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Assessing the Spatial Pattern of Health Inequalities and Driving Blueprint during the COVID-19 Pandemic in Kolkata Municipal Corporation, West Bengal in India

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Abstract

This present study assessed the health inequalities and evaluated the relationship between urban development and pandemic vulnerability through the Composite Ibrahim Index (CIb) and framed the blueprint of multiple socio-economic drivers in the Kolkata Municipal Corporation (KMC) of India. The COVID-19 pandemic exacerbated pre-existing health and socio-economic inequalities across urban India, and Kolkata, being a leading megacity of India, conceptualizes its health as an emerging and critical hotspot area of investigation. The primary objective is to analyze spatial patterns of COVID-19 vulnerability across 141 wards of KMC and identify key determinants influencing household-level health inequality. Secondary data were sourced from the Census of India, the Bureau of Applied Economics and Statistics, and KMC records, and analytical techniques included time-series analysis (3-month moving average), Lorenz Curve, and Gini coefficient (0.75 indicating high inequality), Composite Z-scores, and multiple linear regression with marginal effect analysis. Results indicate that highly populated and socio-economically weaker wards, such as 31, 33, 66, and 70, reported higher active cases, while development status and COVID vulnerability showed a significant negative relationship ($R^2 = 0.05$, $p < 0.001$, N=141). Drivers such as open latrines, dilapidated housing, and households with no sanitation or drainage significantly reduced CIb values, while overcrowding increased vulnerability. The study concludes that socio-economically underdeveloped wards are disproportionately affected, and the null hypothesis of no relationship is rejected. As a policy measure, sustained vaccination, hygiene awareness, targeted urban health interventions, and strengthening of the National Urban Health Mission are essential to mitigate inequality and ensure resilient urban health systems. A data-driven, integrative approach is necessary for future pandemic preparedness in the context of rapid urbanization and sustainable management of Kolkata.

Keywords: Health inequality; Pandemic; COVID-19; Ibrahim index; Regression; Drivers; Kolkata

1 Introduction

COVID-19 (Coronavirus Disease 2019) pandemic hit the health and socio-economic conditions almost globally, devastatingly. Poverty and inclusive development were examined concerning COVID-19 by Gupta et al. in 2021 [1]. The pandemic, in Pawar's estimation (2020), has had a profound effect on people's mental health and the general well-being of nations [2]. According to Boza-Kiss, Pachauri, and Zimm's assessment in 2021 [3], the epidemic had caused poverty and inequality among the populace. According to Shadmi et al. (2020) [4], further epidemics that might raise socio-economic and health vulnerability are not being adequately controlled. In South Asian Countries, the duration and extent of the health issue will determine how much of an impact there will be on the economy [5]. Various studies have looked at COVID-19 from a global viewpoint as well as its effects on socio-economic inequality and health. During the COVID-19 pandemic, Capolongo et al. (2020) [6] conducted a study on urban health solutions and difficulties. Singu et al. (2020) [7] centered their attention on the COVID-19 pandemic's effects on social variables on health in the United States. Meurisse et al. (2022) [8] conducted a municipality-level investigation of the connection between regional inequality and COVID-19 outbreaks in Belgium. During the COVID-19 pandemic in China, Nie et al. (2021) [9] discovered income-based health disparities among the adult population. During the epidemic in China, He, Zhang, and Qian (2022) [10] also noticed socio-economic inequalities among local migrants. The circumstances and difficulties of medical rehabilitation during the pandemic in Indonesia were examined by Nugraha et al. (2020) [11]. The socio-economic impacts were studied by Billah (2021) [12], who concentrated on Bangladesh, and Kumar & Pinky [13]. The first COVID-19 case was reported in India on January 30, 2020. By May 19, it had reached 100,000 cases, and by June 3, it had grown to over 200,000 cases with 5,800 fatalities [14]. According to Aneja and Ahuja's postulation from 2021 [15], domestic violence and mental illness would also pose a significant issue in India during the pandemic, with the current poverty and inequality having a significant detrimental influence on migrants, casual, and informal workers. Dey et al. (2013) [16] have previously noted a deficiency in the Indian health infrastructure. Due to a lack of suitable infrastructure and medical professionals concerned about the huge number of possible patients needing critical care, the situation during the COVID-19 pandemic steadily got worse [17]. Compared to other Indian states, Delhi, Goa, Kerala, and Puducherry had a disproportionately greater number of COVID-19 instances [18]. Population density, the accessibility of necessities like drinking water and sanitary facilities, and the elderly population were some of the factors highlighted by Pandey et al. (2021) [19] as contributing to the COVID-19 pandemic. The first COVID-19 case was discovered in Kolkata on March 17, 2020, according to the West Bengal Health Portal report of 2022 [20]. Due to the global pandemic, the number of active cases grew daily, rising from 908 on May 4 to 3141 on June 1, 5959 on July 1, and 20631 on August 1 in the year 2020 [20]. According to Hati and Majumder (2011) [21], there are 9 Medical College Hospitals, 16 District Hospitals, 45 Sub-divisional Hospitals, 346 Community Health Centers, 922 Primary Health Centres, and 10356 Sub-Centres spread throughout West Bengal. In their study, Hati & Majumder (2011) [21] also noted that West Bengal's general state of health care was underdeveloped. The most severe COVID-19 case was observed in Kolkata, West Bengal, according to the study by Biswas et al. (2022) [22]. Banerjee (2013) [23] argued that while overall healthcare facilities are better in the private hospitals of the Kolkata Municipal Corporation, the government hospitals were mandated to bear the medical costs for the poor and middle-class people. The healthcare infrastructure and medical facilities in the Kolkata Municipal Corporation areas were inequitable and disparate [24,25]. West Bengal was badly affected by COVID-19 in several industries, including health and pharmaceuticals. Mondal et al. (2021) [26] reported that, based on West Bengal's budget allocation, the health and family welfare sector changed by 6.8% between 2019-2020 and 2020-2021. Due to a lack of social isolation and public awareness, pandemic susceptibility, inadequate health and hygienic conditions, and other socio-economic and household health infrastructure issues in the Kolkata Municipal Corporation area, the overall risks and vulnerability of the COVID-19 pandemic were increased [27]. Based on the context, the primary objectives of the study are

1. To state the situation of COVID-19 in the Kolkata Metropolitan Area.
2. COVID-19's socio-economic and health disparities' contributing factors.
3. To identify COVID-19 susceptibility zones within the study area.
4. To ascertain how socio-economic development and COVID-19 susceptibility are related.

2 Materials and Methods

2.1 Study area

The study area for the present study is the Kolkata Municipal Corporation (KMC), the capital of the Indian state of West Bengal. Early in March 2020, COVID-19 struck, and the lockdown period began on March 17 [20]. In West Bengal, the KMC is the only congested megacity with the biggest population (4,496,694) [28]. According to the 2011 Census of India [28], KMC has 141 wards (presently 143). The city has excellent connections to other West Bengal districts and other Indian states. Kolkata often receives foreign visitors for a variety of reasons. Figure 1 shows the location map of the study area.

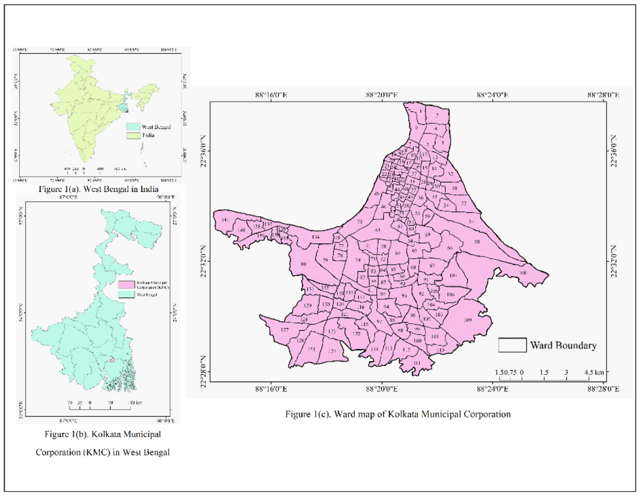

Fig. 1. (a,b,c). Location Map of the Study Area

2.2 Sources of data

The study has mostly relied on GIS tools for secondary data. Data have been gathered from the Kolkata Municipal Corporation, the Bureau of Applied Economics and Statistics, and the online Census of India database.

2.3 Selection of the indicators

The primary criteria of the household inequality drivers of COVID-19 vulnerability in KMC have been narrowed down to a total of 16 indicators. Table 1 displays the selected indicators.

2.4 Methods and techniques

2.4.1 Time-series analysis and measures of inequality

To show the temporal changes in COVID-19 cases and additional deaths, active cases, and discharge of patients, a 3-month moving average of time series analysis has been used in the present study. A moving average of order m can be written as

$$\widehat{T}_t = \frac{1}{m}\sum_{j=-k}^{k} y_{t+j} \tag{1}$$

where

m=2k+1. In other words, the time series values within *k* periods of *t* are averaged to get an estimate of the trend cycle at time *t*.

The Gini Coefficient[29,30] formula is

$$Gini\ Coefficient = \frac{A}{A+B} \tag{2}$$

where

A is the area above the Lorenz Curve, and B is the area below.

2.4.2 Formulation of composite indices

The Composite Ibrahim index (CIb) and mean composite standardized scores (Mean Composite Z-scores) have been computed to assess ward-wise socio-economic development, household conditions, and assets, as well as the composition of the selected household inequality drivers of COVID-19, respectively, in KMC. The formulas for CIb and the mean composite Z-scores are listed below.

The formula of the Ibrahim Index[31,32] is as follows.

$$Ibrahim\ Index\ (Ib) = \frac{X_t \sim Min\,(X)}{Max\ (X) - Min\ (X)} \times 100 \tag{3}$$

where

X_t = Socio-economic development, household conditions, and assets in the wards of KMC in the year t, and Min (X) and Max (X) = The minimum and maximum values for the indicator of socio-economic development, household conditions, and assets throughout the entire period of all the wards in KMC.

For calculating the Composite Ibrahim Index (CI_b), the following formula has been used.

$$CIb = \frac{(I_bA + I_bB + I_bC + \cdots + I_bN)}{16} \tag{4}$$

where

CI_b is the Composite Ibrahim index

I_b is the Ibrahim index of the concerned indicators A,B,…,N

$$Standard\ Score = Z = \frac{x-\mu}{\sigma} \tag{5}$$

where

Z = Standard Score

x= Observed Value

μ = Mean

σ = Standard Deviation

$$\begin{matrix} Mean\ Composite \\ Z-Score \end{matrix} = \frac{\begin{matrix} Summation\ of\ the \\ Z-Scores\ of \\ selected\ variables \end{matrix}}{\begin{matrix} Total\ Number \\ of\ Variables \end{matrix}} \tag{6}$$

2.4.3 Multiple linear regression and marginal effect analysis

Multiple linear regression analysis and the marginal effect (regression coefficients) have been calculated to identify the relationship between the Composite Ibrahim index and its predictors of COVID vulnerability. The formula of the multiple linear regression model and marginal effect analysis are as follows. The formula of the 'Multivariate Regression' model[33] is

$$Y = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n + e_t \tag{7}$$

where

Y is the dependent variable (here, CI_b)

X_i *(i=1,…,n)* are the independent variables

β_1 is a parameter

e_t is error

The formula of the marginal effect (regression coefficients) is

$$Marginal\ Effect\ of\ Xi = \frac{dY}{dX_i} = \beta_i \tag{8}$$

where

Xi = The i-th independent variable (i=1,…,n)

$\frac{dY}{dX_i}$ = Marginal effect of Xi on Y

β_i = Regression coefficient (slope) of Xi

The root mean square error[34] approach has been used to evaluate the model validation by evaluating the error in forecasting the data. The RMSE equation is

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_t - y_i)^2}{n}} \tag{9}$$

where

$\hat{y}_1, \hat{y}_2, \ldots, \hat{y}_n$ are predicted values 207

$y_1, y_2, \ldots, y_n$ are observed values 208

n is the number of observations

3 Results and Discussion

3.1 An outline of the COVID-19 situation in the Kolkata Municipal Corporation area

From May 6 to January 1, 2021, the COVID-19 situation progressively worsened. Up until April 1st, 2021, the situation remained largely steady. Before June 1st, 2021, the situation was quickly becoming worse. The situation then gradually became worse up until January 1, 2022, then got worse very quickly until February 1, 2022, after which it remained mostly stagnant until March 6, 2022. Here, the Government-level datasets stand for the total number of COVID-19 patients, discharges, active cases, and fatalities in KMC from May 4, 2020, to March 6, 2022, as well as beds available in Government Hospitals (in 2022) and as of 11.07.2020, respectively. Early in May, there were 683 total cases of COVID-19, 123 total discharges, 35 total fatalities, and 473 total active cases (4th May 2020). The number of COVID-19 cases was 123887 on January 1, 2021, 118310 on January 1, 2022, 2962 on January 1, 2022, and 7957 on January 1, 2022, respectively. The number of discharges was 329283, the number of fatalities was 5323, and 2613 on January 1, 2022. The COVID-19 growth rate was modest during the first and second unlock phases (June and July 2020), but it later picked up throughout the unlock periods from August to November 2020. Based on the available data, wards 31, 33, 66, 70, 71, 73, and 74 had the highest concentration of COVID-19 active patients. In KMC, most of these wards have a high population density. Government-level data also informs the deaths due to COVID-19, the concentration of the COVID-19 Contaminant Zone, and the point density distribution of the COVID-19 Contaminant Zone in KMC. Figure 2 **(a-d)** depict, respectively, the 3-month moving averages, rising trends, and lowering trends of the total number of COVID-19 active cases, discharges, and fatalities in the KMC.

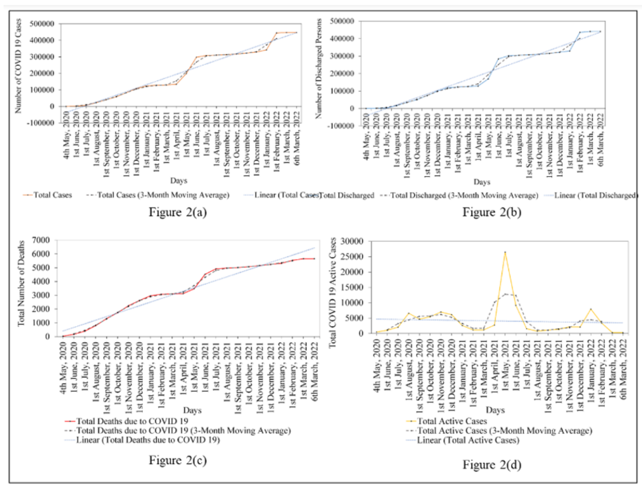

Fig. 2. (a). 3-Month Status of Total COVID-19 Cases in KMC (May 2020 to March 2022); (b). 3-Month Status of Discharged Persons of COVID-19 Cases in KMC (May 2020 to March 2022); (c). 3-Month Status of Death of COVID-19 in KMC (May 2020 to March 2022); (d). 3-Month Status of Active COVID-19 Cases in KMC (May 2020 to March 2022)

3.2 Health status and infrastructural inequality during COVID-19 in KMC

During COVID-19, health status and infrastructural inequality have been arising in KMC. The active COVID cases were higher in the corporation wards 31, 33, 66, 70, 71, 73, and 73; moderate in 7-10, 13, 16-29, 32, 34, 40, 42-44, 47-51, 53, 54, 60, 62, 64, 65, 68, 72, 76-78, 81, 82, 84-86 and 88; and lower in the rest of the municipal wards. The household and population concentration is also high, where the COVID-19 cases were highly active in the municipal wards of KMC. The Lorenz Curve of the COVID-19 instances in KMC is shown in Figure 3 as a measure of household-wise inequality. When compared to the line of inequality when the Gini Coefficient is 0.75, the real curve is well behind that line, indicating that COVID-19 instances are highly unequally distributed among

KMC families. Table 2 shows the descriptive statistics of the selected indicators for calculating the Ibrahim index (Ib), and in this instance, Figure 4 displays the Composite Ibrahim index of socio-economic development, household circumstances, and assets in the wards of KMC. The map (along with Table 3) shows a very high developmental status (value of CIb is > 52.14) in the corporation wards 10, 16, 41-43, 4, 63, 70, and 73; high (47.73-52.14) in 11, 22, 23, 28, 30, 39, 44, 47, 49, 50, 53, 54, 60-62, 64, 65, 68, 69, 71, 72, 74, 77, 85-87, 90 and 138-140; moderate (43.31-47.72) in 1-9, 17, 19-21, 24-27, 29, 31-35, 37, 38, 40, 48, 51, 52, 56, 59, 66, 67, 76, 78, 79, 81, 83, 84, 89, 91-94, 97-99, 103-107, 112, 119-121, 123, 128, 130, 131 and 133-137; low (38.89-43.30) in 12-15, 18, 36, 45, 58, 75, 82, 88, 95, 96, 100-102, 109-111, 113, 115-118, 122, 124, 126, 127, 129 and 132 and very low (CIb is < 38.89) in the municipal wards 57, 80, 108, 114, 125 and 141. The COVID-19 cases were variedly distributed compared to the developmental status of the corporation wards in KMC.

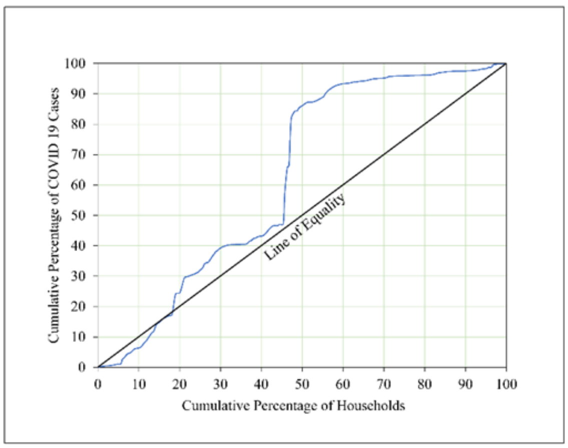

Fig. 3. Household-wise Inequality Measure (Lorenz Curve) of COVID-19 Cases in KMC

3.3 Drivers and spatial pattern of household-oriented socio-economic and health vulnerability of COVID-19 in KMC

The following indicators have been used (Table 1) to calculate the Composite Z-Score map of COVID-19 vulnerability in the wards of KMC. Analytical procedures examine these variables, which are typically thought of as COVID-19's socio-economic and health vulnerability drivers.

Table 1 displays the mean and standard deviation of the key household inequality drivers of COVID-19 vulnerability in KMC. The value of SD is highest for families with open drainage and lowest for households with a married pair (five plus). Figure 5 displays the mean composite standardized scores (Z-Scores) of the household-level vulnerability of COVID-19 in the KMC. The vulnerability is very high in the

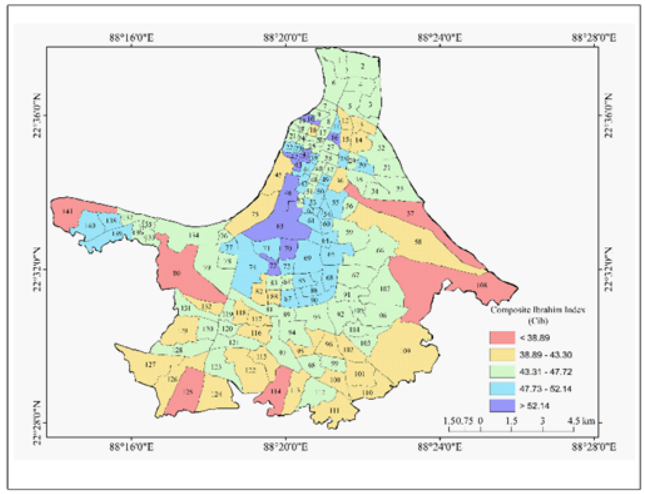

Fig. 4. Composite Ibrahim Index of Socio-Economic Development, Household Conditions, and Assets in the Wards of KMC

Table 1. Descriptive Statistics of the Selected Criteria of Significant Household Inequality Drivers of COVID-19 Vulnerability in KMC

	Descriptive Statistics	
Criteria (Percentage to Total Household) (Census of India, 2011) [28]	**Mean**	**Std. Deviation**
Household Dilapidated	2.71	1.76
Households with No Exclusive Rooms	4.53	2.89
Household Size (Nine Plus)	5.08	3.21
Household with Married Couple (Five Plus)	0.14	0.20
Households with Tap Water (Untreated)	2.73	2.96
Household with Uncovered Well	0.16	0.44
Households with No Lightning	0.20	0.27
Households with Night Soil Disposed	0.13	0.46
Household with Open Latrine	0.69	1.46
Households with No Latrine	5.08	5.55
Households with Open Drainage	11.79	14.83
Households with No Drainage	3.82	6.07
Households with No Cooking	0.84	0.88
Households with None of the Significant Assets	3.57	2.96
Semi-Permanent Households	4.79	3.72
Total Temporary Households	0.86	1.82
Valid N (listwise): 141		
(Source: Authors' Calculation)		

Table 2. Descriptive Statistics of the Selected Indicators for Calculating the Ibrahim Index (Ib)

Descriptive Statistics			
Indicators (Census of India, 2011) [28]	**Mean**	**Std. Deviation**	**Variance**
Male percent_HH	239.4728	51.30707	2632.416
Female_percent_HH	209.8663	25.50313	650.41
Total_Child_percent_HH	32.686	13.12412	172.242
SC_percent_HH	19.5356	19.37046	375.215
ST_percent_HH	0.9132	1.11356	1.24
Total_Literate_percent_HH	358.0762	36.83522	1356.833
Workers_Male_percent_HH	182.5016	35.97942	1294.519
Workers_Female_percent_HH	145.631	37.77931	1427.276
Workers_Main_percent_HH	36.8706	8.85264	78.369
Workers_Marginal_percent_HH	160.9444	31.31989	980.935
HH_Livable	21.557	10.8227	117.13
HH_with_exclusive_room	97.2794	1.7551	3.08
Tapwater_facilities	95.4759	2.89094	8.358
Tank	90.6262	12.89297	166.229
Electricity	0.3631	0.68613	0.471
Latrine_facility_with_premices	96.2887	3.13216	9.81
Public_Latrine	94.9156	5.55492	30.857
Bathroom	4.3965	4.82229	23.254
Drainage_facilities	82.6865	11.54131	133.202
LPG	96.1837	6.06511	36.786
Households_with_assets	64.6092	17.89572	320.257
Households_Permanent	9.7688	7.01601	49.224
(Source: Authors' Calculation)			

Table 3. Category-wise Wards of Composite Ib

Categories	**Ward Number**
Very high (> 52.14)	10, 16, 41-43, 4, 63, 70, 73
High (47.73 – 52.14)	11, 22, 23, 28, 30, 39, 44, 47, 49, 50, 53, 54, 60-62, 64, 65, 68, 69, 71, 72, 74, 77, 85-87, 90, 38-140
Moderate (43.31 – 47.72)	1-9, 17, 19-21, 24-27, 29, 31-35, 37, 38, 40, 48, 51, 52, 56, 59, 66, 67, 76, 78, 79, 81, 83, 84, 89, 91-94, 97-99, 103-107, 112, 119-121, 123, 128, 130, 131, 133-137
Low (38.89 – 43.30)	12-15, 18, 36, 45, 58, 75, 82, 88, 95, 96, 100-102, 109-111, 113, 115-118, 122, 124, 126, 127, 129, 132
Very low (< 38.89)	57, 80, 108, 114, 125, 141
(Source: Authors' Calculation)	

municipal wards 36, 80, and 108; high in 6, 12, 29, 32, 37, 43, 45, 57, 58, 79, 109, 114 and 138-141; moderate in 7, 13, 15, 20, 21, 22, 28, 39, 42, 44, 46, 52, 59, 61, 63, 65, 75, 82, 90, 107, 110, 113, 122, 126, 127, 133-135 and 137; low in 1, 3, 4, 11, 14, 18, 23-26, 30, 31, 33, 35, 38, 41, 47-49, 50, 53-56, 60, 62, 64, 66, 67, 70-73, 77, 78, 81, 83, 85, 88, 91-94, 100-102, 105, 106, 111, 115-117, 123-125, 128, 129, and 136 and very low in the municipal wards 2, 5, 8-10, 16, 17, 19, 27, 34, 40, 51, 68, 69, 74, 76, 84, 86, 87, 89, 95-99, 103, 104, 112, 118-121, 130 and 131 (Table 4). The COVID-19 vulnerability zones are also variedly distributed compared to the developmental zones among the corporation wards of Kolkata.

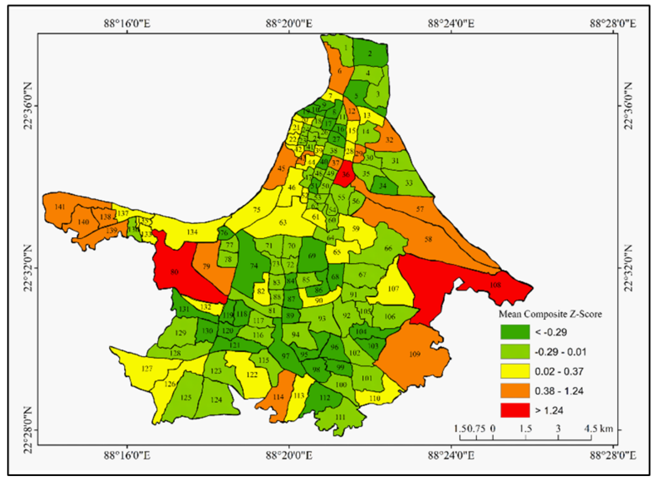

Fig. 5. Mean Composite Standardized Scores (Z-Scores) of the Household-Level Vulnerability of COVID-19 in the Wards of KMC

Table 4. Category-wise Wards of Composite Z-Score

Categories	**Ward Number**
Very high (> 1.24)	36, 80, 108
High (0.38 – 1.24)	6, 12, 29, 32, 37, 43, 45, 57, 58, 79, 109, 114, 138-141
Moderate (0.02 – 0.37)	7, 13, 15, 20, 21, 22, 28, 39, 42, 44, 46, 52, 59, 61, 63, 65, 75, 82, 90, 107, 110, 113, 122, 126, 127, 133-135, 137
Low (-0.29 – 0.01)	1, 3, 4, 11, 14, 18, 23-26, 30, 31, 33, 35, 38, 41, 47-49, 50, 53-56, 60, 62, 64, 66, 67, 70-73, 77, 78, 81, 83, 85, 88, 91-94, 100-102, 105, 106, 111, 115-117, 123-125, 128, 129, 136
Very low (< -0.29)	2, 5, 8-10, 16, 17, 19, 27, 34, 40, 51, 68, 69, 74, 76, 84, 86, 87, 89, 95-99, 103, 104, 112, 118-121, 130, 131
(Source: Authors' Calculation)	

3.4 Relationship between socio-economic development and COVID-19 vulnerability

In the post-estimation analysis of the multiple linear regression model, the selected components or drivers of COVID-19 socio-economic and health vulnerability have been examined using the coefficients of marginal effect analysis (Table 5). Here, the value of the coefficient of determination is 0.694, which indicates that the selected dependent variable changes at 69.4 percent with a 1 percent chance of the predictors. The independent variable significantly predicted the dependent variable (CIb, F< 0.001). The Durbin-Watson value is 1.540 (ranges between 1.50 to 2.50) signifies relatively normal in the case of autocorrelation status. The marginal effect analysis model is justified using the value of root mean square error (Root MSE= 2.3412). It means that the square root of the squared differences between the predictions and observed values is 2.3412. It is a relatively lower value that indicates a better fit for this model. Figure 6 **(a -d)** represents the relationship between the dependent variable and regression standardized predicted values (ZPR), and the relationship between the dependent variable and regression standardized residuals (ZRE), as well as the plots the ZPR and ZRE, respectively.

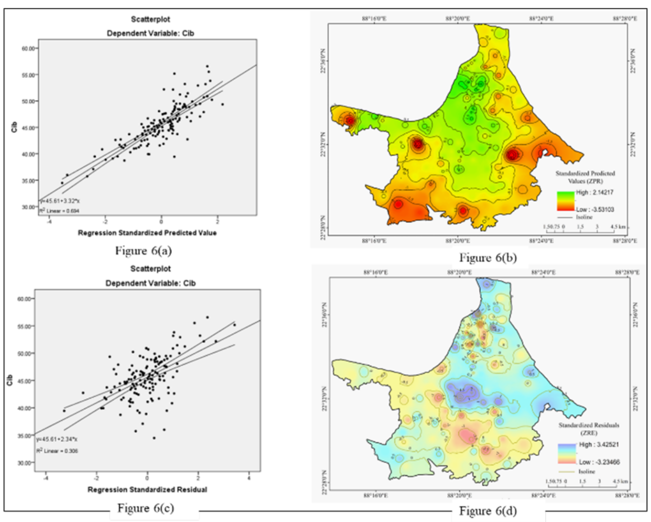

Fig. 6. (a). Relationship between CIb and Standardized Predicted Values; (b). Plots of Standardized Predicted Values in KMC; (c). Relationship between CIb and Regression Standardized Residuals; (d). Plots of Regression Standardized Residuals in KMC

Figure 7**(a-c)** depict the isoline zones of the mean composite standardized scores (Z-Scores) of the household-level vulnerability of COVID-19, plots of the similar isolines on the Composite Ibrahim index zones, and the relationship between the Composite Ibrahim index (CIb) and mean composite Z-Scores. The two factors have a low negative relationship (R-squared = 0.05), indicating that COVID vulnerability reduces when KMC's developmental level rises and vice versa. But health inequality must be reduced to decrease susceptibility.

The results show that the COVID-19 epidemic started on May 6th, 2020, and spread until January 1st, 2021. Before April 1, 2021, the situation was steady; however, from June 1 to March 6, the situation deteriorated, with more cases, discharges, and fatalities occurring in areas with a high population density. Three-month moving averages reveal growing trends in cases, discharges, and deaths, while revealing diminishing trends in active cases. Inequitable health and infrastructural conditions result from the COVID-19 epidemic in KMC. Active COVID instances are more prevalent in corporate wards, more moderate in other wards, and less prevalent in municipal wards.

Due to the large family and population concentrations in these wards, there are uneven health and infrastructural conditions. With a Gini index of 0.75, the Lorenz Curve reveals significant inequality among COVID-19 families. The Composite Ibrahim index of socio-economic development, household conditions, and assets in KMC wards indicates that corporate wards have a very high developmental status, while other wards have a moderate developmental level, and municipal wards have a very low developmental status. Since it is based on household-by-household data, the index offers a reliable indicator of inequality in COVID-19 contexts. To determine how vulnerable families are to COVID-19 in Kolkata Municipal Corporation, the study looks at the isoline zones of the Composite Ibrahim index and the mean composite standardized scores (Z-Scores). The results show that a range of factors, including socio-economic and health vulnerability, as well as the availability of resources and services, affect how vulnerable families in Kolkata are. The study shows a significant unfavourable relationship between socio-economic development and COVID-19 household-level vulnerability. Homes with more than nine occupants, married couples, untreated tap water, exposed wells, no lighting, midnight soil disposal, open latrines, open drains, no drainage, no cooking, semi-permanent households, and temporary households were more susceptible to COVID-19. The major negative driver, albeit it was not substantial, was households without lightning. To say the least, the COVID-19 pandemic has significantly impacted the susceptibility of Kolkata Municipal Corporation households.

The following factors are taken into consideration when determining a house's condition: age, size, water type, fixtures, lighting, night soil, open latrine, open drainage, cooking, and important assets.

The criteria's average value is 141. The proportion of families without private bedrooms, covered wells, lighting, night soil, open latrines, open drainage, cooking, and any other notable assets is also considered. The study provides descriptive information on household income, including

Table 5. Marginal Effect Analysis (Regression Coefficients) of the Selected Variables

Marginal Effects (Regression Coefficients)						
Predators	**dy/dx**	**Delta-method Std. Err.**	**t**	**P>|t|**	**[95% Conf.**	**Interval]**
Constant	46.21	0.63	73.46	0.00	44.97	47.46
Household Dilapidated	-0.520	0.158	-3.300	0.001**	-0.832	-0.208
Households with No Exclusive Rooms	-0.104	0.094	-1.110	0.267	-0.290	0.081
Household Size (Nine Plus)	0.479	0.122	3.920	0.000*	0.238	0.721
Household with Married Couple (Five Plus)	4.118	1.705	2.420	0.017**	0.744	7.493
Households with Tap Water (Untreated)	-0.136	0.074	-1.840	0.068***	-0.283	0.010
Household with Uncovered Well	-0.149	0.703	-0.210	0.832	-1.542	1.243
Households with No Lightning	-0.726	0.816	-0.890	0.375	-2.341	0.888
Households with Night Soil Disposed	0.036	0.554	0.060	0.949	-1.061	1.133
Household with Open Latrine	-0.525	0.266	-1.970	0.051***	-1.051	0.001
Households with No Latrine	0.121	0.055	2.210	0.029**	0.013	0.230
Households with Open Drainage	-0.055	0.019	-2.940	0.004**	-0.091	-0.018
Households with No Drainage	-0.208	0.051	-4.110	0.000*	-0.309	-0.108
Households with No Cooking	0.769	0.307	2.510	0.014**	0.162	1.376
Households with None of the Significant assets	-0.344	0.128	-2.700	0.008**	-0.597	-0.092
Semi- Permanent Households	0.061	0.074	0.820	0.414	-0.086	0.207
Total Temporary Households	0.334	0.251	1.330	0.186	-0.163	0.830

[a] Dependent Variable: Composite Ibrahim Index (CIb) Number of obs = 141
R Square: 0.694
Adjusted R Square: 0.655
Std. Error of the Estimate: 2.34197
Root MSE= 2.3412
Durbin-Watson: 1.540
F< 0.001
*Significant at 0.001 significance level
**Significant at 0.05 significance level
***Significant at 0.1 significance level

(Source: Authors' Calculation)

gender distributions (male and female), total family and child percentages, SC and ST distributions, and overall literacy distributions. Additionally included in the article are worker percentages, living conditions, restrooms, electricity, latrines, public restrooms, bathrooms, drainage facilities, LPG, and permanent homes with assets. The data, which has a mean value of 239.4728 and a standard deviation of -0.257, is based on 127 dwellings in the sample. The classification of risk factors for various illnesses is explained in the book. The highest danger levels are seen in the risk variables with high-risk scores (> 52.14), moderate risk factors (43.31-47.72), low-risk factors (38.89-43.30), and very low-risk factors (38.89). Four categories—extremely low risk, moderate risk, high risk, and low risk—are used to categorize the risk variables. The risk factors for many diseases and the risk factors associated with those diseases are thoroughly examined in this article.

The essay suggests a system for classifying the risk of major diseases based on the severity of the sickness. The highest risk zones are 36, 80, and 108, whereas the lowest risk zones are 6-12, 29, 32, 37, 43, 45, 57, 58, 79, 109, 114, 138-141, 138-141, and 137-137. The categorization method aids in pinpointing the patient's most at-risk locations. The research investigates the marginal effects on household demographics. The findings indicate that households with dilapidated homes are less likely to have exclusive rooms, larger household sizes (Nine plus), married couples with more than five children, untreated tap water, uncovered wells, no lighting, night soil disposal, open latrines, open drainage, no cooking, none of the significant assets, semi-permanent households, and total temporary households. The dependent variable, the composite Ibrahim Index (CIb), has significant levels of 0.001, 0.05, and 0.1. The findings

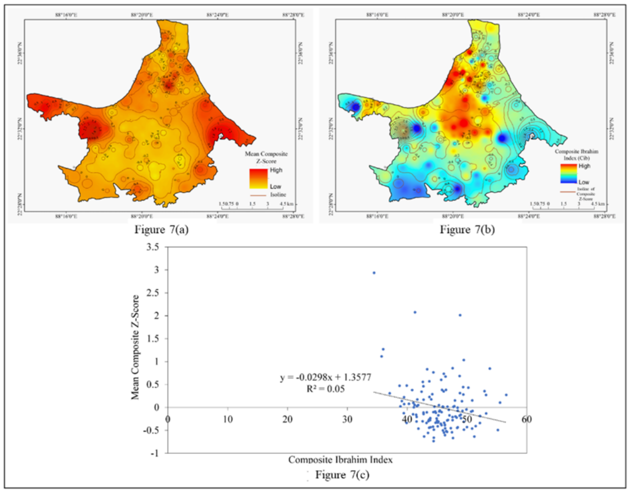

Fig. 7. (a). Isoline Zones of the Mean Composite Standardized Scores (Z-Scores) of the Household-Level Vulnerability of COVID-19 in the Wards of KMC; (b). Plots of the Similar Isolines on the Composite Ibrahim Index Zones in KMC; (c) Relationship between the Composite Ibrahim Index (CIb) and Mean Composite Z-Scores

imply that variables like family size, the number of rooms, and the availability of major assets have an impact on how households are distributed. The assessment of a house's state in the text considers the structure's age, size, water source, fittings, lighting, night soil, open latrine, open drainage, cooking, and major assets. It provides descriptive data on household income, living standards, restrooms, electricity, latrines, public toilets, drains, LPG, households with assets, and permanent households. With a mean of 239.4728 and a standard deviation of -0.257, the data is based on a sample of 127 homes. In the study, risk factors for numerous illnesses are also categorized into four categories: high, moderate, low, and extremely low-risk factors. According to the study, which looks at the marginal effects on the household demographics, households with dilapidated homes are less likely to have exclusive rooms, larger households, married couples with more than five children, untreated tap water, uncovered wells, no lighting, nighttime soil disposal, open latrines, open drainage, no cooking, no significant assets, semi-permanent households, and total temporary households. The dependent variable, the composite Ibrahim Index (CIb), indicates that variables like household size, the number of rooms, and the availability of major assets all have an impact on how many households there are.

3.5 Major findings

The socio-economic development status of the least developed nations is mostly calculated using the Ibrahim index. A high score in the current study denotes a high socio-economic position at the household level in the wards of Kolkata. The data's distance from the histogram's center is not unduly skewed, indicating that in the cases of poor socio-economic development, the observed and predicted values of the socio-economic development index do not lie on the same line. The dependent variable was predicted by the projected value in 69.4 percent of cases and by the residual values in 30.6 percent of cases. Here, the percentage of CIb predictions by projected value is higher than the percentage of CIB predictions by residuals. The other two maps show how the two types of predictions are distributed ward-by-ward. Additionally, the results show that in wards with low Ibrahim Index values, the covariances tend to exhibit higher values in the upper range (U) and lower values in the lower range (L). In contrast, wards with higher Ibrahim Index values show comparatively lower covariance values across both ranges. This pattern indicates that, for very marginal-effect indicators, socio-economic and household-level inequality exerts a substantial influence on the Ibrahim Index of development. The interpretation is based on the association between the Ibrahim index, and the selected inequality drivers and their marginal impact. The key conclusions of the study are listed below based on the analysis and overall results.

1. The inhabited areas of KMC had higher COVID-19 infection rates (2011) out of 141 wards. In wards 31, 33, 66, 70, 71, 73, and 74, a significant number of COVID-19 active patients were discovered.
2. The earlier active cases gradually increased from May 2020 to early 2021. The overall increasing rate was positive in the case of COVID-19 total cases, deaths, and patients discharged. Only the active COVID cases were in a negative trend of change.
3. The active COVID-19 cases were variedly distributed along with the developmental status of all the wards of KMC.
4. In the COVID-19 instances, there was significant inequity in the distribution of KMC families. The inequality line where the Gini Coefficient is 0.75 is considerably behind the real curve.
5. The most significant driver against the development, which influences the occurrences of COVID-19 in KMC, was in households with open latrines. A 1 percent increase in households with open latrines decreases 52.5 percent of CIb.
6. Socio-economic progress and COVID-19 household-level vulnerability are significantly inversely correlated (R square = 0.05).
7. The socio-economically underdeveloped wards in KMC that were previously indicated in this article have a significant percentage of COVID-19 susceptible zones. As a result, the alternative hypothesis is accepted, and the null hypothesis is rejected ($p<0.001$).

4 Conclusion and Suggestive Measures

Urban residents have seen a variety of serious effects from COVID-19 infections. Significant disparities in household health and socio-economic conditions were found in the wards of the Kolkata Municipal Corporation. Out of 141 wards, most of the wards from the eastern and central-western portions of KMC were infected by COVID-19. Compared with the socio-economically developmental status zones, the COVID-19 vulnerability areas are situated in the less developed wards of KMC. From early 2020 to early 2022, the number of COVID-19 total cases, deaths, are patients discharged were in an increasing trend. The active cases were in a decreasing trend till March 2022. During the lockdown period, the household-oriented COVID health inequality was highest in the wards of KMC. In this study, significant drivers of COVID-19 against the development are identified. The relationship between socio-economic development and household-level COVID-19 susceptibility is considerably positive, supporting the supposition that there is one. To sustain the socio-economic development of corporation wards while minimizing the vulnerability of COVID-19 or similar acute respiratory diseases, maintaining hygiene, COVID protocols, a healthy lifestyle, and mass consciousness, with further Governmental and non-Governmental research and assistance are required in an integrative way.

Abbreviations

BAES	Bureau of Applied Economics and Statistics
CIb	Composite Ibrahim Index
COI	Census of India
COVID-19	Coronavirus Disease 2019
F	F-statistic
GIS	Geographic Information System
Ib	Ibrahim Index
IIAG	Ibrahim Index of African Governance
KMC	Kolkata Municipal Corporation
LPG	Liquefied Petroleum Gas
RMSE	Root Mean Square Error
SC	Scheduled Caste
SD	Standard Deviation
SE	Standard Error
ST	Scheduled Tribe
Z-score	Standardized Score

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