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A GEOSTATISTICAL APPROACH TO SPATIO-TEMPORAL ANALYSIS OF COVID-19 IN INDIAN HIMALAYAN REGIONS (IHR) – A CASE STUDY OF UTTARAKHAND.

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***Abstract*:** The outbreak of Coronavirus disease (COVID-19) is the most vital concern for all the regionsacross the globe now. The remote Himalayan states of India are not even untouched by the impacts of this novel virus. Uttarakhand, a state of western Himalayas, has the highest number of COVID-19 cases and deaths among all the states in Indian Himalayan Region (IHR), except the partial states as Assam and West Bengal. This study analyzes and shows the spatio-temporal patterns of COVID-19 in the state of Uttarakhand with the help of GIS and spatial modelling techniques, especially geostatistical tools. The prime focus of this study is to analyze the patterns of spatial and temporal distribution, spatial autocorrelation and identify hot-spots of the contagion in the state.

KEYWORDS: Coronavirus disease (COVID-19), Uttarakhand, Spatio-temporal Analysis, Spatial Auto correlation, Hot-spot Analysis, Geostatistical analysis, IDW, Moran's I, Getis-Ord Gi* statistics.

1. INTRODUCTION

In late December 2019, a new unknown etiological agent of severe pneumonia was reportedin Wuhan City, Hubei Province of China further tagged as 2019 Novel Coronavirus (2019-nCoV) [Zhou, P. et al, 2020, Giovanetti et al., 2020]. Afterwards, this virus is renamedas severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) and the disease is named as COVID-19 by the World Health Organisation (WHO) on 11 February 2020 [National Health Portal, India]. This is a highly transmissible viral infection and has even been declareda pandemic by the World Health Organization (WHO) on 11 March 2020 [Andersen. K.G. et al., 2020]. Globally, as of (10:21 am CEST, 8:21 am GMT and 1:51 pm IST), 25 June 2021, there have been 179,513,309 confirmed cases of COVID-19, including 3,895,661 deaths reported to WHO [Coronavirus (COVID-19) Dashboard, WHO]. Till the date, Americaswith the 71,448,935 cases has the highest number of cases among the WHO regions, followed by Europe (55,535,202), South-East Asia (34,354,123), Eastern Mediterranean (10,827,780), Africa (3,880,790) and Western Pacific (3,465,715) [Coronavirus (COVID-19) Dashboard, WHO]. Highest number of COVID-19 cases are in United states of America (33,257,768) followed by India (30,082,778), Brazil (18,169,881), France (5,653,580) and Russian Federation (5,388,695) till 8:21 am GMT, 25 June 2021 [Coronavirus (COVID-19) Dashboard, WHO]. India, the second most populous country in the world after china accountsfor almost one-fifth of the world's population (Census, 2011), is also facing COVID-19 pandemic since the first SARS-CoV-2 positive case was reported in the state of Kerala on January 30th, 2020. Subsequently, the number of cases drastically rose [Kumar S. Udhaya et al., 2020]. As of 1:51 pm IST, 25 June 2021, India reported the second highest number of COVID-19 cases (30,880,778) after the USA in the world [India, WHO]. Maharashtra state has the highest number of cases 6,007,431 followed by Kerala (2,854,325) and Karnataka (2,823,444), on the other hand Andaman and Nicobar Islands has the lowest number of cases 7440 followed by Lakshadweep (9601) and Dadra and Nagar Haveli & Daman and Diu (10,526) [MyGov.GOI]. The impact of COVID-19 outbreak in India intensely affects the urban centers and populous regions but the remote Himalayan regions do not remain untouched despite having comparatively low accessibility and connectivity with the outer world, lower number of urban centers, towns and population density. Among Indian Himalayan regions (IHR), Uttarakhand has the highest number of confirmed 339,373 cases and 7,083 deaths followed by Jammu and Kashmir (313,476) and Himachal Pradesh (201,210) [MyGov.GOI]. With low infrastructural facilities, lack of doctors, skilled people and resources, it is very difficult to track the trend and spatial distribution of pandemic in the Himalayan states especially when disease can travel so quickly. Geographic information systems (GIS) and methods including advanced spatial statistics and analyst tools are vitalkey elements of epidemiologic research nowadays. Online real or near-real time mapping of spatio-temporal distribution of diseases, dynamics, vulnerability analysis, hot-spot identification, predictive risk mapping and many more are proving inevitable data and information for the timely understanding of the disease

source, dynamics, epidemiology, and in shaping our effective response to it. Indeed, health professionals have long considered conventional mapping, and more recently geographic information systems (GIS), as critical tools in tracking and combating pandemic situations such as COVID-19 [Kamel Boulos, M.N., Geraghty, E.M., 2020]. Geospatial and Statistical modelling in the field of epidemiology in small areas have been developed in order to solve problems such as the identification of disease clusters and hotspots. Some of the principal spatial techniques for emerging infectious diseases (EID) briefly explored by Robertson & Nelson are global spatialautocorrelation, spatial time interactions, hotspots mapping and cluster analysis. [Robertson, C., & Nelson, T. A., 2014]. Understanding the spatio-temporal pattern, clustering and distribution of Covid cases in Uttarakhand with the use of geospatial and statistical analysis approach, will help in informing, responding and controlling Covid pandemic situations at a smaller scale especially in remote Himalayan states. The aim of this research is to analyze thespatio-temporal distribution of COVID-19 and its trend and clustering to predict the spread ofdisease in the state Uttarakhand with the help of geospatial and statistical approach.

2. MARERIALS AND METHODS

2.1 Study Area

Popularly known as Devbhoomi, Uttarakhand is one of the most scrumptious states of northern India. Adorned in the lap of Himalayas, with its incredible scenic landscapes, alluring hill stations nestled with snow-capped peaks, unco villages along serpentine mountain roads and rivers, this state was carved out from Uttar Pradesh in the 2000. Stretches between 28º 43' N to 31º 28' N and 77 º 34' E to 81 º 03' E, Tibet marks it's boundary from north, Nepal from east, Uttar Pradesh from south and Himachal Pradesh from west and north-west. Administratively, the state is divided into two regions, Kumaon and Garhwal, which further breaks into 13 districts [Bisht. H.S. 2020]. Out of its total area (53,483km2), 93% is mountainous mainland, of which, 19% area is under permanent snow cover, glaciers and steep slopes. State can be divided mainly into four physiographic zones – the Greater Himalaya, Middle Himalaya, Shivalik ranges and Doon and Terai regions. Climatic conditions vary from subtropical to temperate and frigid cold with temperature ranging from sub-zero to 43ºC along with average annual rainfall of 1550 mm [Sati V.P., Bandooni S.K., 2018]. According to the Census of India 2011, Uttarakhand has a population of 10,086,292, of which 69.77% of the population lives in rural areas. Having 0.83% of the population on 1.63% of the land, Uttarakhand is the 20th most populous state/UT of the country and second most populous state/UT among Indian Himalayan Regions (IHR) after Jammu and Kashmir [Census of India, 2011]. The main reasons for selecting Uttarakhand as the study area, because it has reported the highest number of COVID-19 cases and deaths among IHR. Also, Uttarakhand has the highest degree of vulnerability among IHR mainly due to high connectivity, accessibility, urbanization and migration. All these factors are so critical for COVID-19 transmission in Uttarakhand.

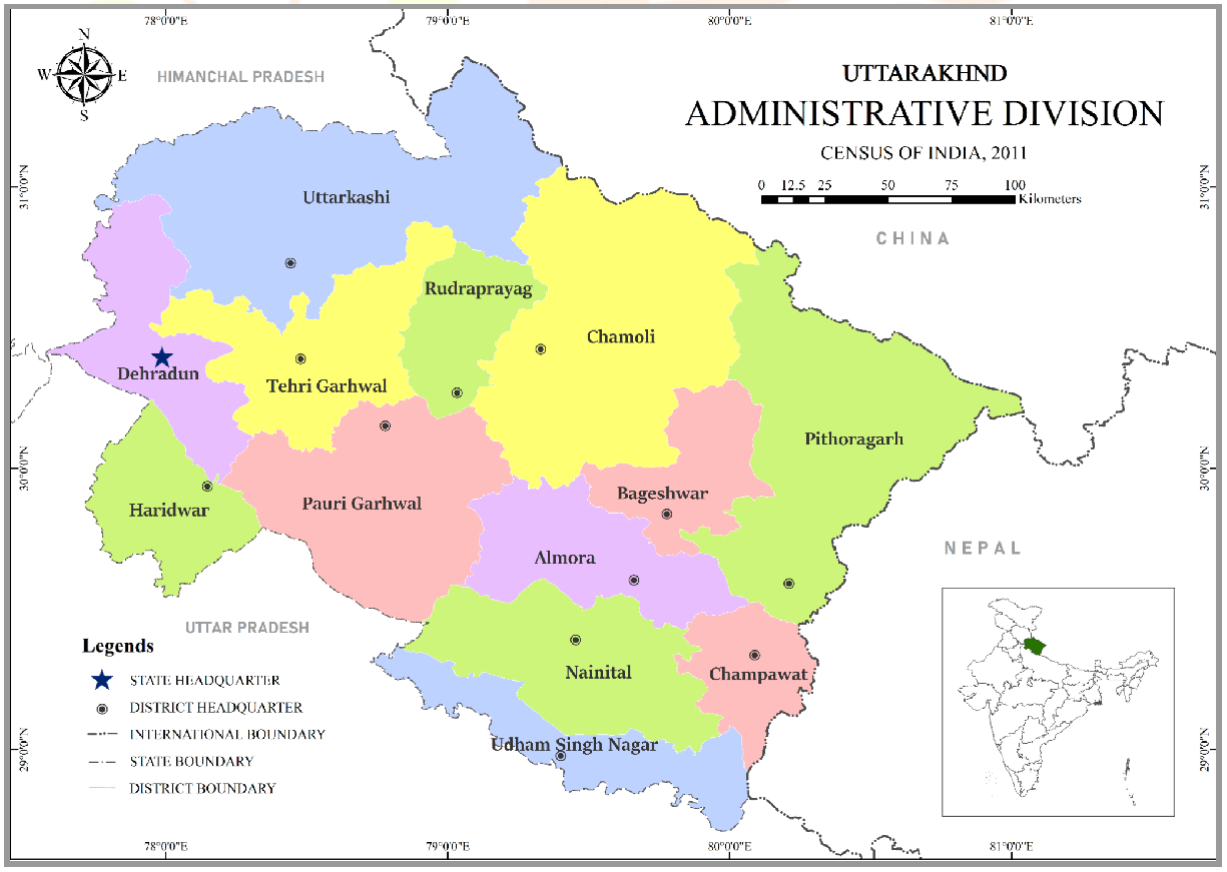

Fig.1 Locational Map of the study area.

2.1 Source of Data Collection

The data incorporated in this study is collected from daily health bulletins available on the official website of the Directed of Medical Health & Family Welfare, Government of Uttarakhand [Covid19 Health Bulletins for Uttarakhand] from 15th of March 2020, when the first COVID-19 positive case identified in the state, up to the latest 25th of June 2021 in monthly terms. These reports consider all the data from districts as well. In this report, the confirmed Covid positive cases, deaths due to Covid, sample datasets and even vaccination datasets along with the transmission types are considered.

2.1 Data Analysis

2.1.1 Spatio-temporal Analysis

The spatio-temporal analysis was performed using the inverse distance weighted (IDW) spatial interpolation technique using ArcGIS (ArcMap10.7.1). Inverse Distance Weighted (IDW) is one of the most widely known interpolation techniques and used by earth scientists [Ware, Knight, and Wells, 1991]. It is used to predict the values for any undetermined zones by calculating the predicted zone of the areas in the neighborhood. The IDW assumes that each input discrete data has a local influence that decreases with distance, and the extent of the influence is directly related to the inverse of the range between the discrete points [Bagyaraj, M. et al. 2020]. The following equation was used for the analysis [Bartier P.M., Keller C.P., 1996].

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

where Z_{xy} is the point to be estimated, Z_i represents the control value for the ith sample point, and W_i is a weight that determines the relative importance of individual control point Z_i in the interpolation procedure. In this study, district headquarters were used as the input points features and cumulative number of COVID-19 positive cases were the z-values to be interpolate. The power and radius variables were used as default, 2 and 12 respectively. Power controls the significance of surrounding points on the interpolated value for each cell in the output interpolated raster, The IDW was calculated from 15th of March to 25th of June to analyze the spatio-temporal change of the pandemic in the state.

2.1.2 Spatial Autocorrelation

Spatial autocorrelation analysis was also used to test the spatial distribution of COVID-19 cases over geographical space. This study employed the Global Moran's I spatial autocorrelation tool, an inferential statistic that measures spatial autocorrelation based on both feature values location simultaneously. The set of features and associated attributes evaluated whether the pattern expression is random, dispersed or clustered. The tool calculates the Moran's I Index value, p-value and z-score to evaluate the significance of that Index. The outcomes of the analysis are always interpreted in the context of its null hypothesis which states that the spatial processes promoting the observed pattern of values are randomly distributed. Inverse distance was used in this study which defines the conceptual spatial relationship that close neighboring features have larger influence than features that are far away with Euclidian distance method. The index is expressed as follows [Moran P.A.P. 1950]:

$$I_x = \frac{n}{\Sigma_i \Sigma_j w_{ij}} \frac{\Sigma_i \Sigma_j w_{ij}(X_j - \overline{X})}{\Sigma_i (X_i - \bar{X})^2}$$

where n is the number of regions under analysis, X_i is the attribute value of the considered region i, X_j is the attribute value of the considered region j, $\overline{X}$ is the calculated mean of the selected variable and w_{ij} is the spatial weight between feature i and j and $\Sigma_i \Sigma_j w_{ij}$ is the aggregation of all spatial weights.

2.1.3 Hot-Spot Analysis

The Hot Spot Analysis was calculated by the Getis-Ord Gi* statistic (pronounced G-i-star) tool to identify the significant clusters with a high frequency of COVID-19 positive cases in Uttarakhand. The both resultant z-score and p-value represent the spatial clustering of the features, either high or low. Having a low negative z-score with a small p-value is an indication of spatial clustering of low values (i.e.,a cold spot), whereas having high positive z-score and a small p-value reveals the presence of hot spots (spatial clustering of high values) [Grekousis G. 2020]. The statistic is;

$$G_i^*(d) = \frac{\sum_{j=1}^{n} w_{ij}(d) x_j}{\sum_{j=1}^{n} x_j}$$

where d is the estimated range of observed spatial autocorrelation, $w$ij is a symmetric spatial weight matrix with ones for all links defined as being within distance d of a given i; n is the total number of observations and x is the attribute value of feature j. In this study the cumulated number of COVID-19 positive cases as of 25th June 2021, were used as input numeric fields. Fixed distance band of 57301.95 meters was used as conceptualization of spatial relationship, which was calculated by incremental autocorrelation, and the distance method was Euclidean.

3. RESULTS

The first SARS-CoV-2 positive case was reported in the state Uttarakhand on March 15th, 2020. Subsequently, the number of cases drastically rose. With a total number of 339,373 confirmed positive cases, 7,083 deaths and death rate of 2.09% (As of 06:30 pm IST, 25 June 2021), Uttarakhand is the highest affected state among IHR now. All statistical data were processed using Microsoft Excel version 11.0 to analyze the trend of COVID-19 in the state and among districts too.

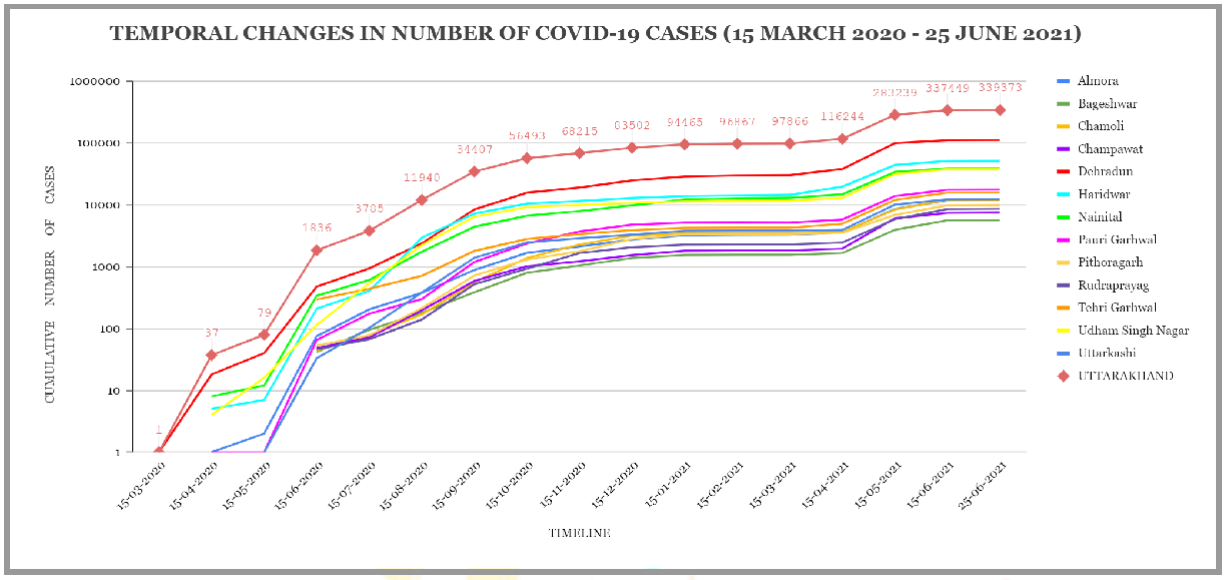

Fig.2 Temporal changes in number of COVID-19 cases in Uttarakhand.

As shown in Fig.2, the highly affected districts are Dehradun, Haridwar, Nainital and Udham singh nagar. All these districts are highly urbanized, populated, accessible and connected to the other parts of India in comparison to the high-altitude hilly districts. 61.38 % of the state's population live in these 4 districts and the remaining 38.62 % population is distributed in the other 9 districts. The trend of positive cases in the state shows an exponential growth till December 2020 but then a stable situation till April 2021 and again rising rapidly till June 2021. District Bageshwar has shown the minimum impact of pandemic as the lowest number of cases and even remains low in comparison to the other districts throughout the time period. Followed by Champawat, Rudrapraya and Pithoragarh. All these are high altitude districts and have low degree of connectivity to the outer world in comparison to the other districts.

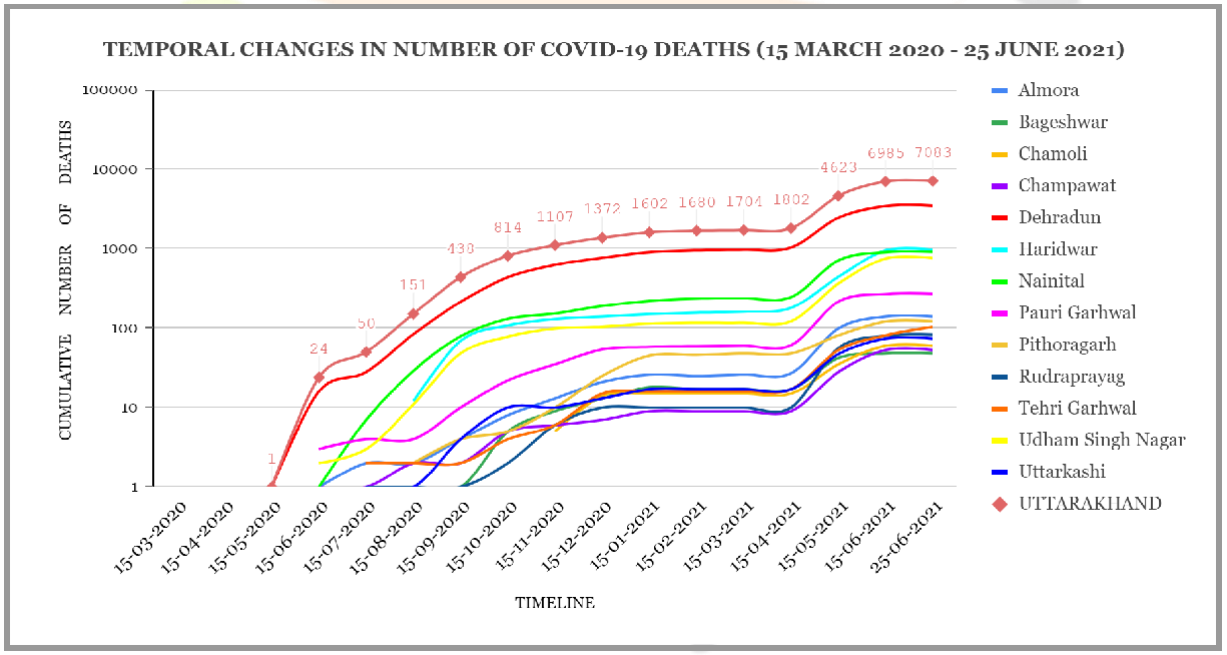

Fig.3 Temporal changes in number of COVID-19 deaths in Uttarakhand.

The first death reported due to SARS-CoV-2 in the state Uttarakhand in the month of May, 2020 particularly from the district Dehradun and till the recent date in consideration, Dehradun reported the highest number of deaths as 3486 out of total number of deaths in Uttarakhand (7083). It means around 50% deaths in the state alone reported from the district Dehradun. On the other hand, district Bageshwar (48) recorded the lowest number of casualties followed by Champawat, Chamoli and Uttarkashi.

3.1 Spatio-Temporal Analysis of COVID-19

With the help of IDW, the degree of contagion was identified throughout Uttarakhand from the very first day of positive case reported to the latest date considered in his study, 25th of June 2021. The results show that the western part of the state was primarily affected by the virus, which includes Dehradun and Haridwar districts. The disease spread to the eastern direction and further infected the zones in the neighborhood. Apart from the western clustering of the disease, the south-east region was also infected rapidly after April 2020, which includes the district Nainital and Udham singh nagar.

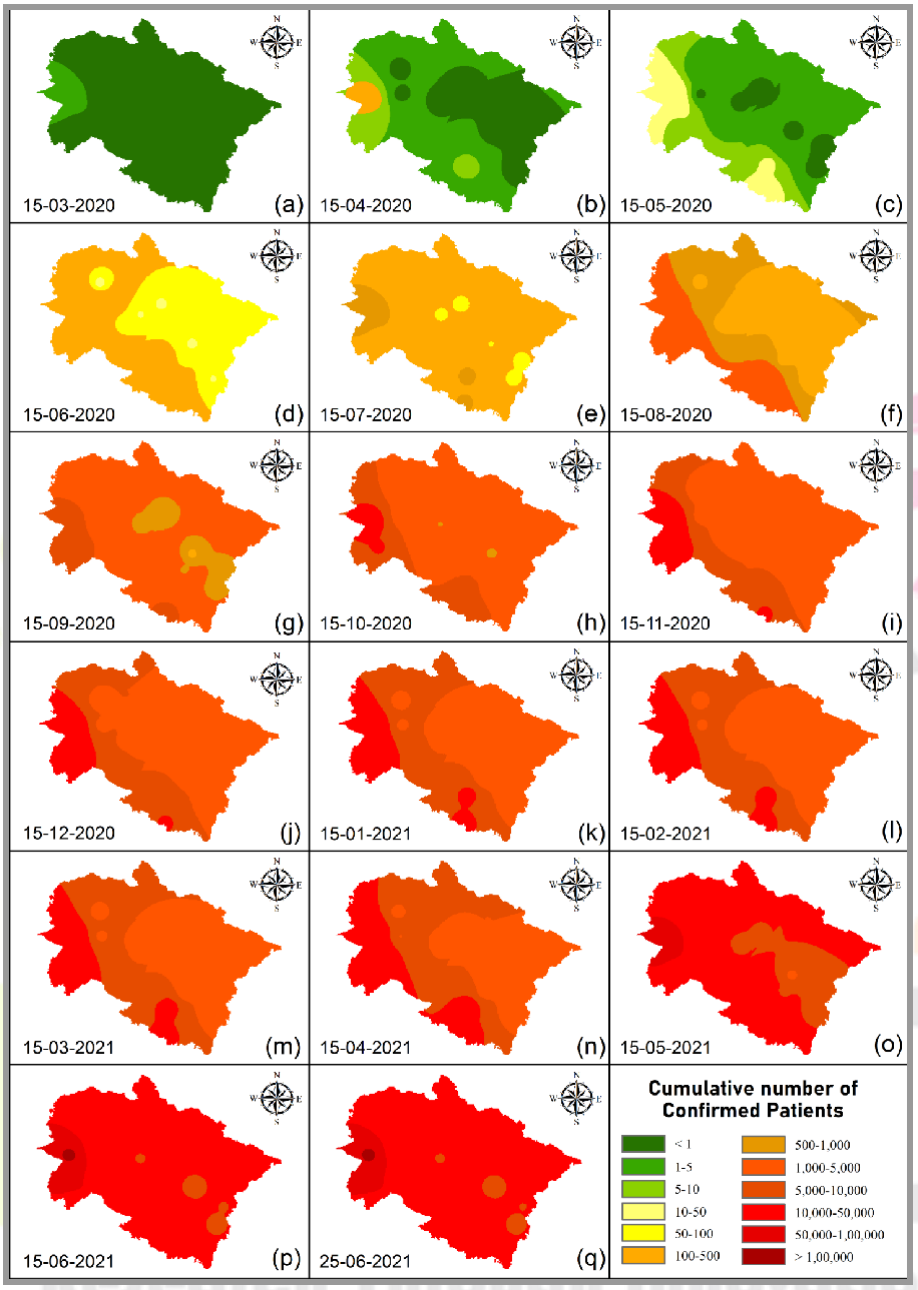

Fig.4 Spatio-Temporal changes in COVID-19 in Uttarakhand.

Both the western and south-eastern clustering of the COVID-19 in the state seems to be responsible for further outbreak of contagion. Till the month of June 2020, the whole state is under the influence of SARS-CoV-2. As shown in Fig.4 (h), the western clustering of the disease still continues to intensify and reach to the mark of 10,000 positive cases in the monthof October 2020. Till June 2021, the number of SARS-CoV-2 positive cases cross the mark of10,000 throughout the state and the western zone of contagion recorded more than 1,00,000 positive cases, which means around one third COVID-19 positive cases in Uttarakhand are reported from the western zone which includes the district Dehradun and Haridwar.

3.2 Spatial Autocorrelation

Fig.5 shows the report of the spatial autocorrelation data calculated through Moran's Istatistics on the cumulative COVID-19 positive cases as on 25th of june 2021. Results show statistically relevant findings from global Moran's I test as z scores was above *1.67* which suggest spatial heterogeneity in the data and significant P value at 90% confidence level. Apositive value of Moran's Isuggests positive spatial autocorrelation which means a combination of high values (Hot-spots) and low values (Cold-spots). The largestMoran's I value indicated thestrongest spatial autocorrelation of Covid affected zones. The *Moran's Index* of *0.285019*, *z-score* of *1.679917* and *p-value* of *0.092974* clearly shows that the distribution of SARS-CoV-2 positive cases in Uttarakhand is not random but significantly clustered.

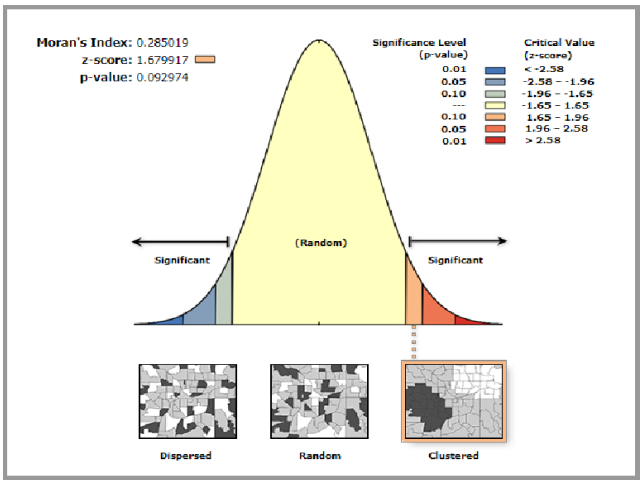

Fig.5 Spatial Autocorrelation Report.

6. Hot-Spots of COVID-19

The geographical location of the COVID-19 hotspots in the state was identified by Getis-Ord Gi* tool and presented on the map of Uttarakhand as Fig.6. The value derived through Getis-Ord Gi* statistics including *z-score* and *p-value*, *neighbors value* and *confidence levelbin*. In this study, the z-score values were significant at a < 0.01 level and high z-score indicate positive spatial auto-correlation. Hence, we could reject the null hypothesis of complete spatial randomness (CSR). The spatial distribution in the data set of high and low values of Covid was spatially clustered. Tool evaluates each Covid infected district and compares the regional situation with the global situation in the neighboring districts.

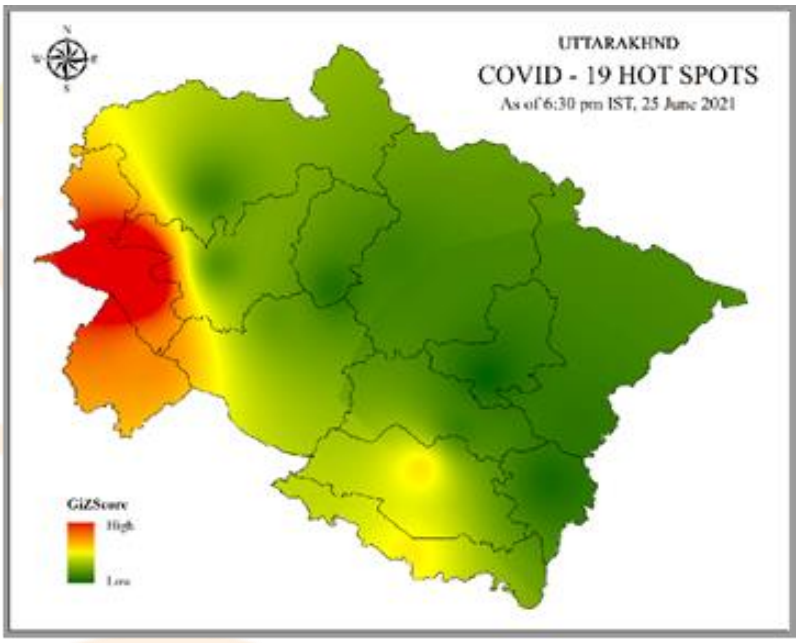

Fig.6 COVID-19 Hot-spots in Uttarakhand

Analysis indicates that 1 hotspot with 99% confidence level (district Dehradun) and another 1 with 95% confidence level (district Haridwar) recorded from thewestern region of the state with highest z-score 3.02 and 1.5 respectively. The southern zone of the state also presents the high z-score values comprising the districts as Udham singh nagar and Nainital. On the other hand, eastern and northern districts show low z-score with low p-value, which means a significantly dispersed pattern of the spatial distribution of COVID-19 positive cases.

7. CONCLUSION

This study employed the GIS and spatial modelling techniques especially geostatistical tools to analyze and show the spatio-temporal patterns of COVID-19 in the state Uttarakhand. The inverse distance weighted (IDW) spatial interpolation, Global Moran's I spatial autocorrelation and the Getis-Ord Gi* statistics were particularly used to analyze and identifythe patterns of spatial and temporal distribution, spatial autocorrelation and hot-spots of the contagion in the state, respectively. The research findings indicated that the western part of the state was primarily affected by the virus (SARS-CoV-2) in mid-March 2020, then began to spread towards eastern direction and further infected the zones in the neighborhood. The trend of positive cases in the state shows an exponential growth till December 2020 but then astable situation till April 2021 and again rising rapidly till June 2021 and still continues. The geographical distribution of COVID-19 in Uttarakhand is found heterogeneous and clustered in the western regions intensely. Apart from the western clustering of the disease, the southern and south-eastern region was also infected rapidly after April 2020. With a higher number of positive cases, the western districts of the state also recorded a high number of deaths due to contagion. More than 60% casualties were recorded from the district Dehradun and Haridwar only, and even district Dehradun is solely responsible for 50% casualties out oftotal human loss in the state due to Covid. The findings of COVID-19 hot spots in Uttarakhand shows district Dehradun and Haridwar as major hot-spots followed by district Nainital and Udham singh nagar. The high-altitude northern districts are not much affected in comparison to the lower altitude southern districts. The state government, health departments,provincial health officers and other responsible departments and bodies should focus in these zones and try to control the contagion in its primary place. If the contagion outbreak begins to spread northward, the situation will become even worse as all the northern districts are Uttarkashi. Rudraprayag, Chamoli and

Pithoragarh are remote districts, full of inaccessible zones and mountainous terrain. The spatial and temporal clusters can also try to empower andendorse highly efficient, effective, locally adapted procedures for the highly spatially heterogeneous COVID-19 disease. Similarly, the study indicates, by focusing where and when available public health facilities and resources should be focused, will aid in managing viral diseases such as COVID-19.

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