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Spatiotemporal Analysis of COVID-19, AIDS, and SARS Epidemics Across Maharashtra, Delhi, and West Bengal

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ABSTRACT

This comprehensive study employs sophisticated geospatial analysis techniques to examine the intricate spatiotemporal distribution and temporal variations of COVID-19, AIDS, and SARS cases in Maharashtra, Delhi, and West Bengal. By meticulously mapping the occurrence and evolution patterns of these diseases, this research sheds light on the distinctive characteristics of the epidemic landscape in each region. The findings underscore the rapid spread of COVID-19, AIDS, and SARS in urban areas, particularly in states with megacities and densely populated urban slums, such as Delhi, Maharashtra, Tamil Nadu, and West Bengal. Additionally, these diseases show a heterogeneous geographical distribution within India, predominantly concentrating in central regions. Emphasizing the significance of understanding urban dynamics and population health characteristics in relation to disease transmission, this research contributes to a deeper understanding of the complex factors driving the spread of these diseases. Ultimately, this study provides insights that can inform the development of targeted interventions and strategies for initiative-taking of disease control, offering guidance to evidence-based decision-making and proactive public health management in the face of ongoing health challenges.

Keywords: *COVID-19, SARS, HIV/AIDS, spatiotemporal, outbreaks, Maharashtra, Delhi and West Bengal, geographical information system, spatial clustering, GIS analysis.*

1. Introduction

The emergence of the novel Coronavirus-2019 disease has presented a significant danger to the global population [1], [2]. Epidemic sickness outbreaks and unregulated spread can cause major social and political public health problems. As a result of their high contagiousness and threat to human life, epidemic-spreading infections (like SARS, AIDS, and Covid-19, for example) impede the growth of society and the economy [3]. The ongoing battle against viral diseases has long held humanity's attention, with outbreaks like Ebola, SARS, MERS, Spanish flu, and the most recent, COVID-19, posing severe threats to global health. In the quest for effective solutions, a recent study titled "Correlation-Based Analysis of COVID-19 Virus Genome versus Other Fatal Virus Genomes" [4] delves into a comprehensive comparative analysis of these deadly viruses, shedding light on potential avenues for treatment and prevention. Over two crore individuals have been afflicted by the COVID-19 outbreak, which began in December 2019 in the Chinese province of Wuhan and has spread worldwide with 7.5 lakh fatalities. On January 30, 2020, news of the first confirmed case in India was released.

More than 22 lakhs-affected individuals are in India, and 45 thousand have passed away [5]. The highly contagious pneumonia-like sickness that has suddenly infected a significant portion of the global population results from the 2019 new coronavirus disease (COVID-19) [6], [7]. WHO declared this virus's outbreak to be a global public health emergency. This virus's first cases were noted in the Chinese province of Hubei, where it is thought to have originated from the Huanan seafood market. Following the COVID-19 crisis, several impacted countries have seen an appalling decrease in social and economic progress [8]. Five years after the first verified cases in the US, HIV was discovered in a group of female sex workers in the south-easterly state of Tamil Nadu in 1986. During the early years of the Indian epidemic, commercial sex workers and their clients were most in danger of catching the virus. Due to its widespread quick transmission, AIDS is an infectious illness that significantly threatens human health and survival. Even though AIDS affects practically every country in the world, The number of sick individuals in each nation is unequal but rising. The human population's quality of life has significantly affected the social and economic spheres. Given the high prevalence of this fatal and curable illness, governments worldwide and the World Health Organization have dedicated a significant amount of time and resources to researching and analyzing the pathogenesis of AIDS to find a successful method of having the AIDS epidemic. AIDS is a highly contagious disease that damages human health and impedes social and economic growth. The AIDS pandemic and expansion have become severe public health, social, and political issues. Individuals living with HIV may be concerned about COVID-19, particularly the risk of serious illness and vaccine safety. Individuals without access to HIV care may be less likely to develop COVID-19 or HIV infection, according to the high incidence of HIV viral suppression in cases of COVID-19 that have been documented [9].

1.1 Utilizing Geographic Information Systems (GIS) for Comprehensive Insights into the Geographical and Temporal Dynamics of Infectious Diseases

Various graphical techniques have been used to check and gain insight into the geographical and temporal distributions of infectious diseases such as cholera, influenza, and plague [10]. In global health, the use of Geographic Information Systems (GIS) is an emerging and potent instrument for mapping and checking infectious diseases' spatial and temporal spread. Geographic information plays a vital role in pandemic surveillance, particularly in identifying spread patterns, resource allocation, prevention and control measures, detection of societal sentiments, and responses during outbreak scenarios [11]. By using GIS, epidemiologists can map current and historical disease occurrences and added parameters encompassing the environment, topography, and population. This abundance of data provides epidemiologists with insights into the causes of epidemics and the patterns and intensity of their spread. This expedites the implementation of appropriate measures for disease control, prevention, and surveillance [12], [13], [14], [15], [16].

Similarly, policymakers, public health organizations, and administrators can use GIS tools to gain real-time insights into epidemic patterns. This enables them to find high-risk populations and implement opportune interventions, such as evaluating existing infrastructure or constructing new healthcare facilities.

Earlier studies provided this study's motivation and significance. Initially, the author gave a thorough examination of the connection between GIS and health, describing spatial analysis and GIS as potential tools for illness understanding, prevention, and treatment. The geographic spread of the disease can be seen using GIS technology, which can also be used to connect the resources available for prevention and treatment. Analyzing specific information in a spatial context enables the assessment of disease risks, outbreak patterns and identification of pandemic hotspots. The alarming surge in COVID-19 cases within the Maharashtra region of India needs implementing various mitigation techniques to stop the deadly coronavirus's unchecked spread. Geographic Information Systems (GIS) have been important in tracking & seeing the spread of COVID-19 within computer science. We undertook a geospatial analysis of the effects of COVID-19 in the densely populated Indian states of Maharashtra, Delhi, & West Bengal to prove the efficiency of GIS in mapping such a large epidemic.

2. Literature Review

Numerous studies have undertaken geographical analyses to understand and manage the rising instances of COVID-19, presenting diverse methodologies and findings. Sanjeev et al. [17] focus on Maharashtra, emphasizing hotspot identification for strategic medical attention. Similarly, Shil et al. [18] examine COVID-19 phases in Maharashtra, noting urban-rural disparities. Biswas et al. [19] explore West Bengal, highlighting population density's role in case concentration. Conversely, Awasthi et al. [20] investigate COVID-19's correlation with Delhi's weather, advocating environmental studies. Guo et al. [21] assess COVID-19 among HIV/AIDS patients, identifying age as a risk factor. Hassen et al. [22] introduce the SIR-Poisson model, offering insights into COVID-19's trajectory. Lakhani [23] targets palliative care service allocation in Melbourne's elderly population. Trepka et al. [24] study gender disparities in HIV care retention in Miami-Dade County. Agegnehu et al. [25] explore media's influence on HIV/AIDS awareness in Ethiopian women. Dey et al. [26] emphasize early detection's importance in responding to the SARS virus. Bag et al. [27] analyse the spatial pattern of Coronavirus transmission in India. Ganguly et al. [28] present an HIV/AIDS overview in West Bengal, underscoring the importance of targeted interventions. These studies collectively illuminate the multi-dimensional disease surveillance, prevention, and management aspects from diverse geographical and demographic contexts. A Comparative Analysis of Studies on COVID-19, Infectious Diseases, and Health Interventions with Insights from Geographical and Demographic Perspectives is mentioned in Table 1.

Table 1: A Comparative Analysis of Literature Reviews

Study	Focus	Methodology & Findings
[17]	Geographical analysis of COVID-19 in Maharashtra	Point-cluster analysis found hotspots needing heightened medical attention. Utilized results to expand testing zones and balance evaluated to confirmed cases ratio. Positive z-scores in spatial autocorrelation visualizations highlighted vulnerable regions.
[18]	Comparative study of COVID-19 phases in Maharashtra	Mathematical modelling & epidemiological data used to analyse the first & second waves. Urban districts had higher attack rates in the first phase, rural population more affected in the second wave.
[19]	Geographic distribution of COVID-19 cases in West Bengal	Specific districts showed concentrated cases due to factors like population density and urbanization. Emphasized targeted interventions and public health measures for managing disease spread in specific regions.
[20]	Correlation of COVID-19 cases with weather in Delhi	Significant link found between COVID-19 cases and temperature. Gaussian model used for forecasting peak cases and recovery period length. Highlighted importance of exploring coronavirus-environment interactions for public health strategies and resource allocation.
[21]	COVID-19 among HIV/AIDS patients in Wuhan	Study focused on COVID-19 outcomes among HIV/AIDS patients. Age identified as a risk factor. Noted low HIV-VL20 copy number among cases. Cohort showed association between COVID-19 and specific antiretroviral regimen.
[22]	SIR-Poisson model for COVID-19 in Maghreb Central	Introduces SIR-Poisson model to forecast COVID-19 progression in Tunisia, Algeria, and Morocco. Innovative approach combined with application to specific geographic region supplies insights into pandemic trajectory and intervention strategies.
[23]	Palliative care services for elderly COVID-19 patients	GIS analysis pinpointed priority areas needing palliative care for elderly COVID-19 patients. Incorporation of climatological analysis enhanced understanding of disease survival and spread.
[24]	Gender differences in HIV care retention	Utilized data from Ryan White Program in Miami-Dade County. Gender differences assessed using logistic regression. Demonstrated successful care retention rates among all genders.
[25]	Media influence on HIV/AIDS awareness	Study revealed media exposure significantly affected awareness among Ethiopian women. Several factors like education, religion, and socio-economic status influenced HIV/AIDS understanding. Recommended interventions for rural populations and marginalized communities.
[26]	Early detection response to SARS virus	Visual data evaluated to emphasize benefits of early detection in responding to viral outbreaks. Importance of vaccinations and preventive measures underscored.
[27]	Spatiotemporal pattern of COVID-19 transmission in India	Spatial statistical analysis examined COVID-19 distribution in India. Highlighted significant spatial variation at state and district levels. Suggested space-specific policy planning for efficient containment.
[28]	HIV/AIDS epidemic overview in West Bengal	Overview of HIV/AIDS epidemic in West Bengal using data from Integrated Counselling and Testing Centres (ICTCs). Noted HIV positivity trends among diverse demographics, including high-risk groups (HRGs) and transgender (TG) population. Importance of targeted interventions highlighted.

3. Research Methodology

3.1 Data Collection:

For this study, publicly available case data of COVID-19, SARS, and HIV/AIDS was sourced from WHO reports. The study focused on confirmed cases, using semi-parametric spatial-temporal models for analysis. ArcGIS, a specialized tool for human infection prevention, was employed to ease data processing and visualization.

3.2 Study Area:

The research encompasses three Indian states: Maharashtra, West Bengal, and Delhi.

Maharashtra: Found in India's western division, Maharashtra spans an area of 307,713 square kilometers with geographical coordinates 19° 39'47.808"N and 75° 18'1.054"E. As a region significantly affected by COVID-19, Maharashtra was chosen for an in-depth examination. The study covers 35 districts within the province.

Delhi: India's capital city, Delhi, lies at coordinates 28.7041° N and 77.1025° E, covering an area of 1484 km². Home to over 19 million residents, Delhi reported its first COVID-19 case on March 2, 2020. By June 30, 2020, the total recorded infected cases had reached 87,360, resulting in 2,742 fatalities.

West Bengal: With a population of 91,347,736 and a land area of 88,752 sq. km, West Bengal shows diverse geographical features. Stretching from the Chhota Nagpur highlands to the Bangladesh-Assam border and from the Darjeeling Himalayas to the Bay of Bengal, the state experiences a monsoon climate. The intricate cultural, religious, and linguistic mosaic of West Bengal influences its social fabric.

3.3 Spatial Distribution and Temporal Analysis:

The spatial-temporal analysis was conducted using the inverse distance weighted (IDW) spatial interpolation technique within ArcGIS (version ArcMap 10.7.1). Inverse Distance Weighted (IDW) is a widely recognized interpolation method often employed by earth scientists [29]. It forecasts values for unspecified zones by computing expected values within neighbouring areas. The IDW method assumes that discrete input data exert local influence, which diminishes as distance increases. The degree of influence is inversely proportional to the range between discrete points [30]. The ensuing equation was employed for the analysis [31]:

$$Z_{xy} = \frac{\sum_{i=1}^{n} Z_i W_i}{\sum_{i=0}^{n} W_i}$$

In this equation, Z_{xy} signifies the target point for estimation, Z_i denotes the reference value for the i^{th} sample point, and W_i is the weight deciding the relative significance of each control point Z_i in the interpolation process. In this study, district headquarters were used as input point features, with the cumulative number of COVID-19 positive cases serving as the z-values for interpolation. Default values of 2 for power and 12 for radius were employed. The power parameter governs the impact of neighbouring points on the interpolated value for each cell in the resulting interpolated raster.

3.4 Statistical analysis

This study aims to conduct a statistical analysis of COVID-19, SARS, and HIV/AIDS cases and deaths in the states of Maharashtra, Delhi, and West Bengal. The research focuses on calculating the Case Fatality Rate (CFR) for each state to understand the proportion of deaths among confirmed cases, thereby supplying insights into disease severity and healthcare system effectiveness. The Case Fatality Rate (CFR) is a vital epidemiological metric used to measure the proportion of deaths among confirmed cases of a specific disease. It supplies insights into the severity of the disease and the potential impact on public health. The CFR is calculated using the following formula:

$$\text{Case Fatality Rate (CFR)} = \frac{\text{Number of Deaths}}{\text{Number of Confirmed Cases}} \times 100$$

Were,

Number of Deaths: This is the total count of individuals who have died due to the specific disease.

Number of Confirmed Cases: This signifies the total count of individuals who have evaluated positive for the specific disease.

The CFR is usually expressed as a percentage by multiplying the calculated ratio by 100. It quantifies the risk of death once an individual has been diagnosed with the disease. A higher CFR suggests a more severe disease impact, while a lower CFR shows a lower risk of death among those diagnosed.

It's important to note that the CFR can be influenced by various factors, including the accuracy of diagnosis, healthcare resources, population demographics, and reporting practices. Therefore, while the CFR provides a valuable snapshot of disease severity, it should be interpreted in the context of these influencing factors and used in conjunction with other metrics for a comprehensive understanding of the disease's impact.

3.5 Implications and Focus:

The research underscores the significance of understanding disease transmission dynamics in the selected Indian states. Given the substantial impact of COVID-19 in Maharashtra, Delhi, and West Bengal, this study's outcomes contribute to targeted interventions and strategies for effective disease control. By employing spatial-temporal analysis, the research looks to illuminate the intricate web of disease transmission, thereby enabling initiative-taking public health management during ongoing health challenges.

4. Results and Discussion

4.1 COVID-19 Pandemic Challenges in India (January 2020 - May 2023)

The COVID-19 pandemic has posed formidable challenges for India, as showed by data from the World Health Organization (WHO). Over the span of January 2020 to May 2023, the country has confronted significant hurdles in its battle against the virus. The gravity of the situation becomes clear when considering the overwhelming count of 44,972,800 confirmed cases and 531,707 reported deaths. Figure 1 underscore the profound impact of the pandemic on India and emphasize the urgency of addressing its repercussions.

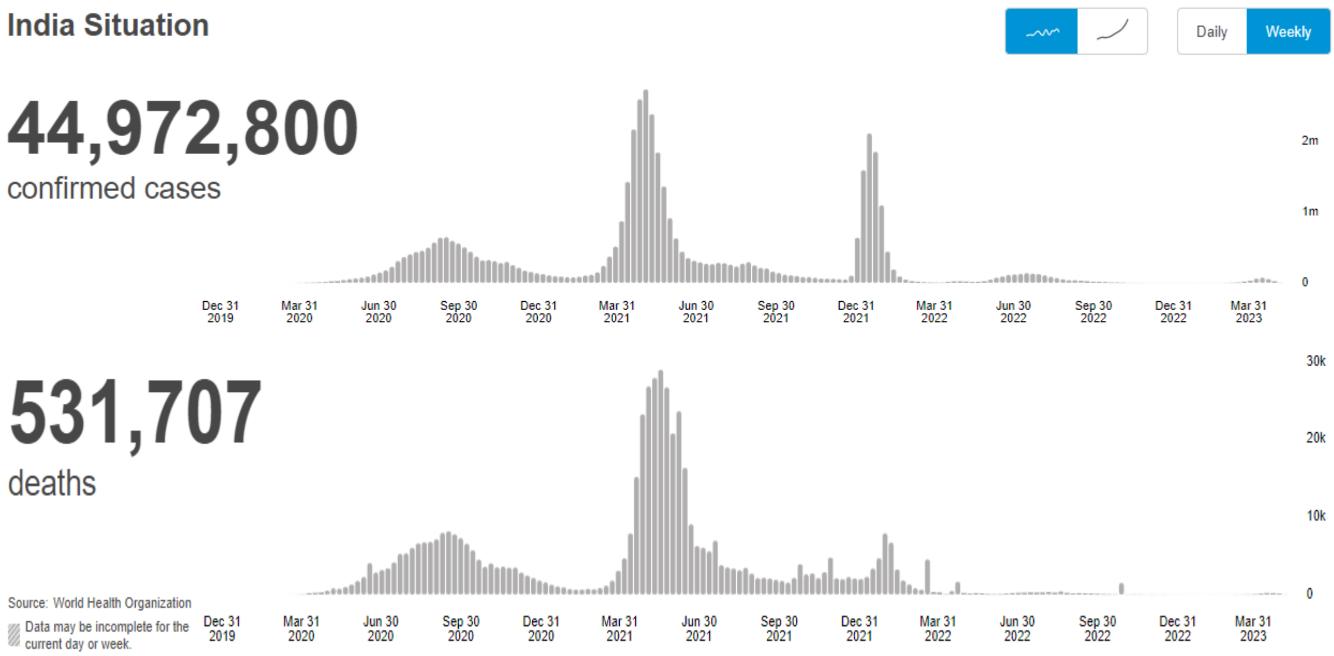

Fig 1: Covid 19 in India

4.2 Multifaceted Struggles and Unique Population Dynamics

India's response to the COVID-19 crisis has been marked by complexity and diversity. The nation's vast population, exceeding 1.3 billion individuals, presents a distinct challenge in terms of disease control and containment. The sheer size of people needs comprehensive strategies and innovative approaches to effectively manage the pandemic's impact. The presence of densely populated urban areas has notably contributed to the rapid dissemination of the virus, amplifying the challenges of curtailing its spread.

4.3 Navigating Complexity: Key Challenges and Impediments

The battle against COVID-19 in India has been characterized by a multitude of obstacles. High population density, particularly in urban centres, has hastened virus transmission. However, addressing transmission dynamics has proven intricate due to factors like limited healthcare infrastructure, testing constraints, and logistical difficulties in reaching remote and rural regions. These hurdles have compounded efforts to curb the virus's progress and mitigate its consequences.

4.4 Geographical Variation in Impact

The pandemic's impact has been non-uniform, manifesting differently across various states and cities within India. Regions such as Maharashtra, Delhi, and West Bengal have experienced disproportionately high case counts and fatalities. The outbreak's concentrated impact in specific areas underscores the importance of tailored interventions and resource allocation to address the disparate challenges faced by different regions [32]. The effects and outcomes of the pandemic have not been consistent or uniform across all regions and areas. In the context of the SARS, AIDS, and Covid-19, this means that different states and cities within India have experienced the pandemic differently in terms of the number of cases and deaths. For instance, regions like Maharashtra, Delhi, and West Bengal have seen a disproportionately high number of confirmed SARS, AIDS, and Covid-19 cases and fatalities compared to other areas. This uneven distribution of cases and deaths highlights that certain places have been more severely affected by the pandemic than others. This variation in impact underscores the need to recognize that different regions face distinct challenges and circumstances. The concentration of cases and deaths in specific areas emphasizes the importance of customizing interventions and resource allocation to address the unique challenges faced by each region. This could include targeted public health measures, healthcare infrastructure strengthening, and support systems tailored to the specific needs of those areas that have been hit the hardest.

Table 1: Covid-19, in Maharashtra, Delhi, West Bengal

States	Confirmed	Death	CFR
Maharashtra	7371757	141971	1.93%
Delhi	1406719	19344	1.38%
West Bengal	1605794	19333	1.20%

The presented table 1 encapsulates a comprehensive overview of COVID-19 data across the Indian states of Maharashtra, Delhi, and West Bengal. It supplies a snapshot of the confirmed COVID-19 cases, reported deaths, and the associated Case Fatality Rate (CFR) for each state. Maharashtra, with 7,371,757 confirmed cases and 141,971 reported deaths, proves a CFR of 1.93%, reflecting the proportion of deaths among confirmed cases. Delhi, recording 1,406,719 cases and 19,344 deaths, has a CFR of 1.38%, while West Bengal, reporting 1,605,794 cases and 19,333 deaths, highlights a CFR of 1.20%. The CFR percentages signify the severity of the disease's impact within each state. A higher CFR shows a more severe impact on health outcomes, thus highlighting the critical importance of public health measures and healthcare system readiness. Figure 2, 3 & 4 illustrates the overwhelming impact of the

COVID-19 pandemic in India. Notably, the states of Maharashtra, Delhi, and West Bengal showed heterogeneous geographic distributions of cases.

Table 2: SARS in Maharashtra, Delhi, West Bengal

States	Confirmed	Death	CFR
Maharashtra	84565	7091	8.38%
Delhi	34074	5225	15.3%
West Bengal	18016	2104	11.6%

Table 2 presents data on severe acute respiratory syndrome (SARS) cases in the Indian states of Maharashtra, Delhi, and West Bengal. The table includes the number of confirmed SARS cases and the corresponding reported deaths, as well as the calculated Case Fatality Rate (CFR) for each state. The CFR shows the proportion of deaths among confirmed SARS cases. Maharashtra reported 84,565 confirmed SARS cases, with 7,091 deaths, resulting in a CFR of 8.38%. Delhi recorded 34,074 cases and 5,225 deaths, leading to a CFR of 15.3%. Meanwhile, West Bengal had 18,016 cases and 2,104 deaths, yielding a CFR of 11.6%. The table's data proves variations in CFR across these states, reflecting differences in the severity and outcomes of the SARS outbreak in each region. This information contributes to understanding the impact of the disease and supplies insights into healthcare system responses and the overall management of the outbreak. Figure 5, 6 & 7 illustrates the overwhelming impact of the SARS in India. Notably, the states of Maharashtra, Delhi, and West Bengal showed heterogeneous geographic distributions of cases.

Table 3: People living with HIV/AIDS and total Death.

States	Confirmed	Death	CFR
Maharashtra	396000	9690	2.45%
Delhi	68000	1100	1.62%
West Bengal	74000	1370	1.85%

Table 3 presents data on the prevalence of HIV/AIDS and associated deaths, along with the calculated Case Fatality Rate (CFR), across three Indian states: Maharashtra, Delhi, and West Bengal. The table reveals that Maharashtra has reported the highest number of people living with HIV/AIDS (396,000) among the studied states, followed by West Bengal (74,000) and Delhi (68,000). In terms of HIV/AIDS-related deaths, Maharashtra records 9,690 deaths, West Bengal reports 1,370 deaths, and Delhi reports 1,100 deaths. The calculated CFR, a significant metric showing the proportion of deaths among confirmed cases, varies across the states: Maharashtra has a CFR of 2.45%, West Bengal has 1.85%, and Delhi has 1.62%. The table suggests that Maharashtra has a comparatively higher CFR, signifying a greater risk of mortality among individuals living with HIV/AIDS in the state, while Delhi and West Bengal have relatively lower CFRs. These figures underscore the differing impact of HIV/AIDS and associated mortality rates across the states, reflecting complex regional dynamics, healthcare accessibility, and intervention strategies. Figure 8, 9 illustrates the overwhelming impact of the HIV/AIDS in India. Notably, the states of Maharashtra, Delhi, and West Bengal showed heterogeneous geographic distributions of cases.

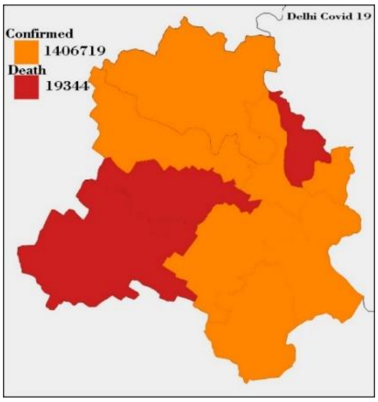

Fig 2: Covid 19 cases in Delhi

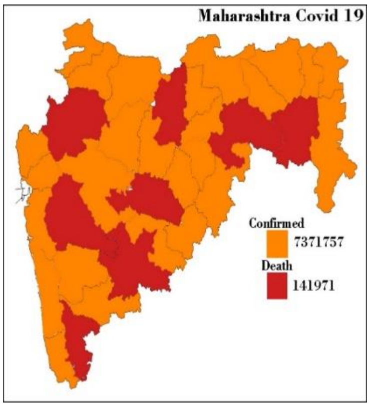

Fig 3: Covid 19 cases in Maharashtra

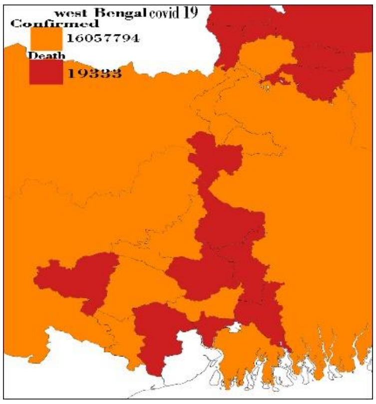

Fig 4: Covid 19 cases West Bengal

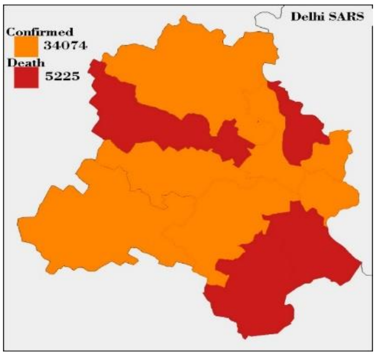

Fig 5: SARS cases in Delhi

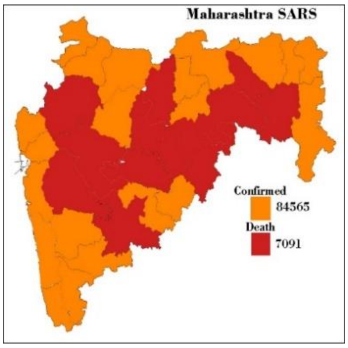

Fig 6: SARS cases in Maharashtra

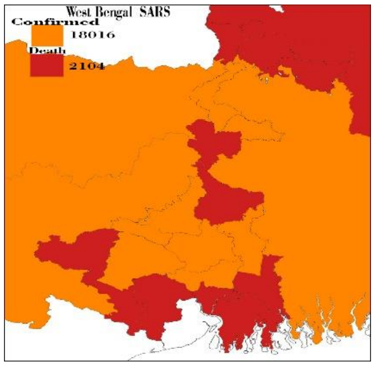

Fig 7: SARS cases in West Bengal

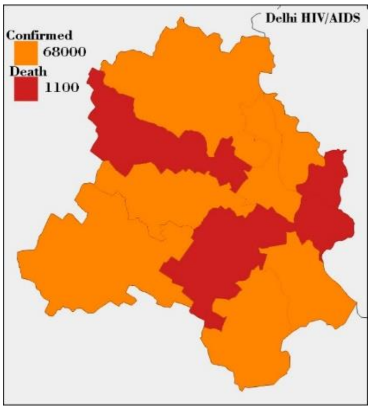

Fig 8: HIV/AIDS cases in Delhi

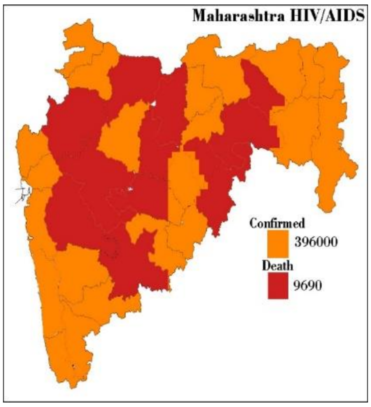

Fig 9: HIV/AIDS cases in Maharashtra

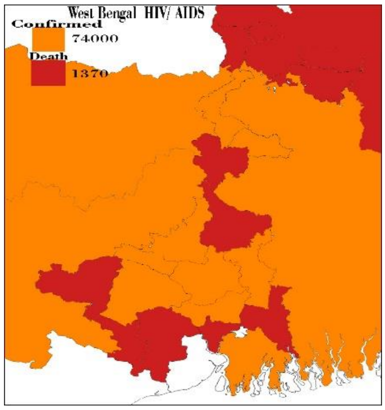

Fig 10: HIV/AIDS cases in West Bengal

4.5 Comparative Analysis of Case Fatality Rates (CFR) for Different Diseases

Figure 11 offers a comprehensive comparison of the Case Fatality Rate (CFR) for three distinct diseases—COVID-19, SARS, and HIV/AIDS—across three prominent Indian states: Maharashtra, Delhi, and West Bengal.

Concerning COVID-19, the CFR exhibits fluctuations among the states. Maharashtra records a CFR of 1.93%, showing that around 1.93% of confirmed COVID-19 cases within the state result in fatalities. Delhi's CFR for COVID-19 stands at 1.38%, while West Bengal's CFR is 1.20%. These statistics imply a relatively heightened risk of mortality for confirmed COVID-19 cases in Maharashtra compared to Delhi and West Bengal. Shifting to SARS, the CFR highlights variations across the states. Maharashtra reports an 8.38% CFR for SARS, while Delhi presents a higher CFR of 15.30%, and West Bengal's CFR stands at 11.60%. These percentages unveil the highest risk of mortality among confirmed SARS cases in Delhi, followed by West Bengal, and then Maharashtra.

Similarly, in the context of HIV/AIDS, the CFR diverges among the states. Maharashtra's CFR for HIV/AIDS is 2.45%, while Delhi's is 1.62%, and West Bengal's is 1.85%. This divergence underscores a relatively elevated risk of mortality among individuals living with HIV/AIDS in Maharashtra compared to Delhi and West Bengal. The comparative analysis of the CFR for the three diseases across the three states reveals varying degrees of severity and risk associated with the diseases. The highest CFR for COVID-19 is in Maharashtra, while the highest CFR for SARS is in Delhi. For HIV/AIDS, Maharashtra has the highest CFR.

The comparative analysis underscores the CFR as a pivotal metric for understanding the proportion of deaths among confirmed cases for each disease. The findings unveil varying degrees of severity and risk associated with the three diseases across the three states. However, it is crucial to acknowledge that these percentages are intricately influenced by multifaceted factors encompassing healthcare resources, testing methodologies, and the demographic composition of the population. Consequently, the interpretation should be grounded in the broader context of these influencing factors.

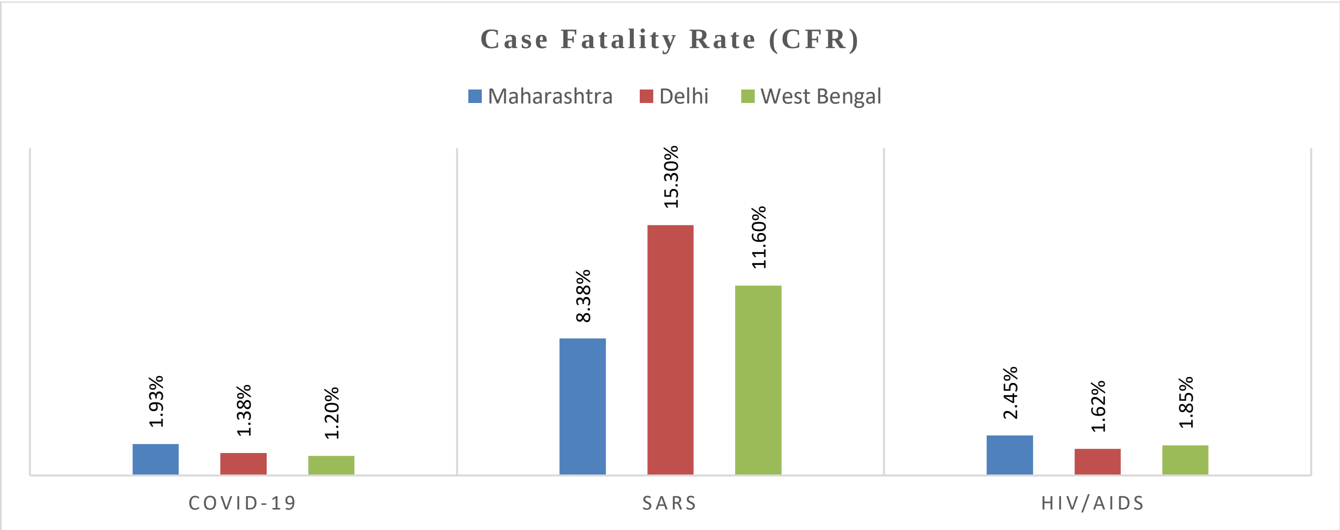

Figure 11: Comparative analysis of CFR

Conclusion

The COVID-19 pandemic has underscored the urgent need for preventative public health measures, highlighting the criticality of swift response plans, robust healthcare systems, and effective communication in mitigating the impact of infectious diseases. A comprehensive analysis of spatial distribution has found hotspots and areas with concentrated disease burden, providing valuable insights to guide targeted interventions and resource allocation for more successful disease control initiatives. Moreover, comparing the incidence of COVID-19 cases with that of AIDS and SARS cases has revealed the intricate dynamics of disease outbreaks, influenced by multifarious factors such as modes of transmission, healthcare accessibility, and societal responses. Consequently, a thorough understanding of disease dynamics assumes paramount significance in helping well-informed decision-making and policy development, as evinced by disparities in case fatality rates and geographic patterns. This research has contributed to the advances in knowledge within the realm of disease epidemiology and its implications for managing public health. The conclusions drawn from this study give a framework for evidence-based solutions that can effectively address ongoing and emergent infectious disease risks, whilst accommodating the evolving landscape of global health concerns. As such, this investigation provides a fundamental basis for the development of agile and responsive public health systems, working towards safeguarding the well-being of populations and averting future health crises through an appraisal of the intricate spatial and temporal dynamics of disease distribution.

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