Spatial and Temporal Mapping of COVID-19 Pandemic Using GIS Technique: A Case Study of Italy

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Abstract
Coronavirus pandemic disease (COVID-19) has spread globally. Presently, there is insufficient data regarding clinical studies and its epidemiological features. However, it is comprehended that most of the COVID-19 infected patients show mild to moderate symptoms which improve without any medical assistance attributing to enhanced immune system by generating antibodies against the viral antigens. In this comparative study, the active cases, recovered cases, deaths, and total confirmed cases from January 2020 to 23rd August 2021 have been analyzed using a geospatial technique inverse distance weighting (IDW). Until latter, the total number of COVID-19 cases reported in Italy were 4,168,699 including 128,715 deceased, 3,904,429 recovered and 135,555 cases were still active carriers. Out of total cases 20.76% were reported in Lombardia region with a death rate of 26.26%. This mortality rate was found higher in comparison with rate followed by Emilia-Romagna (10.35%), Piemonte (9.10%), and Vento (9.06%). While percentage of recovery was found variable i.e. in Lombardia 20.98%, followed by Veneto 10.89%, Campania 10.88% and Emilia-Romagna 9.72%. COVID-19 evolution in Italy has majorly affected the urban area i.e., Rome, Milan, Naples, Bologna, and Florence. Geospatial technology played a vital statistical role by tracking infected patients, active cases, and the recovered cases. Thus, it is acknowledged that geospatial techniques are an important tool in statistical evaluation of disease spread and their control among populations.

1. Introduction

A deadly B-coronavirus (CoV) pandemic, with patients presenting with cases of extreme pneumonia, has spread globally since origination in Wuhan, China in December 2019. It was initially designated as novel coronavirus (2019-nCoV) by WHO and has also been labeled coronavirus disease 2019 (COVID-19) (Lu et al., 2020, World Health, 2015, Gorbalenya et al., 2020, Huang et al., 2020 and Wang et al., 2020). The International Committee on the Taxonomy of Viruses (ICTV) termed it as SARS-CoV-2 virus based on its similarity to the severe acute respiratory syndrome coronavirus (SARS-CoV) (Gorbalenya et al., 2020).

Universally COVID-19 has affected around 213 million people with 4.4 million deaths reported to WHO (WHO, 2021). Even though Chinese researchers were able to provide the SARS-CoV-2 genome sequence (Lu et al., 2020) but continuous human to human transmission of this contagious virus has produced devastating effects on the human health sector. Not only human health but also world's economy has been negatively impacted to an unprecedented level (Chan et al., 2020). The potential public health risks of COVID-19 are quite high and detrimental (Gao, 2018 and Cascella et al., 2020).

In Italy, between 29th January and 16th June 2020, there have been 238,720 confirmed cases of COVID-19 with 34,345 deaths reported (WHO, 2020). The fatality rate of COVID-19 infected persons in the Italian population, based on data up to March 17, was estimated to be 7.2% (Livingston and Bucher, 2020). This rate is comparatively higher than other regions of the world, for reasons based on numerous factors, such as testing strategies and population age (Onder et al., 2020), etc. The increased mortality burden has required national and international governments to employ strategies and policies worldwide to limit the spread and transmission of this contagious virus, via social distancing and other means, such as the use of personal protective equipment, face masks and sanitizers, etc. (Dowd et al., 2020).

Various clinical manifestations are associated with COVID-19, including a serious decline in lung function, pneumonia etc. Infected carriers may have mild to moderate symptoms or be asymptomatic (Wu and McGoogan, 2020). Increased mortality rates are observed for individuals with a pre-existing respiratory malfunction, prior asthma, any other lung disorder. Serious illness caused by COVID-19 has been clinically treated with mechanical support via ventilators and by maintaining sufficient oxygen saturation levels (Berlin et al., 2020). With the latest reports and data, studies have investigated virus' features, disease transmission, and incubation as well as management protocols (Brochard et al., 2017 and Cascella et al., 2020).

Researchers have employed various techniques and strategies to address the spread of SARS pandemics (Center, 2020 and Gatto et al., 2020). Keeping various variables such as availability of appropriate health care systems and measurements to keep up the pace with patients' needs such as isolation practices and continuously emerging spread have led to several research studies in this domain. In addition to these measures, spatial distribution analysis and explicit geographic models are needed to predict and estimate the time series analysis of COVID-19 pandemic. The demand of geospatial mapping in health sector started in 20th century (Friede et al., 1993, Baker et al., 1995 and Yu and Edberg, 2005) which led to growth of information technology (IT) in the health care system. Advances in IT and its amalgamation with spatial data analysis led to the development of visualization tools for disease burden (Schriml et al., 2009 and Robertson and Nelson, 2010). Geospatial technology is a useful tool for disease mapping with its spatial and temporal information utilizing the geographical distribution of the disease (Bergquist and Rinaldi, 2010 and Saran et al., 2020).

The present study was conducted on COVID-19 spread using the GIS and mapping approach. Geospatial tools can be of essential value for obtaining knowledge, developing treatment center, understanding trends, and the mitigation of the disease. Together, these tools/methods can facilitate the design, planning, and distribution of international health aid for treatment and prevention services (Murugesan et al., 2020). The objective of the study is to provide the Spatio-temporal mapping of COVID-19 in Italy using geospatial technology for statistical evaluation of the viral spread. And to understand the influence of population density and COVID-19 cases in Italy.

1.1 Study Area

Italy is located in South-Central Europe but is considered a part of western Europe, with its capital is Rome. The total geographical area of Italy is 301,340 Km^2. It shares borders with France, Switzerland, Austria, and Slovenia. Geographically Italy consists of a peninsula delimited by the Alps mountains in the north and surrounded by sea and various islands. Italy is the third most populous country of European Union member states. The major cities in Italy are Rome, Milan, Naples, Bologna, Florence, Turin, and Genoa. According to 2019 data, the total population of Italy is 60,317,116 with a population density of 200.16 people/Sq.km (Figure 1). Most populous region I Italy is Lombardia while the least is Valle d'Aosta (Figure 1).

The overall representation of COVID-19 statistics in Italy are shown above in Figure 2. A total of 4,168,699 cases were reported from the last week of January 2020 till date. Out of the total 4,168,699 cases, 93.66% have completely recovered, but unfortunately 3.09% of the infected people lost their lives while fighting the deadly virus and 3.25 % cases are still active (Figure 2).

2. Material and Methods

COVID-19 data for Italy was obtained from various sources (ISS, 2020, MOH, 2020 and Outbreak, 2020). The data used in this study are the number of COVID-19 confirmed cases, deaths, active patients, and recoveries. In the present study, to show the pattern of disease transmission and forecast, an interpolation technique was used, specifically, the Inverse Distance Weighted (IDW) method. Initially the data was downloaded from available sources, and it was set according to the objective of the study. The downloaded data was in excel sheets for all regions of Italy with its latitude and longitudinal information, number of confirmed cases, deaths, recoveries, and active cases. The shapefile of regions of Italy was downloaded from (DIVA-GIS) website. Consequently, the shapefile of regions was imported to ArcGIS software, the excel file with latitude and longitude information was also imported to the software and then converted it to shapefile format, eventually, the IDW technique was applied on it and maps of total cases, total deaths, total recovered cases and active cases were prepared in ArcGIS software.

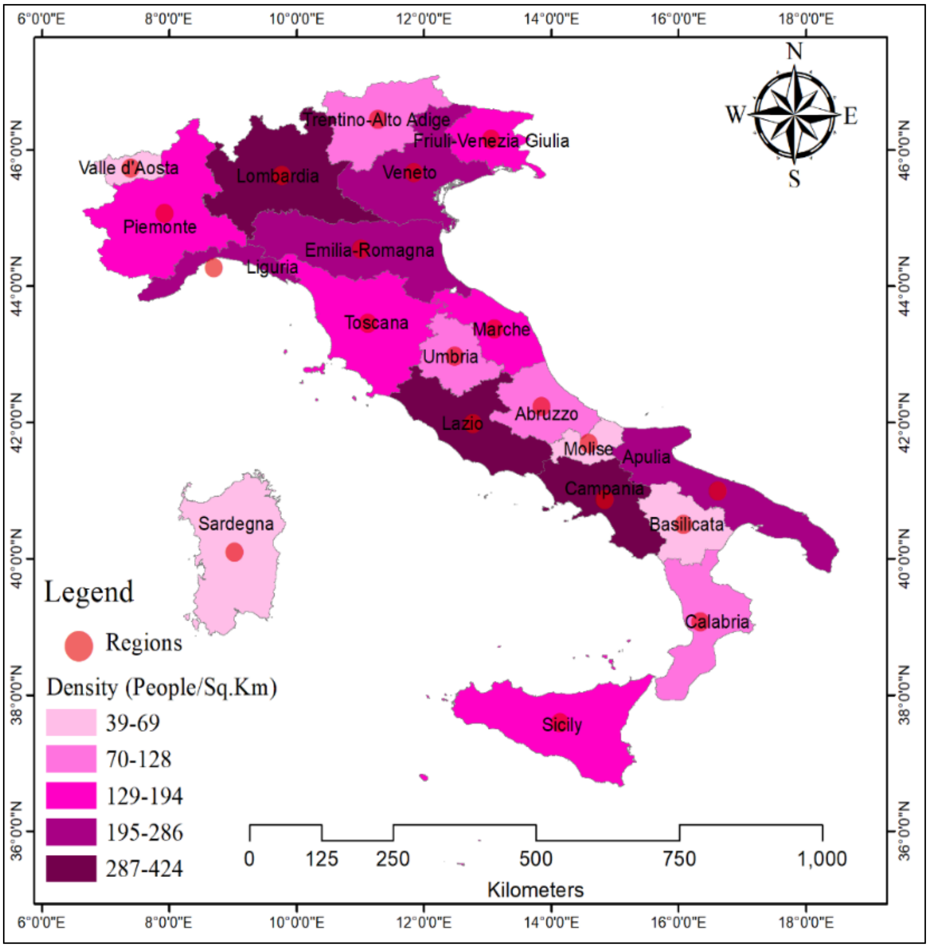

Figure 1: Study area and population density/Sq.km

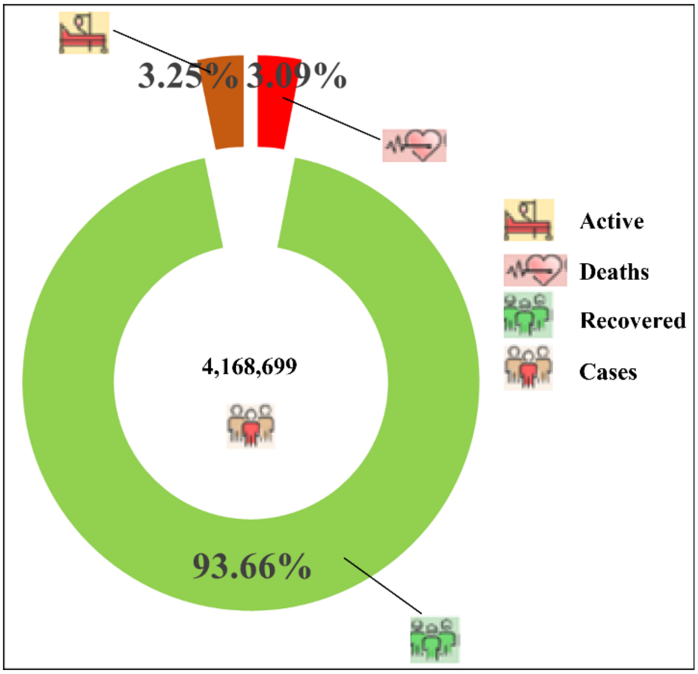

Figure 2: Statistics of COVID-19 in Italy (23rd August 2021)

2.1 Interpolation IDW

IDW is based on the concept of Tobler's first law (the first law of geography) from 1970. It states that everything is related to everything else, but nearer things are more related than distant things. The IDW was developed by the U.S. National Weather Service in 1972 and is classified as a deterministic method since it does not require calculations to meet specific statistical assumptions. Thus IDW is different from stochastic methods (e.g., Kriging and TRA) (Chen and Liu, 2012). The spatial interpolation (IDW) method is based on the function of inverse distances, in which weight increases as the distance decreases and vice versa. This means that data points with known values are used to estimate the values of unknown points. The necessities of known points are to discriminate spatial interpolation from isopleth mapping, which uses allocated points such as polygon centroids for interpolation.

Basic theory in spatial interpolation is the value to be assessed at any point is more influenced by near known points than those that are farther away. While the assumption of a random process is usually mandatory for a stochastic method, Inverse Distance weighted (IDW) interpolation is an exact method that estimates the value of a point that is influenced by nearby known points, more than those farther away. The general equation of the IDW method is:

$$K_{xy} = \frac{\Sigma_{i=1}^{N} K_i W_i}{\Sigma_{i=1}^{N} W_i}$$

Equation 1

where K_i is the control value for the Ith sample point, W_i represents a weight determining the relative importance of individual control point K_i in the interpolation process, K_{xy} is the point to be estimated and N is the number of sample points (Bartier and Keller, 1996).

3. Results

There was a total of 4,168,699 cases reported between January 2020 and 23rd August 2021 (Table 1). In this study, the regional data was collected and linked with the point data. The data from 20 regions in Italy were analyzed to determine variability. The IDW technique showed the status and magnitude of the infection disease spread (COVID-19) in Italy using ArcGIS 10.5. Interpolation using IDW was applied to predict the spread of the coronavirus in Italy. As of August 23rd, 2021, a total of 135,555 (3.25%) COVID-19 cases are still active in Italy. The map obtained from IDW of active cases as of 23rd August 2021 was divided into eight classes using the natural break classification method. The patterns of classes were below 4,759, 4,760 to 5,982, 5,983 to 7,299, 7,300 to 8,709, 8,710 to 10,403, 10,404 to 13,224, 13,225 to 17,739, and more than 17,7340, as shown in Figure 3(a).

Table 1: Region wise breakdown of COVID-19 Statistics in Italy

Region	Cases	Deaths	Recovered	Active
Abruzzo	78323	2520	73550	2253
Apulia	261641	6694	250316	4631
Basilicata	28444	597	26569	1278
Calabria	75549	1299	70194	4056
Campania	441753	7682	424701	9370
Emilia Romagna	407449	13324	379393	14732
Firuli Venezia Giulia	109913	3796	105206	911
Lazio	371257	8484	345696	17077
Liguria	108599	4378	102195	2026
Lombardia	865282	33800	819181	12301
Marche	109115	3045	103124	2946
Molise	14139	493	13458	188
Piemonte	50660	11711	35367	3582
Sardegna	69674	1560	60221	7893
Sicilia	265673	6239	235288	24146
Toscana	266785	6978	247610	12197
Trento	121791	2549	118147	1095
Umbria	60876	1427	57562	1887
Valle d Aosta	11982	473	11362	147
Veneto	449794	11666	425289	12839

**Ministry of Health, Italy (23rd August 2021)*

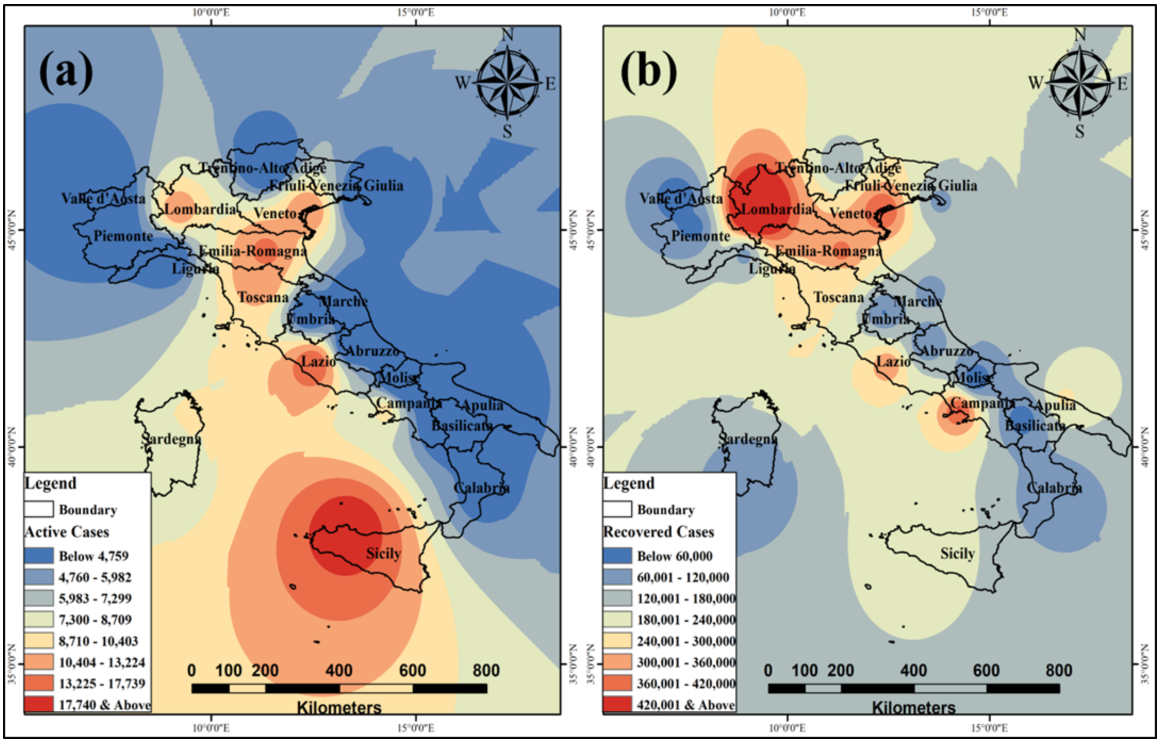

Figure 3: Spatial distribution of Coronavirus in Italy (a) Active cases (b) Recovered cases

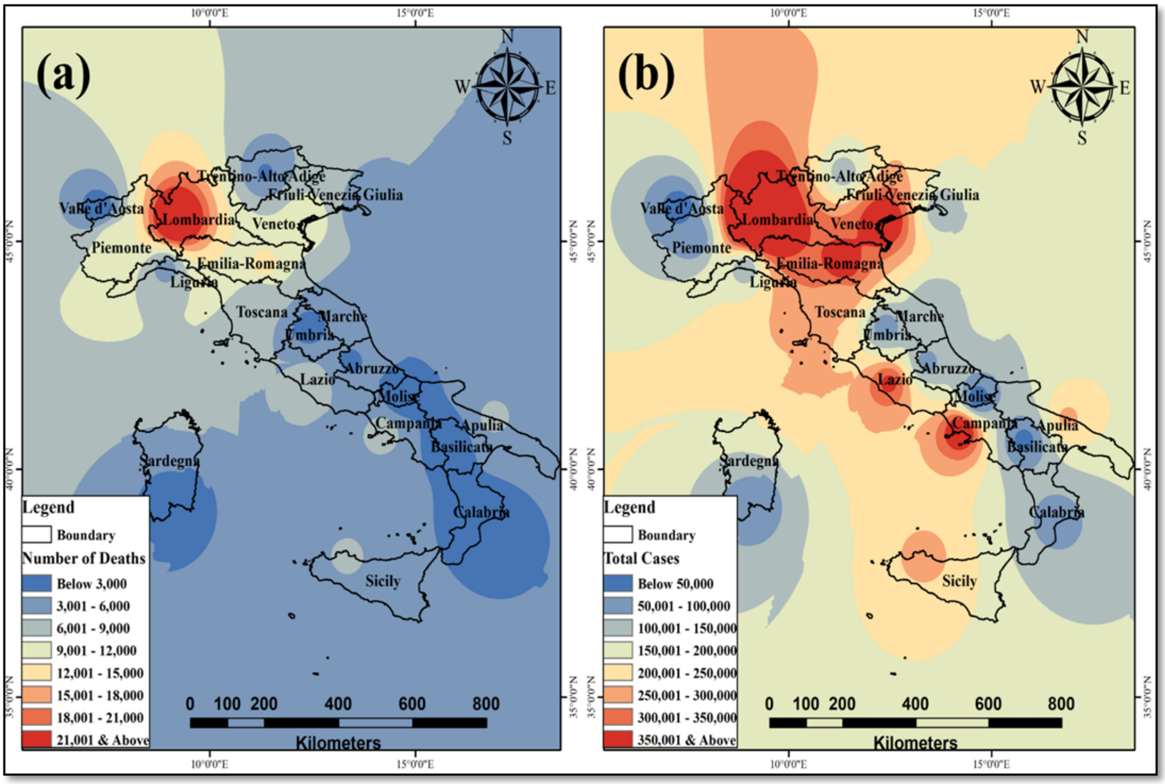

Figure 4: Spatial distribution of coronavirus in Italy (a) Total deaths (b) Total cases

Table 2: Association between population density and COVID-19 variables using Pearson correlation

Variables	Test Statistics (t)	Degree of freedom (df)	P value	Correlation Co-efficient
Active Cases	2.929	18	0.009	0.323
Total Deaths	2.727	18	0.014	0.292
Recovered Cases	2.867	18	0.010	0.313
Confirmed Cases	2.898	18	0.010	0.318

The various regions in Italy are at higher risk based on population density. A higher number of active cases was revealed in the Sicily region (18%) followed by Lazio 12% and 20% of active cases found in northern regions (Lombardia, Emilia Romagna). To understand the influence of population density and COVID-19 cases, a Pearson correlation coefficient was performed using COVID-19 data. There was a positive correlation seen in the number of active cases and population density [where $r(18) = 0.323$)] (Table 2).

Figure 3b showed the spatial distribution of recovered cases. It can be observed that densely populated region (Lombardia) has the highest number of recovered cases which is followed by Campania and Veneto (10.88% & 10.89%) respectively. The data presented in Table 2 shows positive association between recovered coronavirus cases and population density [where $r(18) = 0.313$)]. A total of 128,715 deaths have been officially reported as of 23rd August 2021 in Italy. According to the Ministry of Health, Lombardia region, which has a population density of 421 people/Sq. Km, alone reported 33,800 deaths due to coronavirus. Nearly 13,324 (10.35%), 11,666 (9.06%), 6978 (5.42%) and 6694 (5.20%) deaths have been reported in the regions of Emilia-Romagna, Veneto, Toscana and Apulia, respectively (Figure 4a). Table 2 clearly depicts the relationship between total deaths caused by COVID-19 and population density [where $r(18) = 0.292$)].

After Wuhan, China, Italy was the next hotspot of infectious virus. The first corona positive case was detected in Italy on the 31st of January, 2020 when two Chinese tourists visited Rome (Severgnin, 2020) and a week later an Italian man returned from China and was found to be positive (Anzolin and Amante, 2020). Later a cluster of positive cases was detected in the Lombardia region (Elisa Anzolin, 2020 and Ravizza, 2020) and then in the first half of March the virus spread all over the country (Redazione, 2020). The resulting COVID-19 infections caused a major health burden and emergency scenario across Italy. It can be observed from Figure 4b below that Lombardia has the highest number of confirmed cases (865,282) which has kept the government on its toes due to sharp surge in the number of cases. Veneto, Campania, Emilia Romagna, Lazio, Toscana, and Apulia with 10.79%, 10.60%, 9.77%, 6.40% and 6.28% of the cases, respectively. The huge number of COVID-19 cases has posed a threat to the citizens of Italy and the nation's economy.

A correlation was found between the number of COVID-19 cases and the populations of various regions in Italy [where $r(18) = 0.318$)] (Table 2).

4. Discussion

The COVID-19 disease has triggered major health loads all over the country. It was found that the Lombardia region has the highest number of cases followed by Veneto, Campania, Emilia-Romagna, and Toscana. Valle d Aosta has the lowest number of confirmed cases, deaths, and active cases. Lombardia also has the highest rate of deaths. The mortality rate in Lombardia is comparatively very high. Doctors and paramedic staff play a very crucial role in the COVID-19 pandemic by treating infected cases. The overall high recovery rate and low death rate in Italy indicate the country has better medical facilities as compared to various countries e.g., India, Brazil, Pakistan

In addition to impacts on human health, COVID-19 and the resulting population lockdown have also affected Italy's economy, as multiple factories have been closed due to the national emergency. The accommodation sector and food services were hardest hit due to emergency measures and the ban on tourism. During 2020, 8.9% of GDP declined in Italy as compared to other countries i.e., 3.5% (USA), 2.2% (Switzerland) (Torre et al., 2021). Northern Italy was knocked out by coronavirus infections, but the economically deprived parts of southern Italy suffered the most from lockdown (Nadeau and Donato, 2020).

5. Conclusion

This research work was carried out using geospatial technology to show the spatial distribution of coronavirus disease in Italy. It is noteworthy that strict steps taken to control the spread of the coronavirus disease during study period were likely responsible for the reductions in daily cases and daily deaths observed after mid-April, as well as the spike in the number of daily recovered cases. The pattern of its spatial distribution was studied using a geospatial approach. The study revealed that the most populous region of Italy (Lombardia) suffered highly from the coronavirus, with 20.76% of total cases with 26.76% of total deaths (Table 1).

A GIS-based spatial interpolation (IDW) approach was used to identify the prospective disease risk areas in Italy. The IDW analysis of spatial interpolation layers and apparent weight of the conditioning factors were also prepared. Analysis of the spatial distribution patterns may offer valuable information to support government monitoring and to image the extent of virus' spread through small and large areas. This study would be appropriate for the relevant departments to carry out detailed studies on the spread of virus and environmental control in the study area. Moreover, the approach does not merely proscribe the foretell mapping of various zones of the country but can also demonstrate the level of improbability in the forecasts, which could be helpful for other countries.

Data Availability: All data used in this manuscript are publicly available. COVID-19 epidemiological data for Italy are available at https://github.com/pcm-dpc/COVID-19. Administrative boundaries area is available at http://www.diva-gis.org/gdata. Population census data are available at http://dati.istat.it/Index.-aspx?QueryId=18460.National level COVID-19 daily updated data is available at https://ourworldindata.org/coronavirus

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