Analyzing the Risk to COVID-19 Infection using Remote Sensing and GIS

Shruti Kanga,1 Gowhar Meraj,1,3 Sudhanshu,1 Majid Farooq,1,3 M. S. Nathawat,4 and Suraj Kumar Singh 2,∗

Globally, the COVID-19 pandemic has become a threat to humans and to the socioeconomic systems they have developed since the industrial revolution. Hence, governments and stakeholders call for strategies to help restore 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 achieve a sustainable solution in the long term. To help the decisionmakers explore viable actions, we propose a risk-based 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 multicriteria risk reduction method. The results showed disparateness in COVID-19 risk areas with a higher risk in north-eastern and south-eastern zone wards within the boundary of JMC. We proposed prioritizing wards 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.

KEY WORDS: COVID-19; CRAM model; GIS; lockdown; risk assessment; spatial analysis

1. 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 (Fan, Zhao, Shi & Zhou, 2019). COVID-19 risk mitigation requires considerable planning if the pandemic has to be eliminated from every area, regardless of developed or developing countries (Koonin, 2020). Highly populated countries of Asia, such as India, Bangladesh, and Pakistan, are significantly more vulnerable to this disease because of the high population densities, weak health care system, and poverty (Chongsuvivatwong et al., 2011). The only
established solution to control this pandemic has been the isolation and quarantine of the infected persons through the government imposed national level lockdowns (WHO, 2020). 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 (Hafiz et al., 2020). 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 (NSD, 2020). 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 (Verhagen et al., 2020).

There are various studies on risk assessments based on communities’ vulnerability and exposure 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 (Prem et al., 2020). Moreover, specific hypothesized parameters such as Bacille Calmette-Guerin (BCG) vaccinated people and women being immune to this virus’s lethality define the resilience of the community toward the contagion of this disease. However, such parameters are still under trials (Franklin et al., 2020). Hence, if the COVID-19 risk assessment has to be performed, hazard and vulnerability parameters need to be defined (Pluchino et al., 2020). Providing sustainable threat protection from the COVID-19 requires approaches that are proven in resisting the spread of this pandemic, mainly when it is a fact that it has no drug or vaccine to date (Rothan & Byrareddy, 2020). An issue that shall increase the likelihood of this pandemic’s recurrence, unless it is available, requires a comprehensive risk assessment to become obligatory.

The framework for the risk assessment of COVID-19 must take all the readily available information and identify the areas 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 mapping the risk, using its defined hazard and vulnerability components, for informed decision making to declare red, orange, blue, and green zones of containment (Meraj, Romshoo, Yousuf, Altaf, & Altaf, 2015; Pandey, Singh, & Nathawat, 2010). We used proximity to hotspots and settlements as the hazard components because the pandemic spread is directly proportional to the hotspot’s distance and density. In contrast, different socioeconomic 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) (Ministry of Health and Family Welfare, 2020). Moreover, due to this area’s high population density, it has become imperative for the authorities to manage lockdowns without affecting the state’s economy 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, that is, from 24 March till 3 May in India, has caused an economic loss of approximately $26 billion per week (Iyer, 2020).

From Fig. 2 and 3, it is evident that India, due to its very high population density and complex socioeconomic setting, is facing the greatest brunt of the COVID-19 pandemic. Even though India started the lockdown strategy very early still, it was not efficient enough in controlling the contagion of the COVID-19 pandemic. Hence, it is prudent to initiate an out-of-box management strategy to curtail its spread, such as the vulnerability assessment-based lockdown strategy demonstrated in the present study. The model we propose for managing the COVID-19, if applied in other South Asian countries, would help restrict the spread of infection, as can be seen in countries such as Italy and China that followed similar restriction strategies.

Till now, COVID-19 risk mapping has not been reported anywhere in the world. Similar strategies are probably implemented across the globe, but formal reporting in any scientific journal is scarce (Kanga et al., 2020; Meraj et al., 2020; Ranga et al., 2020). Hence, to the best of our knowledge, we believe this study is the 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 toward COVID-19 risk-informed planning and management of the area.
Fig. 1. Location map: (a) The location of Jaipur city with respect to India; (b) The location of Jammu municipal corporation (JMC) with respect to 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.

2. 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, socioeconomic data, and biophysical data. The second step involved the integration of hazard and vulnerability to generate risk assessment. The third and final step in CRAM involved risk mapping for informed decision making and prioritizing COVID-19 risk areas using the Jaipur city’s ward-level administrative boundaries for prompt action. Individual steps are further briefly discussed below. Fig. 4 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 (Campos et al., 2020; Imdad et al., 2021; Mishra, Gayen, & Haque, 2020; Rahman, Islam, & Islam, 2020, 2021). These include various hazard, biophysical, and socioeconomic parameters, determining an area’s actual risk to COVID-19 disease (WHO, 2019). Hence, we calculated the risk by integrating 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

\[ C_{19}R_i = \text{HAZARD}_i \times \text{VULNERABILITY}_i, \]  

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

2.1. Data sets

We used census 2011 data of Jaipur city and related specific socioeconomic 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
804 Kanga et al.

Fig 2. (a) COVID-19 pandemic by South Asian Countries as of 23 November 2020, (b) Pie-chart representation of the confirmed cases only (Source: Johns Hopkins University, Coronavirus Resource Center).

Table I. 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 socioeconomic and biophysical set up of the communities, making them prone to this infection. See Sections 2.1 and 2.3 for details |

analysis. Preprocessed Worldview satellite imagery of 21 September 2019 was used for land-use/landcover (LULC) mapping to be used as a hazard component.

2.2. Hazard

We hypothesized, hazard in our study as the potential of COVID-19 posing a danger of exposure to Jaipur’s population. We used proximity to hotspots, that is, 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 (350–700 m), blue zone (700–1,050 m) and green zone (1,050–1,400 m) (Fig. 5(a)). Besides, LULC of
Fig 3. Cumulative COVID-19 deaths on January 11, and the first day of following months up to November 2020 (Source: Coronavirus Disease (COVID-19) Situation Reports. World Health Organization).

Fig 4. COVID-19 risk assessment and mapping framework (CRAM) for the JMC, Jaipur India.
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. Using ArcMap 10.1, we conducted a level-II classification of the study area using visual image interpretation technique on the Worldview satellite imagery (Beluru & Hegde, 2016; Bhatt et al., 2017; Liu, Jia, Han, & Zhang, 2018) (Fig. 5(b); Meraj et al., 2018; Meraj, Romshoo, & Altaf, 2016; Singh, 2016).

2.3. Vulnerability

In our case, vulnerability refers to the area’s susceptibility to COVID-19 infection due to its demographic, economic, and availability of clean water for sanitation conditions. As far as the current understanding of this pandemic is concerned, densely populated areas, people who do not have access to clean water for frequent sanitation, and people who need to leave their houses for livelihood are significantly more vulnerable. That is why 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 as a parameter in the vulnerability component (Fig. 6(a)–(d)).

Moreover, we digitized all the Jaipur city roads to provide routing information to the agencies dealing with this pandemic in emergencies (Fig. 1(c)). Using the kriging spatial interpolation technique, we generated a well-density layer, using well-location data in ArcMap 10.1 (Fig. 6(e)). Finally, the integration of all the layers is carried out using a GIS-based weighted overlay analysis (Pandey et al., 2010). The weights for different classes are shown in Table II and were developed using the current knowledge about these parameters in governing the infection and spread of COVID-19 pandemic (WHO, 2019).

It is to be noted that while defining the hazard and risk parameters, we categorized them into individual classes. Each class was assigned weight from 1–5, according to its role in making an area vulnerable to increased COVID-19 contagion. Weightage of
Fig 6. Vulnerability parameters (a) Total population, (b) Population density, (c) Percent literacy rate, (d) Percent main workers and (e) Well density of the JMC.
5 was assigned to a class that imposes more threat to COVID-19 contagion, for example, highest population density and built-up class. Whereas the weightage of 1 was assigned to a class that imposes the least threat to the COVID-19 contagion, for example, open-space LULC class.

### 3. RESULTS AND DISCUSSION

Fig. 5 (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 this figure’s map. 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.

#### 3.1. COVID-19 Risk Analysis of the Study Area Under JMC, Jaipur

Using Equation (1), the spatial distribution of the COVID-19 hazard, vulnerability, and risk for all the wards under JMC are shown in Fig. 7(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

| COVID-19 Risk Indicators | Classes | Weight | Index (i) |
|--------------------------|---------|--------|-----------|
| Hazard                   | Buffer Zones (in m) (PHt) | 350 | 5 | Very high |
|                          |         | 700 | 4 | High     |
|                          |         | 1,050 | 3 | Moderate |
|                          |         | 1,400 | 2 | Low      |
| 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 |
| Vulnerability            | Population density (Pd) | 2,205—21,808 | 1 | Very low |
|                          | 21,808—41,412 | 2 | Low     |
|                          | 41,412—61,015 | 3 | Moderate |
|                          | 61,015—80,619 | 4 | High     |
|                          | 80,619—100,223 | 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      |
| Total population (TP)    | 20,000–35,000 | 1 | Very low |
|                          | 35,000–50,000 | 2 | Low     |
|                          | 50,000–65,000 | 3 | Moderate |
|                          | 65,000—80,000 | 4 | High     |
|                          | 80,000—95,000 | 5 | Very high |
| 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 |
Fig 7. (a) Hazard map and area statistics, (b) Vulnerability map and area statistics, (c) Final risk map and area statistics of the JMC.
Table III. Proposed Activities in Each Risk Zone Prepared in Consultation with the Authorities Managing COVID-19 in the Area (Source: Kanga et al., 2020)

| Zone             | Health/Corona Virus Management/Isolation | Hostels | Hospitals | Marginal Labour/Day Work | Wearing of Masks/Gloves | Social Distancing | Transportation (Air/Rail/ Roads) | Use of Air Conditioning/Heat | School/Colleges | Group A Members/Daily Needs | Group B Members/Others | Recreational Areas/ Parks/Zones |
|------------------|-----------------------------------------|---------|-----------|--------------------------|--------------------------|----------------------|----------------------------------|-----------------------------|-----------------|-----------------------------|-------------------------|-----------------------------|
| **RED (Very High Risk)** | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] |
| **Orange (High Risk)** | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] |
| **Blue (Moderate Risk)** | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] |
| **Green (Low Risk)** | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] | ![ ] |

**Note:** No entries shall be allowed within red and 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.
of hazard and vulnerability components is shown in Fig. 7 (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 the 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 the pink risk zone. The risk assessment results indicate that most areas under high-risk zones (red and orange) concentrate along the north-eastern and south-western zones of the study area, with some scattered red and orange zones in east 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, these wards’ population is particularly under a more significant threat of the COVID-19 infection.

3.2. 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. 7 (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 the 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 and lower population density, and greater water availability for sanitation, as depicted in Fig. 6 (a)-(e). 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 water for sanitation. This information is vital for risk-informed planning for the eradication of the COVID-19 threat in these areas.

We propose that the wards under very high risk and high risk may be considered containment zones through extended lockdowns until the daily number of confirmed positive cases is near zero. Moreover, such areas shall need an increase in testing for COVID-19 infection to identify infected persons for isolation and quarantine. Overall, we propose a detailed management strategy shown in Table III for all the areas under different risk zones shown in Fig. 7 (c).

Currently, the COVID-19 threat is a global pandemic, and countries can combat it in the long run only through risk-informed planning. It appears that the disease will remain in the category of noncurable diseases for some time (Li G & De Clercq, 2020). 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 the 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.

4. CONCLUSIONS AND LIMITATIONS

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

The authors understand that there are scores of limitations in the proposed CRAM framework, mainly due to the incomplete knowledge of 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 area’s sanitation conditions. We recommend using water supply data if available. Further, if parameters that govern the community’s resilience to COVID-19 lethality are available, we then advise using a hazard-vulnerability-resilience-based risk assessment framework, making the CRAM more focused and broader in scope.

CONFLICTS OF INTEREST

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

ACKNOWLEDGMENTS

We thank all the three anonymous reviewers whose constructive criticism and comments on the earlier version of our article greatly improved its quality and research value. We are also grateful to Prof. James H. Lambert, Dr. Karen Lowrie, and the editor-in-chief, Prof. Tony Cox, for having full faith in our work and conducting a fast-track peer-review of the article. We further thank Suresh Gyan Vihar University, Jaipur for providing us appropriate facilities for taking up this research.

REFERENCES

Beluru Jana, A., & Hegde, A. V. (2016). GIS based approach for vulnerability assessment of the Karnataka coast, India. Advances in Civil Engineering, 2016(64), 1–10
Bhatt, C. M., Rao, G. S., Farooq, M., Manjusree, P., Shukla, A., Sharma, S. V. S. P., … Dadhwal, V. K. (2017). Satellite-based assessment of the catastrophic Jhelum floods of September 2014, Jammu & Kashmir, India. Geomatics, Natural Hazards and Risk, 8(2), 309–327.
Campos, I. S., Aratani, V. F., Cabral, K. B., Limongi, J. E., & de Oliveira, S. V. (2020). A vulnerability analysis for the management of and response to the COVID-19 epidemic in the second most populous state in Brazil. medRxiv. https://doi.org/10.1101/2020.07.20.20158345
Chongsuvivatwong, V., Phua, K. H., Yap, M. T., Pocock, N. S., Hashim, J. H., Chhem, R., … Lopez, A. D. (2011). Health and health-care systems in southeast Asia: Diversity and transitions. The Lancet, 377(9763), 429–437.
Fan, Y., Zhao, K., Shi, Z. L., & Zhou, P. (2019). Bat coronaviruses in China. Viruses, 11(3), 210.
Franklin, R., Young, A., Neumann, B., Fernandez, R., Joannides, A., Reyahi, A., & Modis, Y. (2020). Homologous protein domains in SARS-CoV-2 and measles, mumps and rubella viruses: Preliminary evidence that MMR vaccine might provide protection against COVID-19. MedRxiv. https://doi.org/10.1101/2020.04.10.20053207
Haﬁz, H., Oei, S. Y., Ring, D. M., & Shnitzer, N. (2020). Regulating in pandemic: Evaluating economic and ﬁnancial policy responses to the coronavirus crisis. Boston College Law School Legal Studies Research Paper (527). http://dx.doi.org/10.2139/ssrn.3555980
Imdad, K., Sahana, M., Rana, M. J., Haque, I., Patel, P. P., & Pramanik, M. (2021). A district-level susceptibility and vulnerability assessment of the COVID-19 pandemic’s footprint in India. Spatial and Spatio-Temporal Epidemiology, 36, 100390.
Iyer (2020). What is the economic cost of an extended covid-19 lockdown? Retrieved from https://www.livemint.com/market/mark-to-market/what-is-the-economic-cost-of-an-extended-covid-19-lockdown-1156852662704.html
Kanga, S., Sudhanshu, Meraj, G., Farooq, M., Nathawat, M. S., & Singh, S. K. (2020). Reporting the management of COVID-19 threat in India using remote sensing and GIS based approach. Geocarto International, 1–8. https://doi.org/10.1080/10106049. 2020.1778106
Koonin, L. M. (2020). Novel coronavirus disease (COVID-19) outbreak: Now is the time to refresh pandemic plans. Journal of Business Continuity & Emergency Planning, 13(4), 1–15.
Li, G., & De Clercq, E. (2020). Therapeutic options for the 2019 novel coronavirus (2019-nCoV). Nature Reviews Drug discovery, 19(3), 149–150.
Liu, P., Jia, S., Han, R., & Zhang, H. (2018). Landscape pattern and ecological security assessment and prediction using remote sensing approach. Journal of Sensors, 2018. https://doi.org/10.1155/2018/1058513
Meraj, G., Farooq, M., Singh, S. K., Romshoo, S. A., Nathawat, M. S., & Kanga, S. (2020). Coronavirus pandemic versus temperature in the context of Indian subcontinent: A preliminary statistical analysis. Environment, Development and Sustainability, 1–11. https://doi.org/10.1007/s10668-020-00854-3
Meraj, G., Romshoo, S. A., & Altaf, S. (2016). Inferring land surface processes from watershed characterization. In N. Janardhana Raju (Ed.), Geostatistical and geospatial approaches for the characterization of natural resources in the environment (pp. 741–744). Cham, Switzerland: Springer.
Meraj, G., Romshoo, S. A., Ayoub, S., & Altaf, S. (2018). Geoinformatics based approach for estimating the sediment yield of the mountainous watersheds in Kashmir Himalaya, India. Geocarto International, 33(10), 1114–1138.
Meraj, G., Romshoo, S. A., Youssuf, A. R., Altaf, S., & Altaf, F. (2015). Assessing the influence of watershed characteristics on the flood vulnerability of Jhelum basin in Kashmir Himalaya: Reply to comment by Shah 2015. Natural Hazards, 78(1), 1–5.
Ministry of Health and Family Welfare (MoHFW), Government of India (GOI) (2020). Retrieved from www.mohfw.gov.in
Mishra, S. V., Gayen, A., & Haque, S. M. (2020). COVID-19 and urban vulnerability in India. Habitat international, 103, 102230.
NSD, (2020). Centre asks states to identify pockets of critical interventions for COVID-19 management: Retrieved from http://newssoar.com/Main-News-Detail.aspx?id=387248
Pandey, A. C., Singh, S. K., & Nathawat, M. S. (2010). Waterlogging and flood hazards vulnerability and risk assessment in Ind0 Gangetic plain. Natural Hazards, 55(2), 273–289.
Pluchino, A., Inturri, G., Rapisarda, A., Biondo, A. E., Moli, R. L., Zappala, C., … Latora, V. (2020). A novel methodology for epidemic risk assessment: The case of COVID-19 outbreak in Italy. arXiv preprint arXiv:2004.02739.
Prem, K., Liu, Y., Russell, T. W., Kucharski, A. J., Eggo, R. M., Davies, N., ... Klepac, P. (2020). The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: A modelling study. *The Lancet Public Health, 5*(5), e261–e270.

Rahman, M. M., Bodrud-Doza, M., Shammi, M., Islam, A. R. M. T., & Khan, A. S. M. (2021). COVID-19 pandemic, dengue epidemic, and climate change vulnerability in Bangladesh: Scenario assessment for strategic management and policy implications. *Environmental Research, 192*, 110303.

Rahman, M. R., Islam, A. H., & Islam, M. N. (2020). Geospatial modelling on the spread and dynamics of 154 day outbreak of the novel coronavirus (COVID-19) pandemic in Bangladesh towards vulnerability zoning and management approaches. *Modeling Earth Systems and Environment, 1–29*. https://doi.org/10.1007/s40808-020-00962-z

Ranga, V., Pani, P., Kanga, S., Meraj, G., Farooq, M., Nathawat, M. S., & Singh, S. K. (2020). National Health-GIS Portal—A conceptual framework for effective epidemic management and control in India. *Preprints, 2020*. https://doi.org/10.20944/preprints202006.0325.v1

Rothan, H. A., & Byrareddy, S. N. (2020). The epidemiology and pathogenesis of coronavirus disease (COVID-19) outbreak. *Journal of Autoimmunity, 109*, 102433.

Singh, S. K. (2016). Geospatial technique for land use/land cover mapping using multi-temporal satellite images: A case study of Samastipur District (India). *Environment & We An International Journal of Science & Technology, 11*(4), 75–85.

Verhagen, M. D., Brazel, D. M., Dowd, J. B., Kashnitsky, I., & Mills, M. (2020). Mapping hospital demand: Demographics, spatial variation, and the risk of “hospital deserts” during COVID-19 in England and Wales.

World Health Organization (WHO). (2019). *Infection prevention and control during health care for probable or confirmed cases of Middle East respiratory syndrome coronavirus (MERS-CoV) infection: Interim guidance: Updated October 2019* (No. WHO/MERS/IPC/15.1 Rev. 1). Geneva, Switzerland: World Health Organization.

World Health Organization. (2020). *Considerations for quarantine of individuals in the context of containment for coronavirus disease (COVID-19): Interim guidance, 19 March 2020* (No. WHO/2019-nCoV/IHR_Quarantine/2020.2). Geneva, Switzerland: World Health Organization.