Risk assessment to curb COVID-19 contagion: A preliminary study using remote sensing and GIS

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Research Article

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Abstract

Globally, COVID-19 pandemic has become a threat to humans and to the socio-economic systems they have developed since the industrial revolution. Hence, governments and stakeholders are calling for strategies that could help to restore the normalcy while dealing with this pandemic effectively. Since, till now, the disease is yet to have a cure; therefore, only risk-based decision-making can help governments to achieve a solution that is sustainable in the long term. To help the decision-makers to explore viable actions, we here propose a risk assessment framework for analyzing COVID-19 risk to areas, using integrated hazard and vulnerability components associated with this pandemic for effective risk mitigation. The study is carried on a region administrated by Jaipur municipal corporation (JMC), India. Based on the current understanding of this disease, we hypothesized different COVID-19 risk indices (C19Ri) of the wards of JMC such as proximity to hotspots, total population, population density, availability of clean water and associated land use/ land cover, are related with COVID-19 contagion and calculated them in a GIS-based multi-criteria risk reduction method. The results showed disparateness in COVID-19 risk areas with higher risk in north-eastern and south-eastern zone wards within the boundary of JMC. We proposed to prioritize wards that are under higher risk zones for intelligent decision-making regarding COVID-19 risk reduction through appropriate management of resources-related policy consequences. This study aims to serve as a baseline study to be replicated in other parts of the country or world to eradicate the threat of COVID-19 effectively.

Introduction

COVID-19 or Coronavirus disease 2019 has been linked with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and is currently responsible for creating havoc to the whole human civilization[1]. COVID-19 risk mitigation requires considerable planning, if the pandemic has to be eliminated from every area, regardless of developed or developing countries[2]. Highly populated countries of Asia, such as India, Bangladesh, and Pakistan, are particularly more vulnerable to this disease because of the high population densities, weak health care system, and poverty[3]. To control this pandemic, the only established solution till now, has been the isolation and quarantine of the infected persons, through the government imposed national level lockdowns[4]. On the other side, the extended lockdowns for restricting its spread in these countries has posed a significant challenge for the governments at different levels, as it has created a state of economic crisis[5]. In India, state governments are planning for risk-informed lockdowns by identifying the areas at varying degrees of risk, using the parameters that have been to date, known to govern the contagiousness of the COVID-19[6]. Furthermore, it is imperative to understand the risk associated with this pandemic spatially, to help the agencies dealing with curbing its spread, for risk-informed decision making[7].

There are various studies on risk assessments based on vulnerability and exposure of communities to various natural disasters. However, the case of pandemic COVID-19 is different, as the exposure parameter is an infected person, itself, or a thing that has been in his contact[8]. Moreover, there are specific hypothesized parameters such as BCG vaccinated people and women being immune to the lethality of this virus, which defines the resilience of the community towards the contagion of this disease. However, such parameters are still under trials[9]. Hence, if the COVID-19 risk assessment has to be performed, hazard and vulnerability parameters need to be defined[10]. Providing sustainable threat protection from the COVID-19 requires approaches that are proven in resisting the spread of this pandemic particularly when it is fact that it has no drug or vaccine till date[11]. An issue that shall increase the likelihood of the recurrence of this pandemic, unless it is available, as such, the need for a comprehensive risk assessment becomes obligatory.

The framework for the risk assessment of COVID-19 must take all the readily available information and use it for the spatial identification of the areas that are currently at high risk. Addressing the issue of the implementation of restricting the virus spread, requires defining the risk zones according to the finest scale of administrative coverage. COVID-19 risk assessment and mapping (labeled hereafter as CRAM) framework, as proposed here, involves the mapping of the risk, using its defined hazard and vulnerability components, for informed decision making to declare red, orange, blue, and green zones of containment[12-13]. We used proximity to hotspots and settlements as the hazard components because the pandemic spread is directly proportional to the distance from the hotspot and density of settlements. In contrast, different socio-economic parameters were used as vulnerability components in the assessment

In collaboration with the Rajasthan state authorities, the area under Jaipur municipal corporation (JMC) was chosen as the study area for COVID-19 risk assessment, mainly because the city has been witnessing an increase in the number of COVID-19 cases, ever since, it had hit India (Fig. 1)[14]. Moreover, due to the high population density of this area, it has become imperative for the authorities to manage lockdowns without affecting the economy of the state and shall only be achieved through a spatial risk assessment of the COVID-19 threat. As an example of the whole country, the extended lockdown of 40 days, i.e., from 24 March till 03 May in India, has caused an economic loss of approximately $26 billion per week[15].

Till now, COVID-19 risk mapping has not been reported anywhere in the world. Probably, similar strategies are implemented across the globe, but the formal reporting in any scientific journal is scarce. Hence, to the best of our knowledge, we believe this study is first of its kind that has used spatial sciences, remote sensing, and GIS for risk assessment of the COVID-19. To provide scientific support, we have already submitted the results of our work in Jaipur, to the Government of Rajasthan in facilitating the COVID-19 risk mitigation plans for the whole state, which is significantly contributing towards COVID-19 risk-informed planning and management of the area.

Methods

The methodology of COVID-19 risk assessment and mapping (CRAM), for simplicity, is divided into three steps. The first step involved the generation of GIS layers of various administrative data (ward), hazard data, socio-economic data, and biophysical data. The second step involved the integration of hazard and vulnerability to generate risk assessment. The third and the final step in CRAM, involved risk mapping for informed decision making and the prioritization of COVID-19 risk areas using ward-level administrative boundaries of the Jaipur city, for prompt action. Individual steps are further briefly discussed below. Fig. 2 demonstrates the complete CRAM framework.

As per the current understanding of the COVID-19, several parameters have been identified to affect its lethality and infection. These include various hazard, biophysical and socio-economic parameters, determining the actual risk of an area to COVID-19 disease[16]. Hence, we calculated the risk through integration of hazard and vulnerability to this pandemic, of each zone of concern (i) - wards in our situation. We defined COVID-19 risk (written-off as, C19R index) as

$$C19R_i = HAZARD_i \times RISK_i \qquad (1)$$

Accordingly, an increase in the hazard and vulnerability will increase the COVID-19 risk of the zone of interest. Table 1 defines the hazard and vulnerability components of C19R and is discussed in more detail in the following sections.

Data sets

We used census 2011 data of Jaipur city and related specific socio-economic parameters to COVID-19 vulnerability, such as population, population density, percentage of main workers, and percentages of literates. Groundwater well data used in this study was provided by the central groundwater Commission, Government of India. Further, hotspot locations provided by Jaipur municipal and health authorities, were used as input data for generating various hazard zones, using GIS-based proximity analysis. Pre-processed World-view satellite imagery of September, 21 2019, was used for land-use/ landcover (LULC) mapping to be used as a hazard component.

Hazard

We hypothesized hazard in our study as the potential of COVID-19 posing danger of exposure, to the population of Jaipur. We used proximity to hotspots, i.e., locations with a high density of confirmed positive COVID-19 cases, as the hazard and defined four levels of hazard zones in consultation with the municipal and health authorities of Jaipur city; Red zone (0-350 m radius), orange zone (350m-700m), blue zone (700m-1050m) and green zone (1050-1400m) (Fig. 3a). Besides, LULC of the wards was used as a hazard parameter as certain LULC types associate with the high probability of COVID-19 infections, such as settlements and agriculture, where people gather and get exposed to the virus. Hence using, ArcMap 10.1, we conducted level-II classification of the study area using visual image interpretation technique on the Worldview satellite imagery[17-22] (Fig. 3b).

Vulnerability

Vulnerability, in our case, refers to the susceptibility of the area to COVID-19 infection due to its demographic, economic, and availability of clean water for sanitation conditions. As for as the current understanding of this pandemic is concerned, densely populated areas, people that do not have access to clean water for frequent sanitation and people that need to leave their houses for livelihood, are particularly more vulnerable. That is the reason we chose population, population density, well-density (as water supply data was not available), and percent workers, respectively, as the parameters that make an area more vulnerable to the COVID-19 infection. Further, we hypothesized that educated people being more aware of this disease would take requisite precautions such as hygiene and isolation to protect them from getting infected. Hence, we took percent literates also as a parameter in the vulnerability component (Fig. 4 a-d).

Moreover, we digitized all roads of the Jaipur city, to provide routing information to the agencies dealing with this pandemic in case of emergencies (Fig. 1c). Also, using kriging spatial interpolation technique, we generated well density layer, using well location data in ArcMap 10.1 (Fig. 4e). Finally, the integration of all the layers is carried out using a GIS-based weighted overlay analysis[12]. The weights for different classes are shown in Table 2 and were developed using the current knowledge about these parameters in governing the infection and spread of COVID-19 pandemic[16].

Results And Discussion

Fig. 3 (a) demonstrates the spatial distribution of the hotspots under JMC. The COVID-19 hotspot density lies more in the north-eastern (NE) zone of the study area, as shown in the map of this figure. It is evident from the map that the density of hotspots is very high in the densely populated zone of the study area. Hence, the hazard level for the wards of the NE zone is comparatively more elevated, and as a result, the communities there are under more significant threat of the infection.

COVID-19 risk analysis of the study area under JMC, Jaipur

Using Eq. (1), the spatial distribution of the COVID-19 hazard, vulnerability, and risk for all the wards under JMC are shown in Fig. 5 a, b and c, respectively. We have categorized them into five classes each, red (*very high)* followed by orange (*high*), blue (*moderate*), green (*low*), and pink (*very low*). The final risk assessment being the integration of hazard and vulnerability components, is shown in Fig. 5 (c) and is being discussed hereunder. The results indicated that out of the total area of JMC (379 km^2), 6.13 km^2 (6.13%) fall in red risk zone followed by 60.38 km^2 (15.91%) in orange, 139.63 km^2 (36.79%) in blue, 164.51 km^2 (43.34%) in green and 8.9 km^2 (2.34%) in pink risk zone. The risk assessment results indicate that majority of areas under high-risk zones (red and orange) concentrate along the north-eastern and south-western zones of the study area with some scattered zones of red and orange in eastern and south-eastern zones along the borders of the JMC. As a result, the risk of all the north-eastern and south-western zone wards of the study area is higher for all the risk categories. As a result, the population in these wards is particularly under a more significant threat of the COVID-19 infection.

Promoting risk-informed COVID-19 management of JMC study area

The results from the CRAM framework depict significant spatial variation, indicating a higher risk for the wards of the north-eastern zone as compared to the wards of other zones, as shown in Fig. 5 (c) referring to the higher number of the hotspots of COVID-19 in this zone of the JMC. We propose that globally, the risks of COVID-19 (C19R) infection and spread can only be managed using risk-informed planning until a cure or vaccine is available, so that the economy and livelihood of the people and countries as a whole, do not suffer. By analyzing the spatial distribution of the C19R to prioritize the lowest levels of administrative boundaries (wards in our case) for planning risk mitigation approaches and resource distribution, it can be achieved. The CRAM framework aims to support this purpose for the area falling under Jaipur municipal corporation (JMC), because the framework had a spatial component in the COVID-19 risk evaluation.

The results have indicated that areas falling under wards 31, 53, 54, 58, 59, 68, 69, 73, are under *very high risk,* as more than 80% of their areas fall under the red risk zone. Whereas areas falling under wards 03, 13, 14, 15, 17, 31, 34, 44, 46, 50, 51, 55, 56, 60, 61, 62, 64, 65, 66, 67, 71, 72, and 74 are under *high risk* as similarly, more than 80% of their areas fall under orange risk zone. The results also indicate the wards of east, west, and north zones are comparatively at lower risk due to the lower hazard probability as well as lower population density and greater availability of water for sanitation, as depicted in Fig. 5 (a-c). Conversely, the results also indicate that north-east and south-west zone wards are at *very high risk* for COVID-19 due to higher total population, population density, and comparatively lesser availability of the water for sanitation. This information is vital for risk-informed planning for the eradication of COVID-19 threat in these areas.

We propose that the wards under *very high risk* and *high risk* may be considered as containment zones through extended lockdowns until the daily number of confirmed positive cases come to near zero. Moreover, such areas shall need an increase in the rate of testing for COVID-19 infection to identify infected persons for isolation and quarantine. Overall, we propose a detailed management strategy shown in Table 3 for all the areas under different risk zones shown in Fig. 5 (c)[23].

Currently, the COVID-19 threat is a global pandemic, and countries can combat it in the long run only through a risk-informed planning, as it appears that the disease is going to remain in the category of non-curable diseases for some time[24]. Moreover, in the developing world, the COVID-19 risk informed decision making has to be taken to the panchayat and local *mohalla* levels to contain virus without affecting the economy. This work shall serve as a baseline methodology in other regions of the country and the world with a similar setup.

Conclusions And Limitations

Human populations have been threatened due to the ongoing COVID-19 pandemic, predominantly those that are living with the settings that make them more prone to higher levels of its risk. To address this, we present an integrated COVID-19 risk assessment and mapping (CRAM) framework, wherein we used hazard and vulnerability parameters linked with the COVID-19 contagion, to identify the areas that are under different levels of risk. COVID-19 risk (C19Ri) indicators have been proposed based on the current knowledge of the disease infection, lethality, and spread[25]. The results of the assessment identified areas that are under very high-risk category, e.g., NE and SE zone wards of the JMC, Jaipur India. Prioritization of regions for decisions regarding containment and isolation is viable using this approach. This approach thus provides opportunities for long term COVID-19 risk management so that the economy and livelihood suffer least in the study area.

The authors acknowledge that there are scores of limitations in the proposed CRAM framework at present, mainly due to the incomplete knowledge regarding the operational mechanism of COVID-19 infection. Moreover, the number of risk indices used are less in number, but since the science related to this pandemic is still evolving, once more indices are available, the same can be used in further studies. At the moment, whatever knowledge is possible, must be utilized to eradicate this threat. Due to data unavailability, we could not use water supply data, instead we used well density data, which we know may sometimes not give a clear picture of the sanitation conditions of the area. We recommend to use water supply data if available. Further, if parameters that govern the resilience of the community to COVID-19 lethality are available, we then advise using hazard-vulnerability-resilience based risk assessment framework, which shall make the CRAM more focused and broader in scope.

Declarations

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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Tables

Table 1: Brief description of different components of COVID-19 risk index

C19R component	Brief description and assessment method
Hazard	Assessed using a GIS-based proximity analysis of the hotspots of COVID-19 cases. See sections 2.1 and 2.2 for details
Vulnerability	Vulnerability in the case of COVID-19 refers to the socio-economic and biophysical set up of the communities, making them prone to this infection. See sections 2.1 and 2.3 for details

Table 2: Weights of the risk indices ($C19R_i$)

COVID-19 risk indicators	Classes	Weight	Index (i)
Population density (*Pd*)	2205-21808	1	Very Low
	21808-41412	2	Low
	41412- 61015	3	Moderate
	61015- 80619	4	High
	80619-100223	5	Very High
Main Workers (in Percentage) (*MW*)	25-27	1	Very Low
	27-29	2	Low
	29-31	3	Moderate
	31-33	4	High
	33-35	5	Very High
Literates (in Percentage) (*L*)	50-57	5	Very High
	57-64	4	High
	64-71	3	Moderate
	71-79	2	Low
	79-86	1	Very Low
Buffer Zones (in m) (*PHt*)	350	5	Very High
	700	4	High
	1050	3	Moderate
	1400	2	Low
Total Population (*TP*)	20000-35000	1	Very Low
	35000-50000	2	Low
	50000-65000	3	Moderate
	65000-80000	4	High
	80000-95000	5	Very High
Landuse/Landcover (*LULC*)	Built-up	5	Very High
	Industry	4	High
	Agriculture	3	Moderate
	Waterbodies	4	High
	Wasteland	2	Low
	Wetland	2	Low
	Open space	1	Very Low
	Miscellaneous	1	Very Low
Well Density (*WD*)	0 - 0.15	5	Very High
	0.15 - 0.31	4	High
	0.31 - 0.46	3	Moderate
	0.46 - 0.62	2	Low
	0.62 - 0.77	1	Very Low

Table 3: Proposed activities in each risk zone (prepared in consultation with the authorities managing COVID-19 in the area (after Kanga et al. 2020)

Zones	Malls/Cinema Hall/Gym/Restaurants/Religious Places or Institutions	Hotel	Hospitals	Marginal Laborer/Daily wagers etc.	Wearing of Masks/Gloves	Section 144	Construction/Industries/ Mining	Transport (Air/Railway/Roads/etc.)	Use of Air Conditioner/Cooler	School/ Colleges	Group A Shops(Basic/Daily Needs)	[illegible]
RED(Very High Risk)			√ Open for Isolation/Covid-19		√	√						
Orange(High Risk)			√ Open for Isolation/Covid-19		√	√					√ One day in a week and 01 person from family allowed (Time-bound)	
Blue(Moderate Risk)			√ Open for Isolation/Covid-19 and emergency cases	√ Labor is allowed within zone and should belong to blue zone only with restricted entries of govt. authorized pass holders	√	√		√ Only restricted entries of govt. authorized pass holders			√ Three days in a week and 01 person from family allowed (Time-bound)	[illegible]
Green(Low Risk)			√ Open for Isolation/Covid-19 and emergency cases	√ Labor is allowed within zone and should belong to green zone with restricted entries of govt. authorized pass holders	√	√	√ Only restricted entries of govt. authorized pass holders with a limit of 30% of staff can join	√ Only restricted entries of govt. authorized pass holders		√ Only essential services like admission staffs etc. with a limit of 30% of staff can join situated in around the campus	√ Five days in a week and 01 person from family allowed (Time-bound)	[illegible]

Note: No entries shall be allowed within RED & ORANGE ZONES. Only essential commodities can be asked through online demand, and the Government shall be ensuring the availability from doorstep services maintaining all the rules of freeze zone, social distancing, etc.

For BLUE AND GREEN ZONES, all the relaxation is permitted only with the permission to take care of social distancing. If social distancing is being broken at any place, the relaxations will be stopped immediately.

Figures

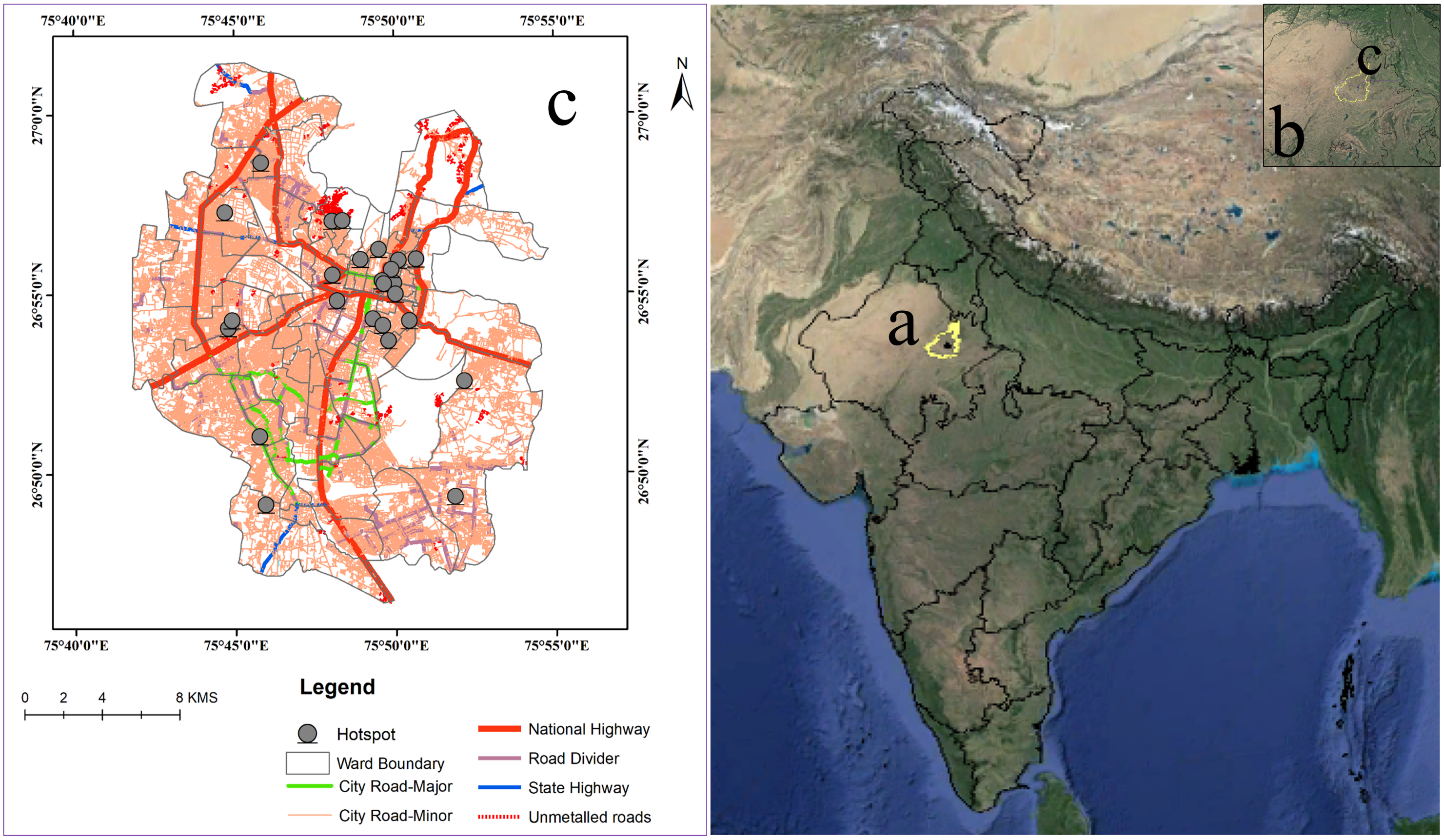

Figure 1

Location map: (a) The location of Jaipur city w.r.t India; (b) The location of Jammu municipal corporation (JMC) w.r.t Jaipur city; (c) The road network map of JMC for emergencies related to COVID-19. The map coordinates are in the UTM 43 (North) World Geodetic System (WGS-1984) reference system.

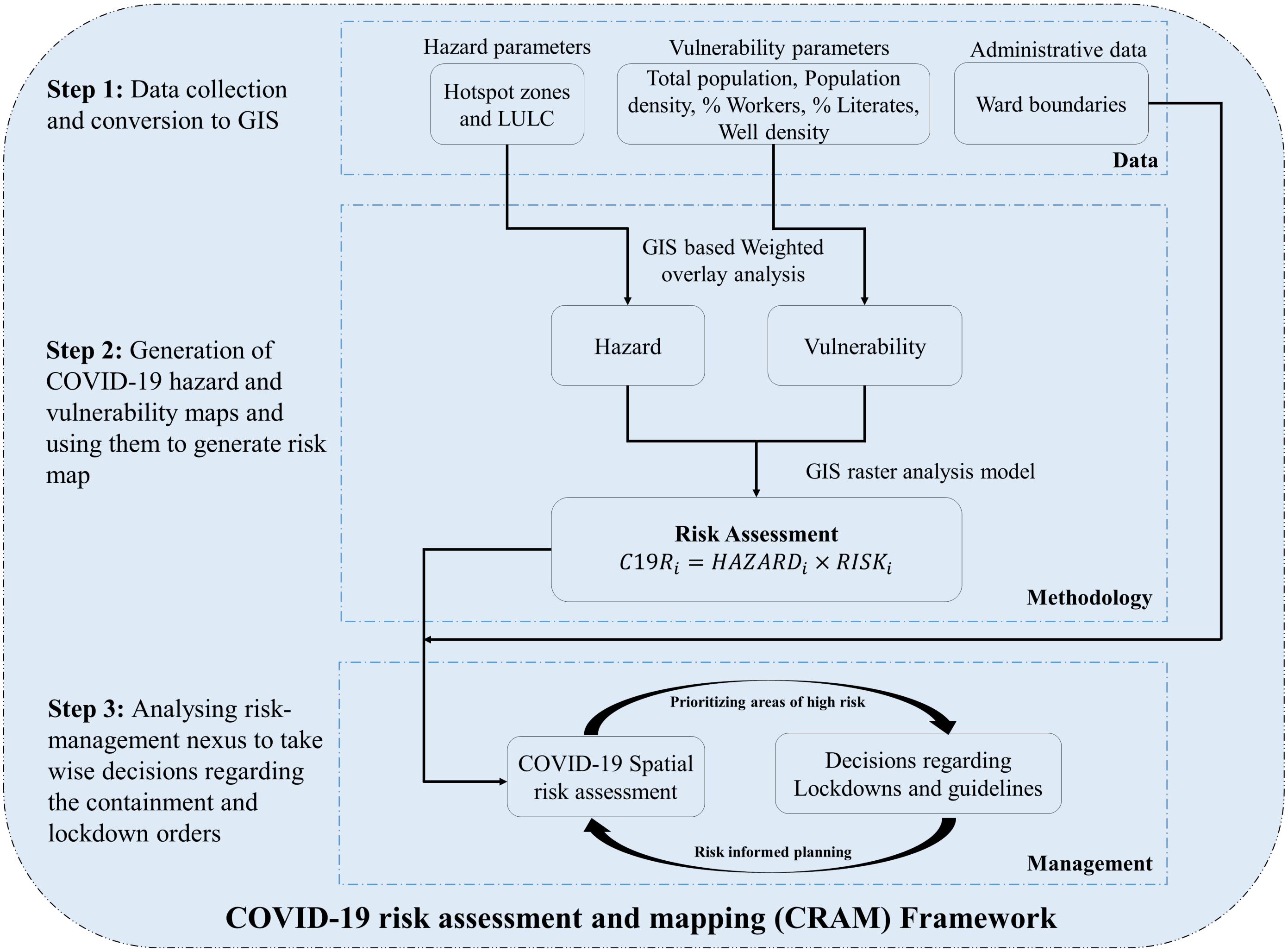

Figure 2

COVID-19 risk assessment and mapping framework (CRAM) for the JMC, Jaipur India.

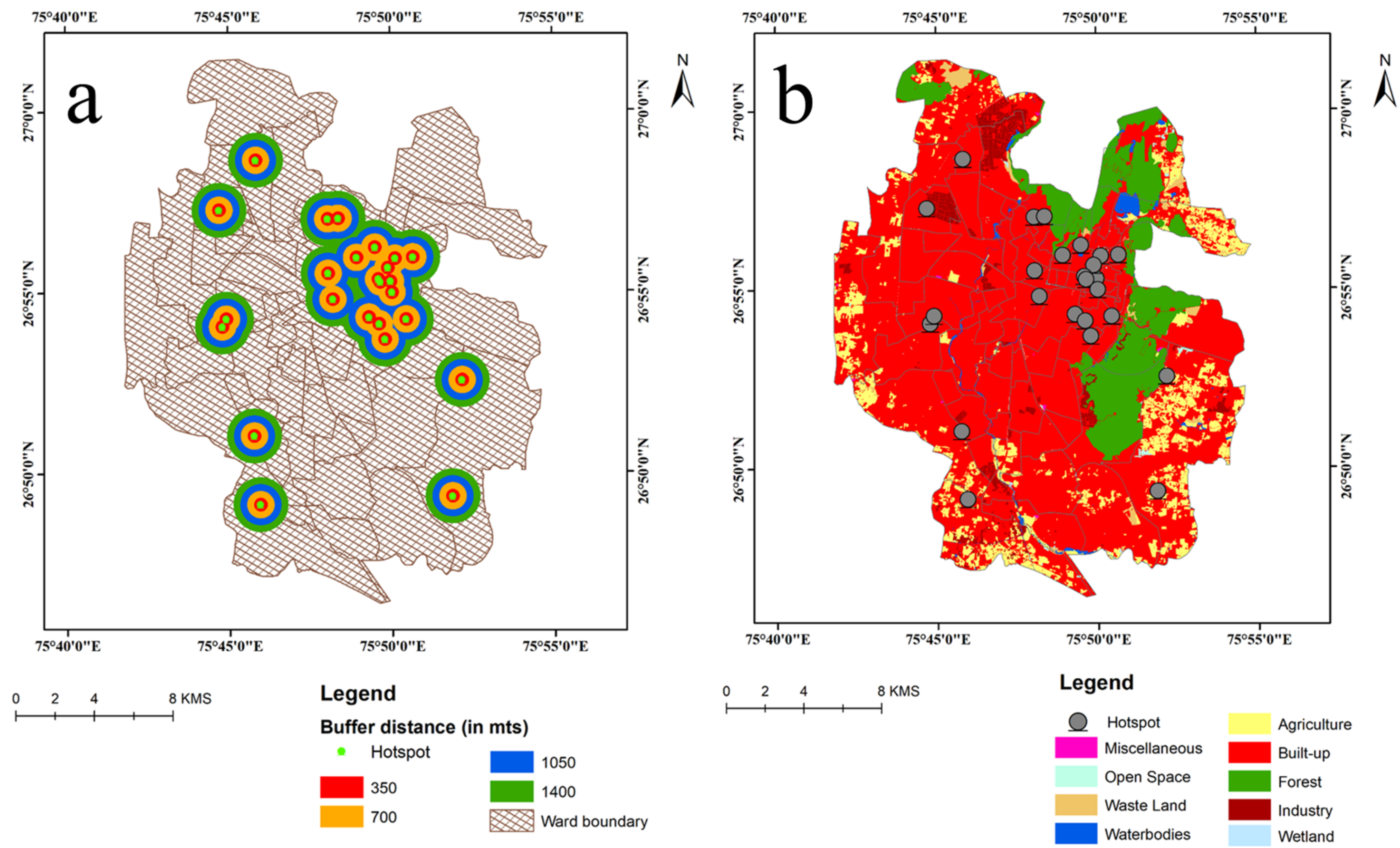

Figure 3

Hazard parameters (a) Hotspot buffer zones of JMC, (b) LULC of JMC.

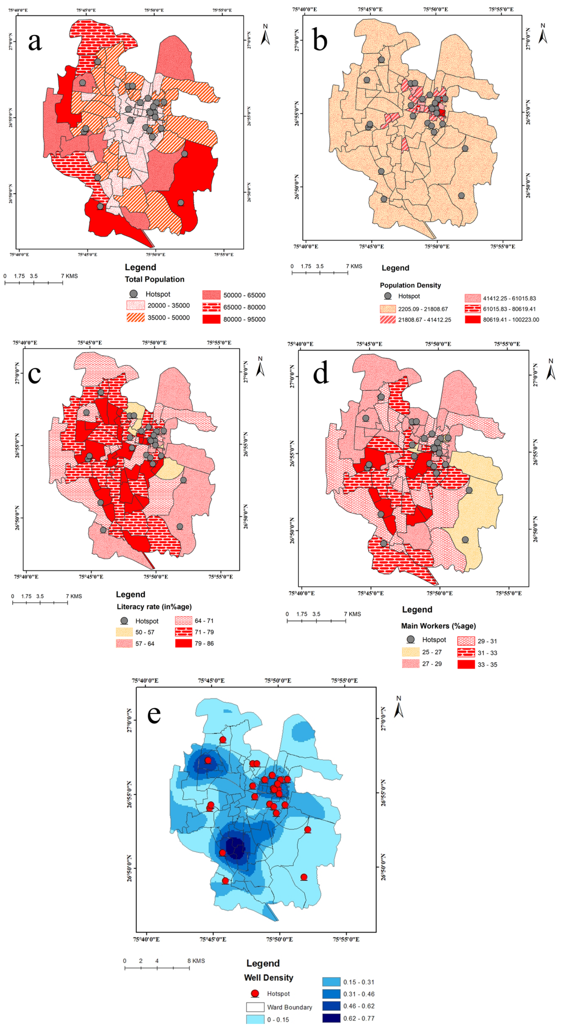

Figure 4

Vulnerability parameters (a) Total population, (b) Population density, (c) Percent literacy rate, (d) Percent main workers, and (e) Well density of the JMC.

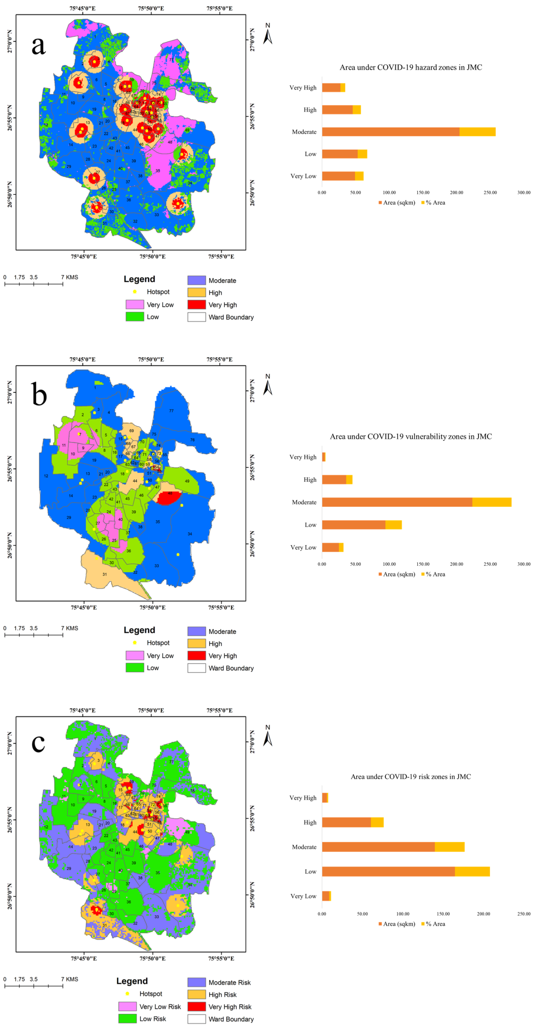

Figure 5

Hazard map and area statistics, (b) Vulnerability map and area statistics, (c) Final risk map and area statistics of the JMC.