ‘% of concrete households’, and ‘distance from Kolkata’ as geographical factors for evaluating the nature and extent of COVID-19 cases etc. Multiple correlation-coefficient technique has been used to identify any relationships among the factors and COVID-19 cases etc.

Result and Discussion

COVID-19 in West Bengal: a brief comparison

Initiation and spatial spread of COVID-19 started much later in West Bengal than the rest of India and World. As on 15th January 2021, West Bengal has 564,032 number of COVID-19 cases which is 0.618% to the total population of the state. However, the COVID-19 case for India is 0.843% and for world 1.341% to its total population respectively. We can say that the rate of COVID-19 infection in West Bengal is much lower in this case (Fig. 2).

The death rate due to COVID-19 in West Bengal is 1.777% which is little higher than the national average of 1.443%. However, the death rate is less in West Bengal than the global average of 2.140% (Table 3).

Figure 2 says that the growth curve of the COVID-19 cases in World, India and West Bengal looks very conforming in shape. COVID-19 related death curve is in steady declining mode. There was a sudden peak in the death curve in case of West Bengal in the middle of May 2020. However, the curve became constantly growing with downward trend. The COVID-19 death curve for the world is always in higher position that

India and West Bengal. The death curve of West Bengal is always standing in between the World's and India (Fig. 2).

Growth of COVID-19 cases in West Bengal

It has already been told that the COVID-19 cases started in West Bengal from 17th March 2020. The Health & Family welfare Department, Government of West Bengal has published its data from 4th May 2020 in the website for public access. From then, the COVID-19 cases, data about deaths and recovery has been steadily growing. The growth curve of COVID-19 cases of West Bengal is similar to that of India and the World. It is very interesting and hopeful to observe that the death curve of West Bengal is very flat and certainly not following the curve of total COVID-19 cases (Fig. 3).

During the entire study period, COVID-19 cases have been rising and the maximum new cases recorded (on 22.10.2020) is 4157. Fortunately, there is steady declining trend in the new COVID-19 cases after 22nd October 2020.

The death curve of West Bengal due to COVID-29 is very flat and maximum single day deaths were 81 on 08.06.2020. The second highest single day deaths were 64 on 22.10.2020. After that, the death rate is declining steadily (Fig. 3).

Spatial Distribution of COVID-19 in West Bengal

Spatial variation of the COVID-19 was analysed with the help of Lorenz Curve. The curve shows unevenness in spatial distribution of COVID-19 cases. The Gini Coefficient of the Lorenz Curve is 0.473, which indicates the skewed distribution of the COVID-19 cases in West Bengal. The data shows that out of 19 districts, 17 (90%) districts hold 84.11% of the total population and carry 56.30% of the total COVID-19 cases. However, the remaining two districts—Kolkata and North 24 Parganas—hold remaining 43.70% COVID-19 cases (Table 4 and Fig. 4). In absolute term, total COVID-19 cases in Kolkata is the highest in West Bengal and it is 126421. North 24 Parganas contains 120,042 COVID-19 cases. South 24 Parganas, Haora and Hugli are the next three districts with higher number of COVID-19 cases.

When we compared the total COVID-19 cases per 1000 households, the districts in the list changed their

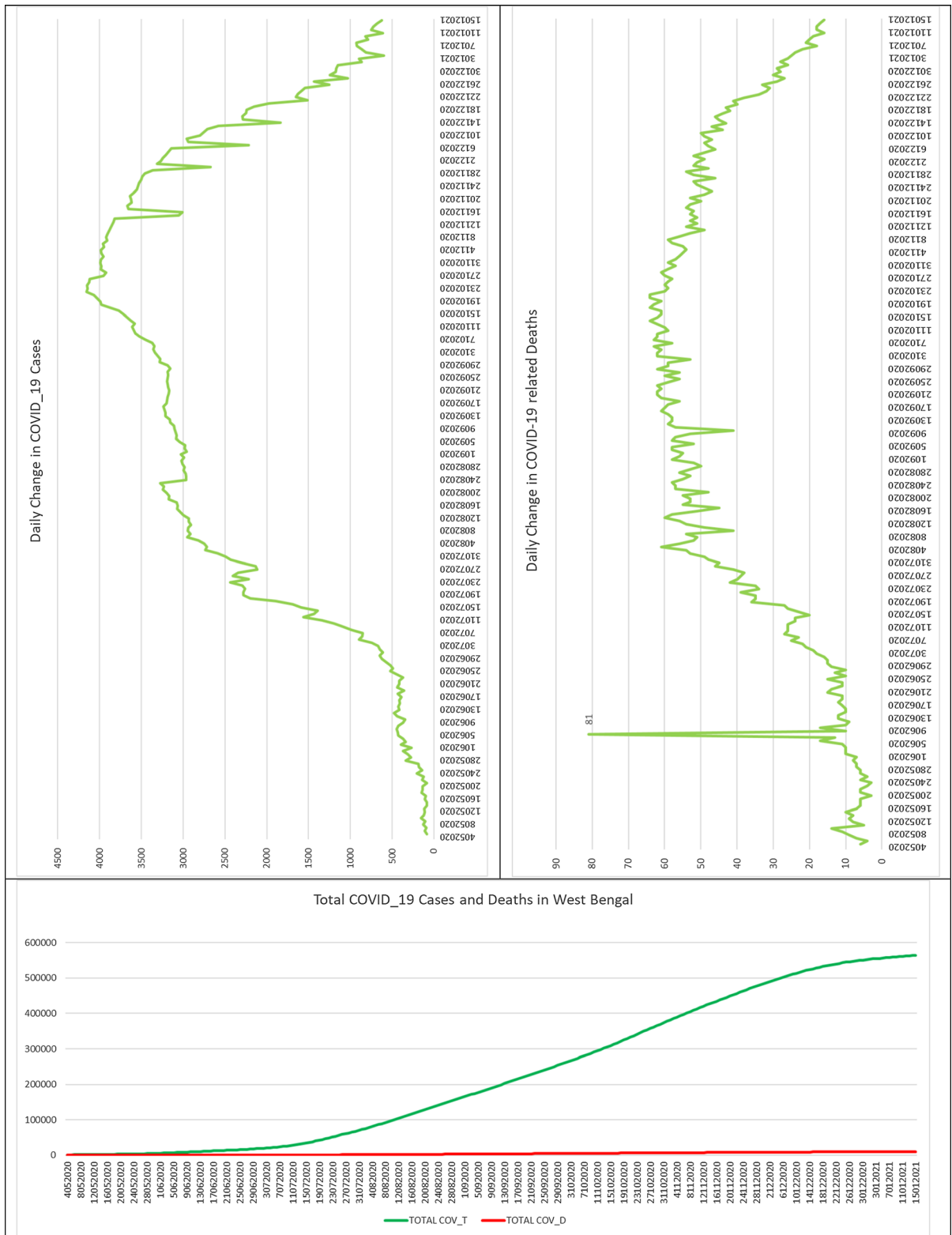
ranks. The top five districts are Kolkata, Darjilling, North 24 Parganas, Haora, and Koch Bihar. COVID-19 cases per 1000 households are 123, 52, 51, 33, and 29 accordingly. Similarly, when we analysed COVID-19 cases per One Million population, North 24 Parganas and Darjilling alter their locations. The top five districts are Kolkata, North 24 Parganas, Darjilling, Haora, and Koch Bihar with 2811, 1199, 1100, 726 and 690 COVID-19 cases per one billion population (Fig. 5).

Peoples' death due to COVID-19 is found to be maximum at 3040 (as on 15.01.2021) in Kolkata. The other top four districts are North 24 Parganas, Haora, South 24 Parganas, and Hugli with 2427, 1029, 701, and 479 deaths. However, the list of top five districts with COVID-19 related deaths changes when we see the percentage of deaths to total COVID-19 cases in the districts. Haora, Kolkata, North 24 Parganas, South 24 Parganas and Hugli are the top five districts. The percentage of deaths due to COVID-19 for these districts are 2.921, 2.405, 2.022, 1.911 and 1.645 respectively. This is really a point of good hope that three districts of West Bengal—Purulia, Bankura, and Koch Bihar are least affected districts in terms of COVID-19 deaths. They have only a total 16, 25 and 56 as number of deaths respectively (Table 5 and Fig. 6).

There are wide spatial variations in the deaths, and a correlations analysis may reveal the underlying factors on the spatial variations in the COVID-19 cases, deaths, and recovery pattern. The correlational study of COVID-19 cases reveals that it is positively related with percentage of Population Density (+ 0.736), Urban Population (+ 0.836), Concrete Roof of their house (+ 0.718), and Non-working Population (0.174). While COVID-19 cases are negatively correlated with percentage of forest cover (-0.118), and Distance from Kolkata (a big metro city) (-0.480) (Table 6 and Fig. 7).

We understand that the correlation coefficient value remains invalid if it is less than ± 0.25 . Therefore, the variables 'percentage of forest cover', and 'non-working population' are neither very effective nor playing any significant role in COVID-19 cases. Hence, in the further analysis these two factors were not considered.

The '*P-value*' of the correlation coefficient with COVID-19 cases and all the variables like population density, urban population, concrete roof and distance



◀ **Fig. 3** Total COVID-19 cases; daily changes in COVID-19 cases and deaths in West Bengal (04.05.2020 to 15.01.2021). Source: Authors' Calculation

from Kolkata are significant at 0.32%; 0.02%, 0.25% and 0.14% level of significance (Table 6).

COVID-19 deaths also show similar correlation as was observed in COVID 19 cases. It is positively related with total COVID-19 cases (+ 0.99), population density (+ 0.80), urban population (+ 0.87), concrete roof of their house (+ 0.75), and Non-working Population (0.15). While COVID-19 death is negatively co-related with percentage of Forest Cover (−0.14), and Distance from Kolkata (a big metro city) (−0.50) (Table 6 and Fig. 8).

We understand that the variables 'percentage of forest cover' and 'non-working population' are not significant as per the result. Secondly, when we evaluate the results with '*P-value*' of the variables and

the COVID-19 deaths are being determined by total COVID-19 cases, population density, % of urban population, concrete roof of their house and distance from Kolkata. The level of significance for each of the variable are 0.00%, 0.03%, 0.08%, 0.22% and 0.11% respectively (Table 7).

Conclusion

Spatial distribution of COVID-19 cases is strongly uneven in West Bengal. Kolkata is clearly the main source point of the disease in West Bengal. 1st COVID-19 case started from Kolkata and the maximum number of patients and deaths until date are recorded here. We can say that the burden of the COVID-19 diseases is much higher in the big city, Kolkata.

Table 4 Calculation of Lorenz Curve for showing disparity in distribution COVID-19 cases among the districts West Bengal

District	COVT_ 15/01/2021	Total population	%_COV	%_Pop	Cum%_pop	Cum%_COV
					0.00	0
Uttar Dinajpur	6539	2,819,086	1.16	3.09	3.09	1.16
Puruliya	7097	2,930,115	1.26	3.21	6.30	2.42
Dakshin Dinajpur	8128	1,676,276	1.44	1.84	8.14	3.86
Birbhum	9859	3,502,404	1.75	3.84	11.97	5.61
Bankura	11,622	3,596,674	2.06	3.94	15.91	7.67
Murshidabad	12,147	5,167,600	2.15	5.66	21.57	9.82
Maldah	12,594	5,913,457	2.23	6.48	28.05	12.05
Jalpaiguri	14,542	7,717,563	2.58	8.46	36.51	14.63
Koch Bihar	19,442	7,103,807	3.45	7.78	44.29	18.08
Darjiling	20,324	3,872,846	3.60	4.24	48.53	21.68
Purba Medinipur	20,432	1,846,823	3.62	2.02	50.56	25.30
Nadia	22,253	3,007,134	3.95	3.29	53.85	29.25
Paschim Medinipur	23,094	5,095,875	4.09	5.58	59.43	33.34
Barddhaman	28,462	3,988,845	5.05	4.37	63.80	38.39
Hugli	29,126	5,519,145	5.16	6.05	69.85	43.55
Haora	35,222	4,850,029	6.24	5.31	75.16	49.80
South 24 Parganas	36,686	8,161,961	6.50	8.94	84.11	56.30
North 24 Parganas	120,042	10,009,781	21.28	10.97	95.07	77.59
Kolkata	126,421	4,496,694	22.41	4.93	100.00	100.00
TOTAL	564,032	91,276,115	100	100		

Source: Govt. of West Bengal; Till:—15/01/2021

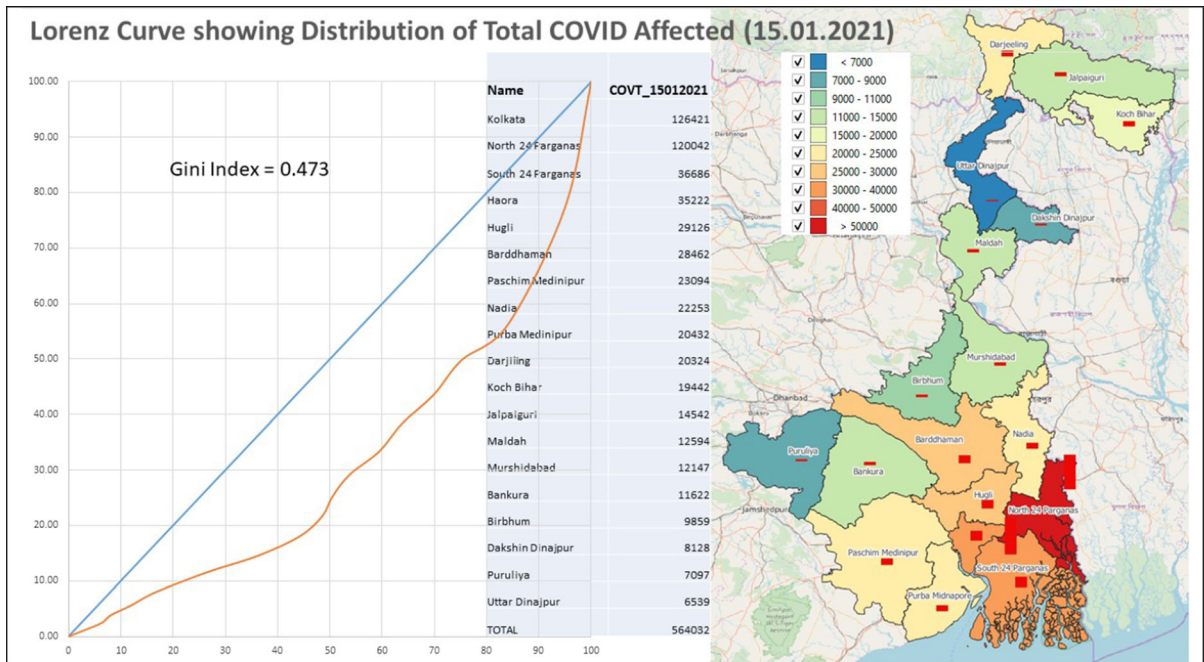


Fig. 4 Lorenz Curve showing Disparity in Spatial Distributin of COVID-19 Cases in West Bengal. Source: Authors' Calculation and Superimposed on Open Street Map (OSM)

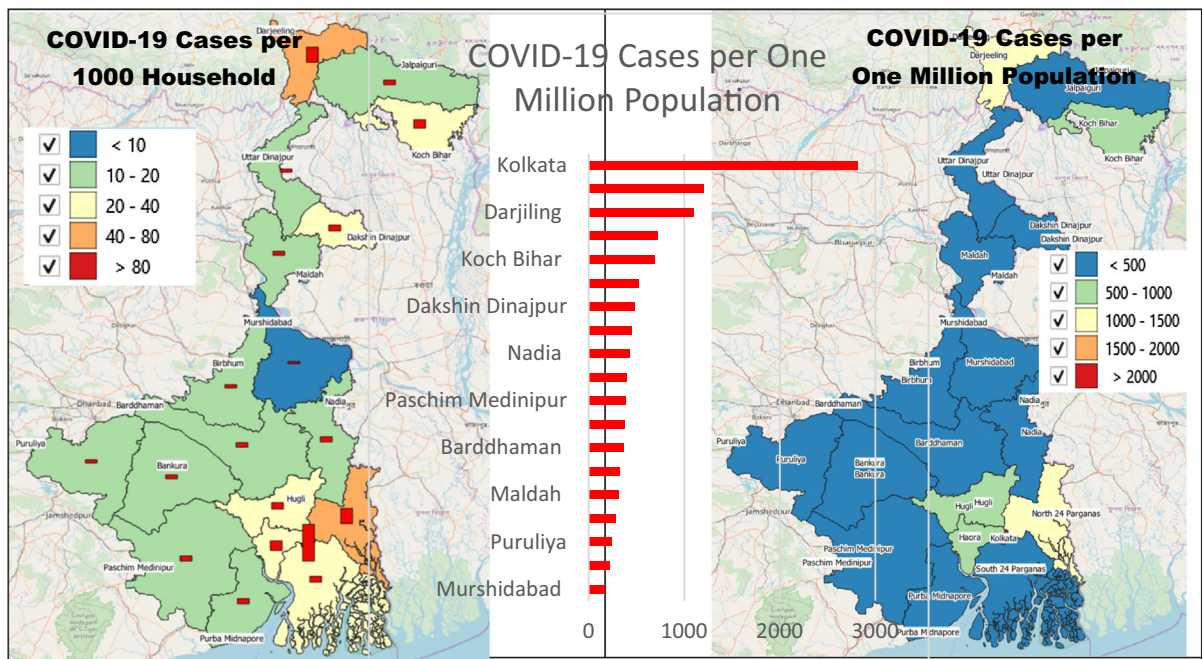


Fig. 5 COVID-19 Cases per 1000 Household and 100,000 Population in West Bengal. Source: Authors' Calculation and Superimposed on Open Street Map (OSM)

Table 5 COVID-19 Cases and Deaths in the districts of West Bengal (as on 15.01.2021)

District	Total COVID-19 cases	COVID-19 cases/million population	COVID-19 cases/1000 ousehold	Total COVID death	Total COVID-19 death/Million pop	% Death to total COVID-19 affected
Bankura	11,622	323	15	91	25	0.783
Barddhaman	28,462	369	16	261	34	0.917
Birbhum	9859	281	12	88	25	0.893
Dakshin Dinajpur	8128	485	21	74	44	0.910
Darjiling	20,324	1100	52	224	121	1.102
Haora	35,222	726	33	1029	212	2.921
Hugli	29,126	528	23	479	87	1.645
Jalpaiguri	14,542	375	17	158	41	1.087
Koch Bihar	19,442	690	29	157	56	0.808
Kolkata	126,421	2811	123	3040	676	2.405
Maldah	12,594	316	15	113	28	0.897
Murshidabad	12,147	171	8	148	21	1.218
Nadia	22,253	431	18	306	59	1.375
North 24 Parganas	120,042	1199	51	2427	242	2.022
Paschim Medinipur	23,094	391	18	329	56	1.425
Purba Medinipur	20,432	401	18	278	55	1.361
Puruliya	7097	242	12	48	16	0.676
South 24 Parganas	36,686	449	21	701	86	1.911
Uttar Dinajpur	6539	217	11	72	24	1.101

Source: Govt. of West Bengal and Author’s Calculation Till:—15.01.2021

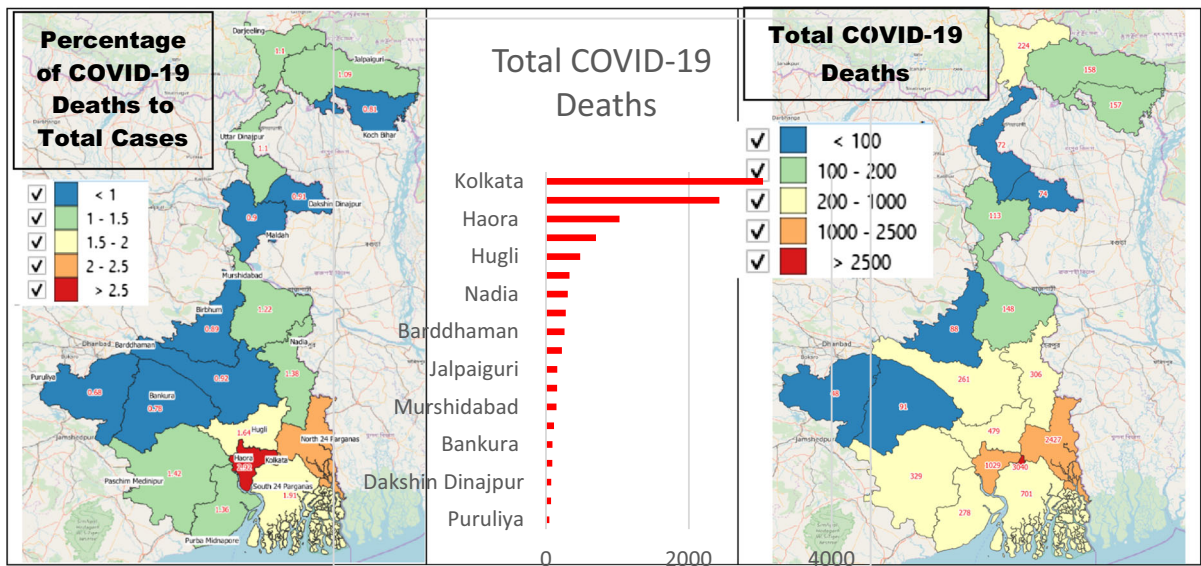


Fig. 6 Distribution of COVID_19 Deaths in West Bengal. Source: Authors’ Calculation and Superimposed on Open Street Map (OSM)

Table 6 Table for Correlation Coefficient among different variables with COVID-19 Cases (15.01.2021)

District	POP_density_sqkm	%_Urban	%_Forest	Non_Wor_pop	%_ConcreteHH	DisfromKOL_km	COVID-19 Cases	
Bankura	522.62	8.33	2.16	59.23	28.38	255	11,622	
Bardhaman	1098.74	39.89	3.17	62.28	40.66	105	28,462	
Birbhum	770.61	12.83	3.51	61.98	23.01	210	9859	
Dakshin Dinajpur	755.42	14.10	0.42	58.06	12.17	450	8128	
Darjiling	586.48	39.42	38.28	62.98	25.16	590	20,324	
Haora	3306.09	63.38	0.00	62.48	50.82	3	35,222	
Hugli	1752.67	38.57	0.17	60.99	48.59	35	29,126	
Jalpaiguri	621.94	27.38	28.75	60.94	8.73	614	14,542	
Koch Bihar	998.69	10.27	1.28	59.99	3.99	710	19,442	
Kolkata	24,306.45	100.00	0.00	60.07	71.06	0	126,421	
Maldah	1068.54	13.58	0.45	61.45	17.20	330	12,594	
Murshidabad	1334.30	19.72	0.14	63.54	30.54	200	12,147	
Nadia	1315.92	27.84	0.31	64.34	36.84	100	22,253	
North 24 Parganas	2444.99	57.27	0.00	64.32	45.16	24	120,042	
Paschim Medinipur	632.79	12.22	18.52	57.57	19.28	100	23,094	
Purba Medinipur	1075.99	11.63	0.23	62.51	20.08	85	20,432	
Puruliya	468.14	12.74	12.00	57.35	22.76	320	7097	
South 24 Parganas	819.47	25.58	44.93	63.68	22.27	5	36,686	
Uttar Dinajpur	957.69	12.05	0.19	64.23	12.56	405	6539	
	POP_density_sqkm	%_Urban	%_Forest	Non_Wor_pop	%_ConcreteHH	DisfromKOL_km	COVID-19 Cases	
POP_density_sqkm	1							
%_Urban	0.794	1						
%_Forest	-0.191	-0.064	1					
Non_Wor_pop	-0.094	0.198	0.031	1				
%_ConcreteHH	0.683	0.864	-0.285	0.185	1			
DisfromKOL_km	-0.320	-0.444	0.215	-0.236	-0.725	1		
COVID-19 Cases	0.736	0.836	-0.118	0.174	0.718	-0.480	1	
	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	28,610.91	21,653.86	1.32	0.21	-17,832.01	75,053.82	-17,832.01	75,053.82
POP_density_sqkm	1.42	1.39	1.02	0.32	-1.56	4.41	-1.56	4.41
%_Urban	1,332.27	504.63	2.64	0.02	249.94	2,414.60	249.94	2,414.60
%_ConcreteHH	-982.93	815.36	-1.21	0.25	-2,731.70	765.85	-2,731.70	765.85
DisfromKOL_km	-53.25	34.41	-1.55	0.14	-127.06	20.55	-127.06	20.55

Source: Authors' Calculation and Census of India, 2011

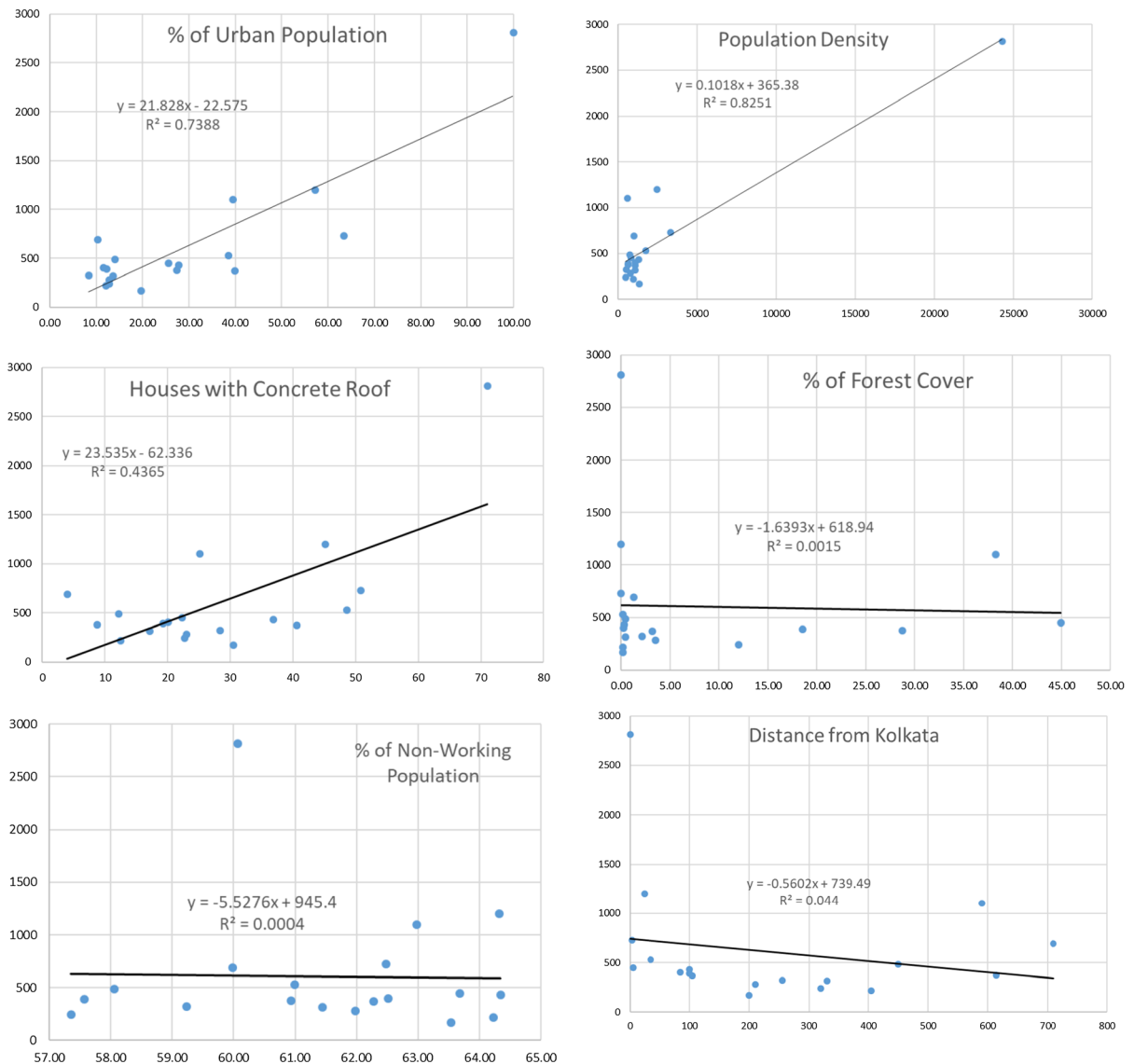


Fig. 7 Dependency of COVID-19 cases with different factors. Source: Authors' Calculation

Correlation coefficient of various factors with COVID-19 cases and deaths has revealed that ‘level of urbanization’, ‘population density’, ‘concrete roof’, and ‘distance from big city (Kolkata)’ are important factors in the nature and extent of spread of COVID-19 cases and related deaths. We could understand that the cities are most vulnerable locations for Corona virus infection. Detailed study is necessary for understanding micro level variations within the city space to

evaluate the role of urban pattern, urban space, and urban morphology on Coronavirus infection.

The preventive measure ‘Lockdown’ or ‘quarantine’ makes every possible economic activity stopped. Therefore, we apprehended that the poor people would be vulnerable to this disease. The most important and surprising result is the good housing condition and COVID-19 cases and deaths are positively related. The main source of urban poor or labour forces are the ‘migratory labours’ from the rural part. The pandemic

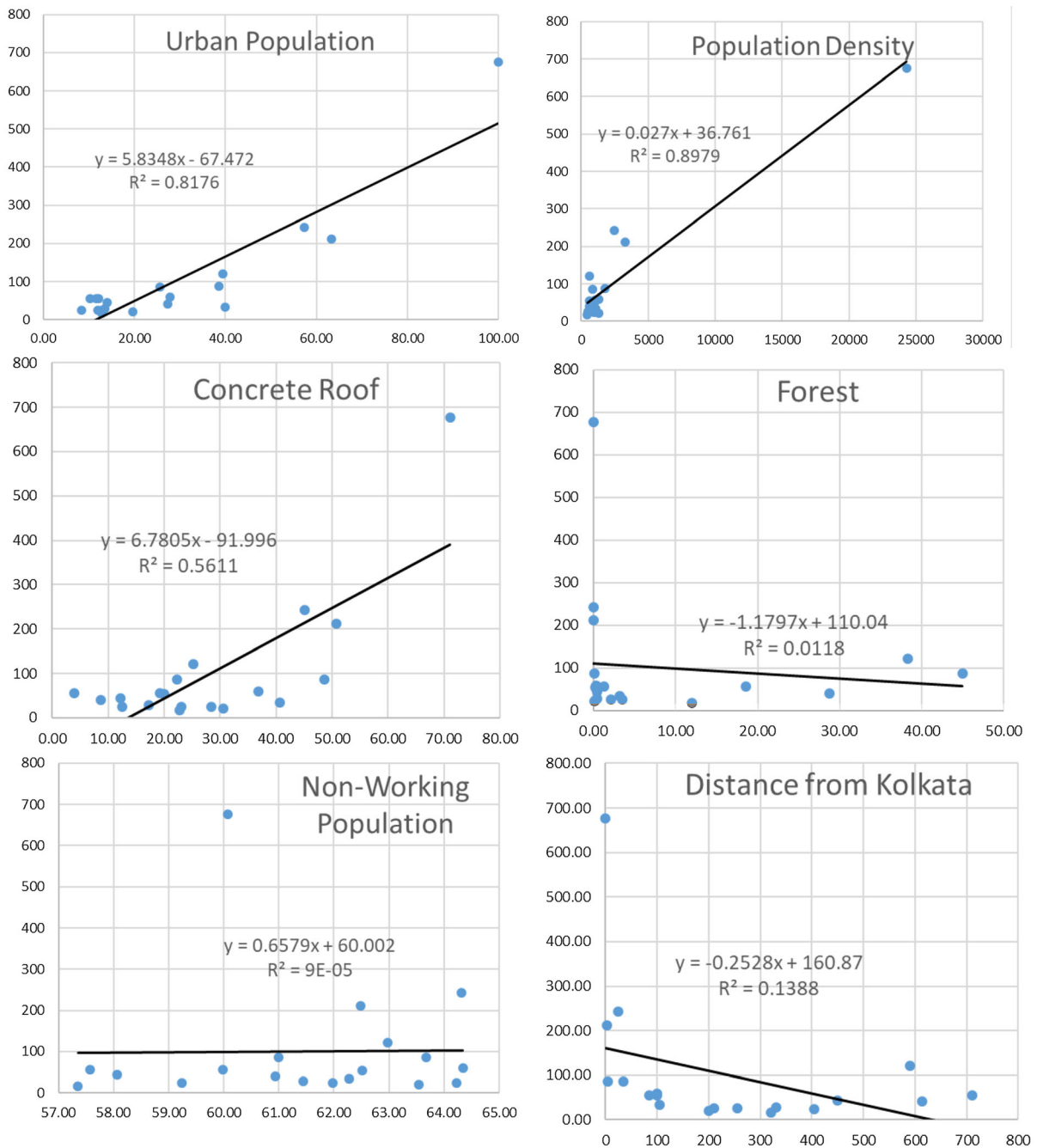


Fig. 8 Dependency of COVID-19 Deaths with different Factors. Source: Authors' Calculation

resulted in a very large-scale counter migration to rural areas from the urban centres. It was thought that the rural areas would be worst hit by the COVID-19 cases.

However, the data does not reveal that. Therefore, the future research question arises here on possible

Table 7 Table for Correlation Coefficient among different variables with COVID-19 Deaths

Districts	COV_population	POP_density_sqkm	%_Urban	%_Forest	Non_Wor_pop	%_ConcreteHH	DisfromKOL_km	COV_D_15012021
Bankura	11,622	523	8.335	2.16	59,234	28.378	255	91
Bardhaman	28,462	1099	39.887	3.17	62,278	40.655	105	261
Birbhum	9859	771	12.833	3.51	61,980	23.008	210	88
Dakshin Dinajpur	8128	755	14.096	0.42	58,063	12.168	450	74
Darjiling	20,324	586	39.417	38.28	62,978	25.157	590	224
Haora	35,222	3306	63.384	0.00	62,478	50.818	3	1029
Hugli	29,126	1753	38.566	0.17	60,993	48.589	35	479
Jalpaiguri	14,542	622	27.379	28.75	60,935	8.728	614	158
Koch Bihar	19,442	999	10.267	1.28	59,988	3.990	710	157
Kolkata	126,421	24,306	100.000	0.00	60,065	71.056	0	3040
Maldah	12,594	1069	13.579	0.45	61,446	17.202	330	113
Murshidabad	12,147	1334	19.717	0.14	63,542	30.542	200	148
Nadia	22,253	1316	27.844	0.31	64,343	36.840	100	306
North 24 Parganas	120,042	2445	57.266	0.00	64,319	45.157	24	2427
Paschim Medinipur	23,094	633	12.221	18.52	57,569	19.285	100	329
Purba Medinipur	20,432	1076	11.631	0.23	62,512	20.085	85	278
Puruliya	7097	468	12.741	12.00	57,352	22.763	320	48
South 24 Parganas	36,686	819	25.579	44.93	63,679	22.270	5	701
Uttar Dinajpur	6539	958	12.046	0.19	64,231	12.556	405	72

	COV_population	POP_density_sqkm	%_Urban	%_Forest	Non_Wor_pop	%_ConcreteHH	DisfromKOL_km	COV_D_31082020
COV_population	1							
POP_density_sqkm	0.74	1						
%_Urban	0.84	0.79	1					
%_Forest	-0.12	-0.19	-0.064	1				
Non_Wor_pop	0.17	-0.09	0.198	0.03	1			
%_ConcreteHH	0.72	0.68	0.864	-0.29	0.18	1		
DisfromKOL_km	-0.48	-0.32	-0.444	0.21	-0.24	-0.72	1	
COV_D_31082020	0.99	0.80	0.875	-0.14	0.15	0.75	-0.50	1

	Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-0.62	128.54	-0.00	1.00	-278.31	277.07	-278.31	277.07
COV_population	0.02	0.00	12.44	0.00	0.02	0.02	0.02	0.02

Table 7 continued

Coefficients	Standard error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
POP_density_sqkm	0.01	2.50	0.03	0.00	0.04	0.00	0.04
%_Urban	3.46	1.91	0.08	-0.86	14.07	-0.86	14.07
%_ConcreteHH	4.79	-1.30	0.22	-16.60	4.12	-16.60	4.12
DisfromKOL_km	0.21	-1.70	0.11	-0.81	0.10	-0.81	0.10

Source: Authors' Calculation

sources of immunity from Coronavirus infection to the poor and rural people.

Although the percentage of forest cover has not played any statistically significant role, we should not ignore the basic science that trees are the major absorbent of air pollutants and make air fresh. Human interference in the forest area may be responsible for the emergence of such kinds of diseases. Therefore, proper care and research should be conducted on the role of fresh air and forest to COVID-19 cases.

Finally, the paper would like to conclude that there is sufficient scope to have faith in humanity for survival from this virus. In addition, as under stressful situations, the immune system of human beings is compromised and they become more prone to infections. *Yoga* based lifestyle (the concept derived from Indian ancient scriptures) can reduce psychological stress, which may have an important role to strengthen the immune system that can prevent associated complications.

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Compliance with ethical standards

Ethical Approval The authors of the paper “Geographical Appraisal of COVID-19 in West Bengal, India” declare that there is no conflict of interest with any individual, institutes and agencies.

Human or animals participants This article does not contain studies with human participants or animals by any of the authors.

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