J-READING
JOURNAL OF RESEARCH AND DIDACTICS IN GEOGRAPHY
1, 11, June, 2022, pp. 27-48 DOI: 10.4458/5116-03

J - READING
JOURNAL OF RESEARCH AND DIDACTICS IN
GEOGRAPHY
homepage: www.j-reading.org

The ECO4CO project among retrospective data, improving of algorithms, predictive hypothesis and future perspectives to tackle health emergencies

Cristiano Pesaresi[a], Sofiane Atek[b], Corrado De Vito[c], Vincenzo Cardinale[d], Filippo Bianchini[e], Simone Novelli[b], Marco Eugeni[b], Massimo Mecella[f], Antonello Rescio[e], Luca Petronzio[e], Aldo Vincenzi[e], Pasquale Pistillo[g], Gianfranco Giusto[g], Giorgio Pasquali[g], Domenico Alvaro[h], Paolo Gaudenzi[b], Marco Mancini[a], Paolo Villari[c]
[a] Dipartimento di Lettere e Culture Moderne, Sapienza University of Rome, Rome, Italy
[b] Dipartimento di Ingegneria Meccanica e Aerospaziale, Sapienza University of Rome, Rome, Italy
[c] Dipartimento di Sanità Pubblica e Malattie Infettive, Sapienza University of Rome, Rome, Italy
[d] Dipartimento di Scienze e Biotecnologie Medico-Chirurgiche, Sapienza University of Rome, Umberto I Policlinico of Rome, Rome, Italy
[e] Telespazio S.p.A, Rome, Italy
[f] Dipartimento di Ingegneria Informatica, Automatica e Gestionale Antonio Ruberti, Sapienza University of Rome, Rome, Italy
[g] e-GEOS, Rome, Italy
[h] Sapienza Information-Based Technology InnovaTion Center for Health (STITCH), Sapienza University of Rome, Rome, Italy
Email: cristiano.pesaresi@uniroma1.it

Received: April 2022 – Accepted: May 2022

Abstract

International literature has evidenced how GIS, geotechnologies and Artificial Intelligence (AI) can provide very useful supports and indications to tackle COVID-19 and health emergencies. This paper starts by giving some synthetic geographical considerations regarding the consequences of the COVID-19 pandemic in different fields of daily life and then provides a literary review concerning the actual state of the art and inputs for future perspectives using GIS, geotechnologies and AI to tackle infectious diseases and global emergencies, starting from the numerous studies conducted in the context of COVID-19. In fact, the current pandemic has also been an event capable of providing notable new indications for the profitable use of GIS applications, simulation and geolocalisation models, AI and satellite images. The paper then focuses the attention on the ECO4CO – Earth Cognitive System 4 Covid-19 project, co-funded by the European Space Agency (ESA) under its Business Applications programme and essentially aimed at advancing innovative proposals, combining geotechnological know-how and interdisciplinary approaches in the healthcare, epidemiological, engineering and geographical fields, through the use of geoinformatics models and algorithms and satellite resources, for ad hoc data elaboration and mapping. In particular, the ECO4CO service concept and service pillars are presented and the work is focused on Logistic Planning, a crucial service used to assist clinical teams and healthcare authorities in the organization of activities useful to tackle health emergencies. Specific applied examples are shown to underline how it is possible to pass from retrospective data to predictive hypothesis through conceptual models based on interdisciplinary synergies and refining and educating algorithms.

Keywords: Artificial Intelligence, COVID-19, GIS, Health Emergencies, Logistic Planning, Predictive Hypothesis, Satellite Images, Simulation and Geolocalisation Models

1. A synthetic geographical consideration on the consequences of the COVID-19 pandemic

The COVID-19 pandemic caused a dramatic and prolonged crisis in the Emergency Departments of hospitals and healthcare systems overall, suddenly and relentlessly causing planned operations and specialist examinations, ordinary therapy, access to hospital facilities to be cancelled and bringing with it a series of protocols on how to tackle and treat the illness and even the frenzied purchase of medicines, supplements and sanitizers just “as a backup supply”.

The pandemic has radically changed social aspects and the logic whereby to organise work and didactic activities, leading to the diffusion of smart working and remote solutions, proposed on various platforms which made it possible to hold distance “meetings” and exchanges between teachers, researchers, students, experts of different sectors and companies, creating – in the tragedy of the events – a network between different countries and new perspectives.

The pandemic has only too clearly modified our way of relating to one another, stimulating moments of “sharing”, for example by means of scheduled appointments (at specific times) on the balconies of flats to sing, pray, hope and comfort one other. It has spread frustration, fear and anxiety, leading to clear differences of opinion on a number of decrees, obligations, restrictions, becoming a main subject of conversation and TV and radio programmes, to the point of escalating into violent protests over the socio-economic exasperation and different ways of interpreting some of the solutions adopted or imposed.

The pandemic and the consequent drastic measures of containment have brought about considerable consequences in our behaviour and lifestyles, at every age and above all at school age, increasing sedentariness, the consumption of quick meals and junk food, the already massive use of technological devices, the isolation of young people with their mobile phones, internet and TV series, bringing about a sort of widespread hesitation and precautionary refusal to go back to the typical social life of their previous daily routine.

The pandemic changed the way of understanding tourism and catering, manufacturing and commercial activities, leisure and free time (above all in closed places but also in the open air), the mobility of people and the flow of goods, traffic with different means of transport, with a series of limitations, reopening, distancing, non-structural modifications (above all) of venues and modalities for access to and the use of services.

The pandemic also determined the ascent in ranking of a new cause of death of infectious origin, among the consolidated ones of a chronic-degenerative type, with the general attention being focussed on this, making us almost “forget”, in the collective hustle and bustle, pathologies which instead insidiously continued to progress and create further momentarily “neglected” dramas but which were ready to surface even more vehemently. At the same time, it greatly exacerbated a number of problems regarding the elderly, connected for example to the impairment and decline of their physical-motor and cerebral functions, with drastic repercussions.

But in this polychrome dramatic picture of daily struggle, while eagerly awaiting improvements, the pandemic has also represented:

a remarkable test case, an opportunity for incremental progress, to test and finalize new, shared and highly technological solutions; a starting point for an increased and conscious responsiveness to the healthcare emergencies; an "extraordinary" possibility to mend and realign worn and frayed connections, so as to create homogeneous systems for data and information sharing; an opportunity to make up for the lost time and to redress what had been neglected; an event capable of providing impressive inputs for the use of GIS applications, simulation and geolocalisation models, Artificial Intelligence and satellite surveys, under the aegis of interdisciplinary research.

2. The current state of the art and inputs for future perspectives using GIS, geotechnologies and AI to tackle COVID-19 and health emergencies

In the framework of the scientific studies which have used GIS to monitor, understand and tackle the COVID-19 pandemic:

- Kim and Bostwick (2020) – carrying out hotspot analysis to recognize clusters of areas and compute bivariate local autocorrelation – estimated the effects of social vulnerability, racial inequality and health risk factors on the geographical distribution of the COVID-19-related deaths in Chicago (USA);
- Azevedo et al. (2020) elaborated geostatistical COVID-19 infection risk maps to predict the spatial distribution of the disease over time in Portugal, functionally to determine greater or lesser containment strategies and recognize the areas which mainly need specific lockdown measures;
- Dangermond et al. (2020), in a joint discussion regarding the USA and Italy, underlined and discussed some GIS applications and dashboards elaborated to support the emergency phases and to share official and detailed data, in the setting of a rigorous system able to record an advancement of the state of the art and to guarantee the management of sensitive data and privacy aspects;
- Murgante et al. (2020) set out to explain why the COVID-19 infection considerably affected first of all the Po Valley area in Italy, comparing the spatial distribution and pattern of COVID-19-related mortality with different geographical, environmental and socio-economic variables and using specific techniques such as LISA (Local Indicators of Spatial Association);
- Kamel Boulos and Geraghty (2020) showed dashboards and applications regarding geographical tracking and mapping of COVID-19 as strategic tools to support the global fight against outbreaks and epidemics;
- Pesaresi et al. (2020) advanced three geotechnological proposals to tackle the COVID-19 emergency, with specific reference to the elaboration of geographical-healthcare-epidemiological models of spatial and temporal diffusion, the realization of an App for data tracking, digital flow mapping and health education, the planning of a geolocalised online questionnaire, towards a smart survey for the identification of possible positives;
- Podda and Scanu (2020) analyzed the contribution of cartography, dashboards, webGIS, digital mapping – according to dynamically interactive formats and the processing of large datasets – to the knowledge of the spread of the COVID-19 pandemic;
- Brunialti et al. (2020) exhibited the COVID-19 mapping project in Trentino (Italy), with particular reference to the Autonomous Province of Trento, to provide an important heuristic instrument for representation and analysis of social, environmental and health data;
- Grekousis et al. (2021) – using the Local Fuzzy Geographically Weighted Clustering (LFGWC) method – mapped the geodemographic racial, economic and health disparities in the USA in relation to COVID-19 mortality inequalities;
- Casti et al. (2021) proposed an approach focused on space-time analysis to study, through reflexive cartographic mapping, the main factors that could have influenced the spread and dynamics of COVID-19 in Italy, with notable differences among regions;

- Iyanda et al. (2021), in the setting of a cross-sectional examination, compared the racial/ethnic heterogeneity and the rural-urban disparity of the COVID-19 case fatality ratio in the USA;
- Lyu et al. (2021) estimated the temporal-geospatial associations between the pre-infection determinants of risk (PIDRs) and COVID-19 infection in South Carolina (USA), using the spatial error model (SEM), spatial lag model (SLM), conditional autoregressive model (CAR) and the geographically weighted regression model (GWR) on the basis of data coming from different sources;
- Kanga et al. (2021) worked in terms of COVID-19 risk assessment and mapping (CRAM) using remote sensing and GIS in an integrated perspective and applied a multicriteria risk reduction method focussing the attention over an Indian study area;
- Wu et al. (2021) applied a combined approach of visualization, spatial regression and Machine Learning (ML), based on multisource data and point grid maps, to analyze the spatial-temporal spread of COVID-19 in Wuhan and other cities of China;
- Carballada and Balsa-Barreiro (2021) mapped and analyzed – also through the application of specific functions, aggregations and heat representations – fine-grained data concerning the incidence of COVID-19 during the first wave in the region of Galicia (Spain) as support for sanitary decision-making in real and near real time;
- Schmidt et al. (2021) developed a webGIS for the analysis of COVID-19 cases based on volunteered geographic information (VGI) and ad hoc data collection (respecting parameters of data protection, ethical and legal aspects) to check, for the city of Cologne (Germany), if certain buildings (i.e. residential or commercial) were visited more frequently by infected people than other buildings;
- Pesaresi et al. (2021) elaborated a dynamic space-time diffusion simulator in a GIS environment to tackle the COVID-19 emergency in Rome, as a useful tool for infection surveillance, precision preparedness, support to decision-making through the identification of clusters, patterns and trends;
- Werner et al. (2022) advanced a distributive and temporal application of the geographic dissemination of COVID-19 in Poland according to spatial interaction models also useful in terms of simulations and predictions of spread of disease as support to policy making decisions;
- Akinwumiju et al. (2022) applied global and local regression models to analyze, in the perspective of geospatial evaluation, the relationship between COVID-19 mortality and many socio-economic and health variables and their cumulative influence in the USA.

At the same time, some studies have underlined and discussed the potentialities of Artificial Intelligence (AI) for the management and containment of the COVID-19 pandemic.

- Alsharif and Qurashi (2020), through a literature review, evidenced the relevant advancements reachable for the COVID-19 pandemic in using AI in the diagnostic field above all in conjunction with computed tomography (CT) imaging and reverse transcription-polymerase chain reaction (RT-PCR);
- Naudé (2020), in an early review, underlined how AI can be a potentially effective tool in the fight against the COVID-19 pandemic but it is not proportionally and satisfactorily used in the epidemiological, diagnostic and pharmaceutical fields, above all due to a lack of ad hoc data, and therefore the availability of unbiased time series data and specific methods for AI training is strategic;
- Barbieri et al. (2021), in a literature review, selected papers that addressed the use of AI and geotechnologies to tackle the COVID-19 pandemic and communicable diseases, with examples i.e. regarding the: acquisition and transmission of knowledge in the population and among clinicians; aspects concerning drugs and vaccines; remote support of patients and remote diagnosis and follow-up; organic planning of human and material resources in the hospital departments;

- Shi et al. (2021) organised a methodological review about AI techniques in imaging data acquisition and diagnosis for COVID-19, and particularly some imaging modalities (X-ray and CT) were used to show the relevance of AI-empowered medical imaging (above all in conjunction with clinical data and laboratory examination) and AI capability in integrating information coming from multiple sources in order to support accurate diagnosis and follow-up;
- Chee et al. (2021) conducted a systematic review regarding AI applications for COVID-19 in intensive care and emergency settings and – in the light of possible notable added value – they concluded by underscoring the need for focused improvements to facilitate the effective clinical adoption of AI, and the need for a closer interdisciplinary integration between geotechnological experts and clinicians.

The analysis of scientific literature underlines the considerable number of applications produced and the different advancements recorded with respect to the previous state of the art. The COVID-19 pandemic has suddenly required the experimentation of new solutions, evidenced tangible delays in computerised data recording systems, shown the need to operate according to shared standards and on the basis of homogeneous platforms for data storage, processing and spread, reiterated the importance of interdisciplinary collaborations and has reminded us that further rigorous steps must be taken to have a wide range of tools and resources useful to tackle future emergencies.

3. The ECO4CO – Earth Cognitive System 4 Covid-19 project

The ECO4CO – Earth Cognitive System 4 Covid-19 project[1], here presented and co-funded by the European Space Agency (ESA) under its Business Applications programme, is contextualised in the framework of the applied intersectoral research aimed at providing support to the institutions in charge of emergencies (Atek et al., 2021). In this perspective, many activities, devices, tools and analyses which use an impressive quantity of data, coming from multiple sources in a harmonized way, must be integrated in order to provide inputs and added value in the management of different critical situations and to support decision-making, as shown in Figure 1.

The ECO4CO project is in fact aimed at advancing innovative proposals based on geotechnological know-how and interdisciplinary approaches in the healthcare, epidemiological, engineering and geographical fields, using geoinformatics models, AI, satellite resources and GIS techniques, and combining geospatial and temporal dimensions for ad hoc data elaboration and mapping. In particular, it is aimed to create a fully autonomous and automated end-to-end system – based on the exploitation and integration of data from Earth observations (image acquisition, GNSS/EGNOS navigation data), Internet (social media, mobile phones and devices, tweets, news etc.), traffic movements (mobile, automotive), medical sources (equipment stock, hospitalization etc.) – able to quickly provide indications about geolocalised events and phenomena and dynamics and trends which can have a relevant impact on the COVID-19 outbreak evolution. The system makes large use of the ingestion of multiple heterogeneous datasets and information to provide a knowledge-based system able to support intelligent decisions and predictive analysis. The ECO4CO project also makes it possible to develop close synergies among different technologies and scientific sectors for the creation of an applied interdisciplinary system able to address sanitary, clinical and social measures, also refining and training

[1] The following industrial and research partners constitute the consortium which works in the ECO4CO project: Telespazio S.p.A as the prime contractor and e-GEOS S.p.A, Leonardo S.p.A, LINKS Foundation (formerly ITHACA), CherryData S.r.l and Sapienza University of Rome as the sub-primes. In particular, the Departments and facilities of the Sapienza University of Rome involved are: Department of Letters and Modern Cultures; Department of Public Health and Infectious Diseases; STITCH (Sapienza Information-Based Technology InnovaTion Center for Health)-DIMA (Department of Mechanical and Aerospace Engineering).

algorithms on the basis of retrospective data and towards predictive scenarios.

3.1 The ECO4CO service concept and service pillars

The ECO4CO service concept (Figure 2) is finalized at providing location-based information to support specific actors, as for example, the Civil Protection authorities and Public Health facilities. To reach this goal, social intelligence information and Earth observation are jointly used to systematically detect potential clusters of contagion and identify and monitor key factors driving the spread of the disease, such as human aggregation and movements. The service, characterized by data crawling, data processing, satellite tasking, crowd detection, crowd tracking, user alerts, is also used to predict the logistic needs of medical centres, Emergency Department admissions and to forecast administrative regional risk notifications according to the development of the pandemic situation (Atek et al., 2021, pp. 3-5; Atek et al., 2022, pp. 3-6). By continuously elaborating and analysing the automatically ingested data, once the procedures have been refined, the system dynamically gives wide geographical area monitoring services and it sends notifications and warnings to the authorities. The surveillance can be focused down to certain targeted places that may have received multiple alarms suggesting a local outbreak, summoning the competent authorities' attention to monitor its progression.

The key parts of the ECO4CO system and architecture are constituted by the following service pillars (Figure 3) which work together according to a logical sequence and progressive steps: Cluster Area Identification; Intelligent Satellite Tasking; Object Detection; Tracking; Logistic Planning.

Particularly:

- the Cluster Area Identification is a predictive data analytics service that analyses internet searches, social networks and news-channel messages to identify the possibility of new outbreak clusters. These data are used as a source of possible rapid disease surveillance, bypassing and integrating traditional communication channels and data. Artificial Intelligence techniques, Machine Learning algorithm, web crawlers and a big data analytics engine are used to have useful indications and to associate COVID-19 taxonomy and keywords (e.g. "Covid symptoms", "cough and Covid", "#covid19") with relevant geographical information regarding possible geo-located clusters;
- the Intelligent Satellite Tasking is a service which automatically tasks new satellite image acquisitions over identified candidate cluster areas provided by the Cluster Area Identification service, and it processes the information and eventually tasks acquisitions over the identified area in order to find possible "hot spots" (spatial clusters which can be useful to define control measures and actions). Moreover, it can receive the tasking request directly from the users via the Graphical User Interface. The simultaneous surveillance of large areas, ranging from entire regions to entire countries, is possible thanks to a scalable automated management of widely distributed satellite systems;
- the Object Detection is a service which receives in input the high resolution satellite images acquired and processed in near real time by the Intelligent Satellite Tasking service in order to detect the density of vehicles in crucial places such as parking lots and open markets. It also has a module which allows the use of video streaming from street surveillance cameras to support analysis concerning the detection of people gathering which can foster opportunities for contagion;
- the Tracking is an intelligent service that tracks traffic and people movements to detect suspicious flows, trends or anomalies, providing information regarding people shifts from a possible identified cluster area to other zones (e.g. from a city/region to another city/region) by means of Terrestrial and IoT (Internet of Things) data. The use of mobile phone data is provided by mobile operators which make available aggregated and anonymized data and further information can be obtained by mobile devices using a mobile

APP. This system makes it possible to monitor road traffic and recognize the congestion of parking lots;

- the Logistic Planning is a crucial service which has been devised to assist clinical teams and health-care authorities in the organization and planning of activities and measures useful to tackle emergency situations due to successive epidemic cluster identifications. This service enhances a predictive data analytics tool to assess regional risk classifications, hospitalization rates and to identify future medical supply requirements. Interactions with clinicians and researchers from the Umberto I hospital and the Sapienza University of Rome were established to address the medical implications of the Logistic Planning service outputs in the decision-making process and to direct the system's design to allow the selection, organization and interpretation of data that can be useful to address the health system response. Many simulations have been done on the basis of open access data obtained with automated requests from national and regional health administrations – or on the basis of ad hoc data obtained with specific requests to the healthcare facilities – with particular reference to the number of Emergency Department admissions, medicines purchase, the number of daily infections, recoveries and fatalities at regional level. Other simulations and algorithm improvements have been made with regard to region colour coding for the COVID-19 classification, with the aim to know with a certain prior knowledge the possible changing scenarios and passages of regions from one colour to another (i.e. from yellow to orange or *vice versa*) according to the tendencies in place. In this service geospatial and multitemporal analyses just us statistical corrective action have a key role for conducting rigorous analysis and advancing hypotheses.

4. The Logistic Planning crucial service

The logistic Planning is a service that runs on the ECO4CO platform and uses advanced technological features to provide predictions of crucial parameters useful for the clinical and medical decision-makers in the management of the COVID-19 pandemic. The service works by regularly ingesting healthcare and medical data provided by the Italian national and regional public health administrations, which publish such information in open format and grant access to the public.

The datasets used by the Logistic Planning service include:

- the Emergency Departments (ED) attendances provided by the Lazio region health service;
- medicines and supplies purchase data provided by the Italian Medicine Agency (AIFA);
- the colour coding of administrative regions for COVID-19 classification provided by the Italian Civil Protection;
- the number of daily infections, recoveries, and fatalities at the regional level provided by the Italian Civil Protection;
- the number of non-critical hospitalizations and intensive care bed occupancy at the regional level provided by the Italian National Agency for Regional Health Services (AGENAS).

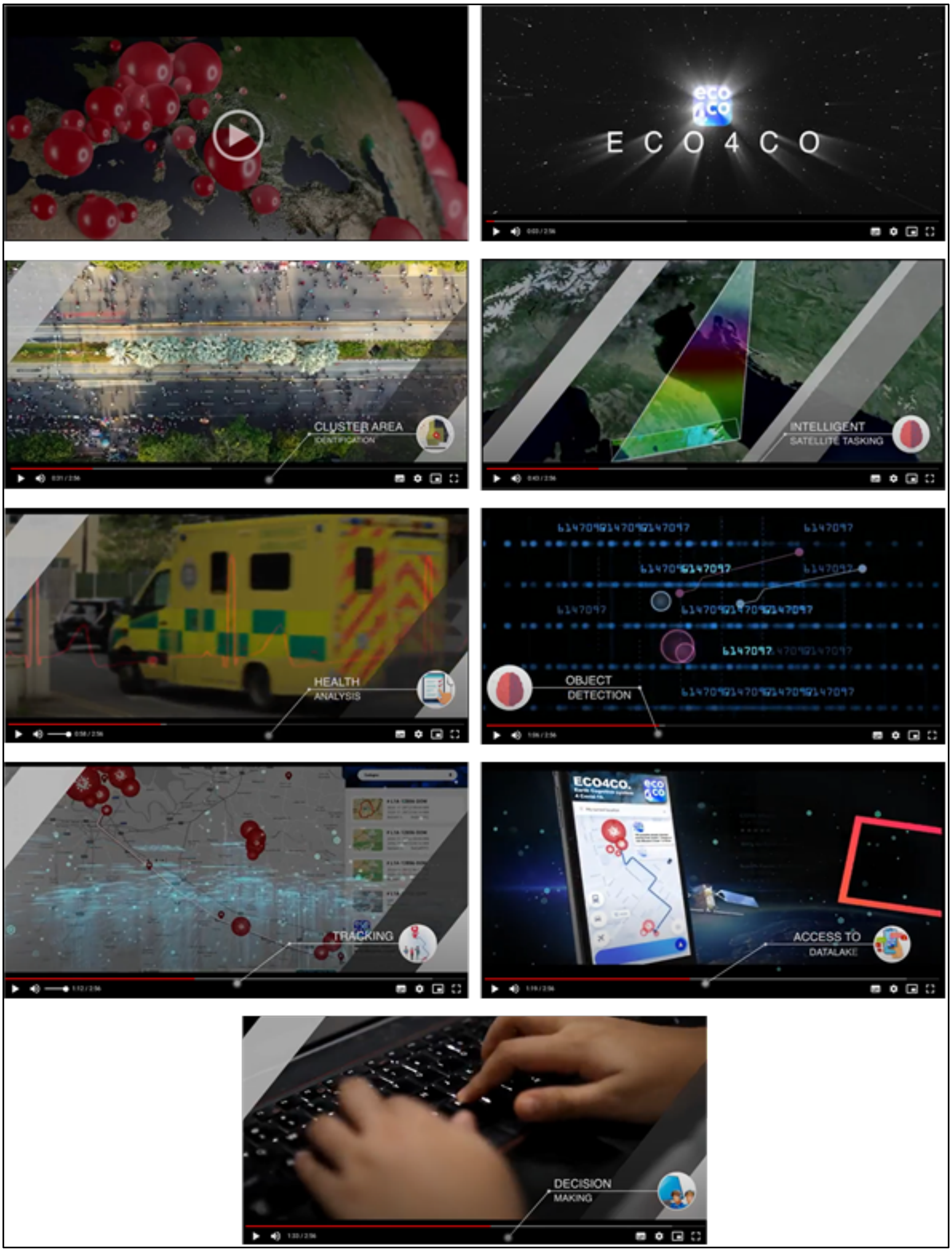

Figure 1. Some activities, devices, tools, analysis which characterize ECO4CO project and use in a harmonized way an impressive quantity of data coming from multiple sources to support decision-making. Collage of screenshots coming from the ECO4CO project presentation video (https://business.esa.int/projects/eco4co; https://corsidilaurea.uniroma1.it/en/node/2454437), property of the ECO4CO consortium led by Telespazio S.p.A. Source: Authors' elaboration.

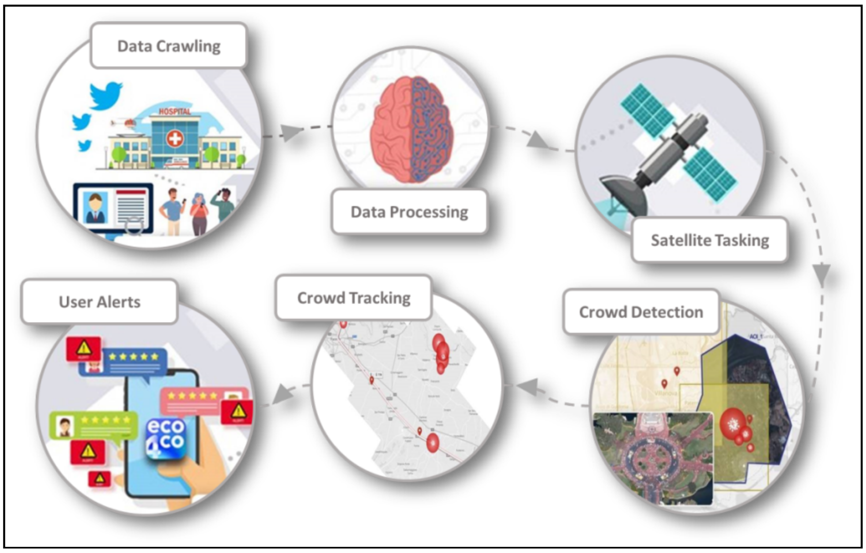

Figure 2. The ECO4CO service concept, characterized by data crawling, data processing, satellite tasking, crowd detection, crowd tracking, user alerts, and finalized at providing location-based information to support specific actors. Source: Authors' re-elaboration on the basis of the ECO4CO project documentation, property of the ECO4CO consortium led by Telespazio S.p.A.

Figure 3. The ECO4CO service pillars. Source: Authors' elaboration.

These data are stored into a dedicated database and processed by a special medical processing engine which uses state-of-the-art Artificial Intelligence algorithms to perform trend predictions and generate warnings when predictions exceed determined thresholds. These techniques include Linear Regression algorithms and Recurrent Neural Networks (RNN), which are a special family of Neural Networks, that are well suited for time-series prediction (Chen, 2016), and k-Nearest Neighbours Networks (KNN), that are often used to solve classification problems (Zhang, 2021).

The warnings generated by the system are specific to the monitoring and prediction of the evolution of the pandemic situation. One type of warning regards the regional risk classification colour switching, which is a code system defined by the Italian Government to indicate an emergency level due to on-going COVID-19 evolution and which entails the implementation of specific measures to reduce the severity of the situation. In addition, other warnings paramount to the management and the response to the healthcare system are the intensive care saturation of the monitored medical sites and the increase of medical supplies purchase at the regional level.

The regional risk classification colour code is a parameter that is estimated on the basis of several variables that are determined by the Italian Government. In the logistic planning service, such parameter is mainly calculated on the basis of the prediction, at regional level, of the number of non-critical hospitalized patients, the number of patients occupying intensive care unit beds and the number of newly COVID-19 positive patients. Some examples showing such predictions are shown in Figures 4, 5 and 6, concerning Liguria, Friuli-Venezia Giulia and Piedmont regions. Particularly: Figure 4 shows a good correspondence between forecast number of non-critical hospitalized patients and real (actual) number of non-critical hospitalized patients in the Liguria region; Figure 5 puts in evidence a good correspondence between forecast numbers of intensive care beds occupancy and real numbers of intensive care beds occupancy in the Friuli-Venezia Giulia region; Figure 6 underlines the good correspondence between forecast numbers of new positives and real numbers of new positives in the Piedmont region.

The regional risk classification colour code is derived on a weekly basis for each administrative region and a warning is generated for every region, regardless a colour code switch is foreseen by the algorithm or not. Figure 7 shows the evolution in time of the colour code during the period March 2021 and January 2022 in the Lombardy region.

The evaluation of the region classification prediction performance yielded good results considering that the obtained accuracy was 85% over the all the Italian regions (Atek et al., 2022) and where mostly the errors were conservative and regarded in particular mis-predictions of white class instances as being yellow.

The colour code classification can be used at macro level by the regional health administrative authorities to assess possible improvement or worsening of the situation in the coming weeks and take possible actions and preventive measures. Therefore, a similar technique makes it possible to hypothesize in advance a possible change of colour, giving the possibility to plan a set of specific measures and actions.

Another parameter that is also evaluated at regional level and that is useful for the management of the medical logistics is related to the prediction of purchases of medicinal supplies performed by the Italian administrative regions. For such purpose, linear regression algorithms were applied to perform such estimation taking into account several conditions going from pre-pandemic ones to pandemic peak and post-peak situations. The evaluation made for two regions, i.e. Lazio and Piedmont, which were considered as reference regions during a pilot evaluation of the ECO4CO platform (also for the availability of the data obtained), yielded a relative error of 16% using the Root Mean Squared Percentage Error (RMSPE) (Atek et al., 2022). An explanatory example of the forecast versus the real pharmaceutical supplies purchases for the Piedmont region is shown in Figure 8.

At a micro level and in particular with what regards the field necessities with which the emergency teams are directly dealing in the medical structures, the Logistic Planning provides with the trends of the emergency rooms attendances calculated with linear regression algorithms and derived for a time window of 4 hours allowing the clinical teams to foresee increases in the affluences and take the necessary measures in advance.

An example is shown in Figure 9 that depicts the predicted attendances in the emergency rooms for the Policlinico Gemelli hospital of Rome. Generally, for the hospitals of the Lazio region, the predictions performed during the system evaluation followed narrowly the actual values and in particular with regard to the crowded hospitals that accept the major bulk of the patients of the Lazio region. A slight lag in the prediction is observed, which however was kept to the minimum. The Root Mean Square Errors (RMSE) between the predictions and the actual values varied between 2 and 11 patients according to the mean affluence of the emergency rooms of the Lazio region.

The Logistic Planning is an important service provided by the ECO4CO, which however needs to be used in context with the other services provided by the platform. Indeed, the advantage of the ECO4CO is that it provides warnings and information coming from heterogeneous sources which describe different and yet correlated aspects of the pandemic situation. In conjunction with the Cluster Area Identification, a surge in Tweets with special keywords can hint to an increase of COVID-19 cases in potential cluster areas and indicate a possible rise in the emergency rooms affluences and bed occupancies. In brief, all the parameters delivered by the ECO4CO platform provide key indicators that the decision-makers can use in their assessment of the COVID-19 pandemic trend and evolution and help them in taking informed decisions. Moreover, this service can be used beyond the current pandemic and shows notable potentials for providing the tools to handle future emergencies.

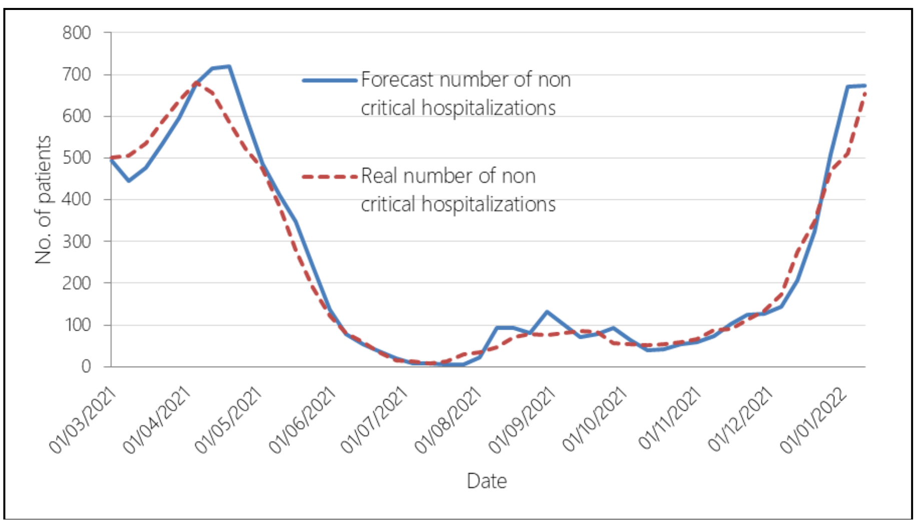

Figure 4. Non-Critical hospitalized patients in the Liguria region: forecast vs. real values. Source: Authors' elaboration.

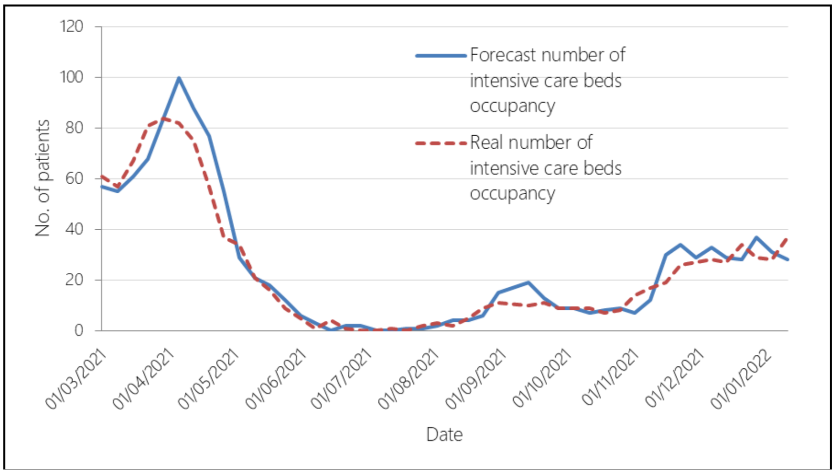

Figure 5. Forecast against real number of intensive care beds occupancy in the Friuli-Venezia Giulia region. Source: Authors' elaboration.

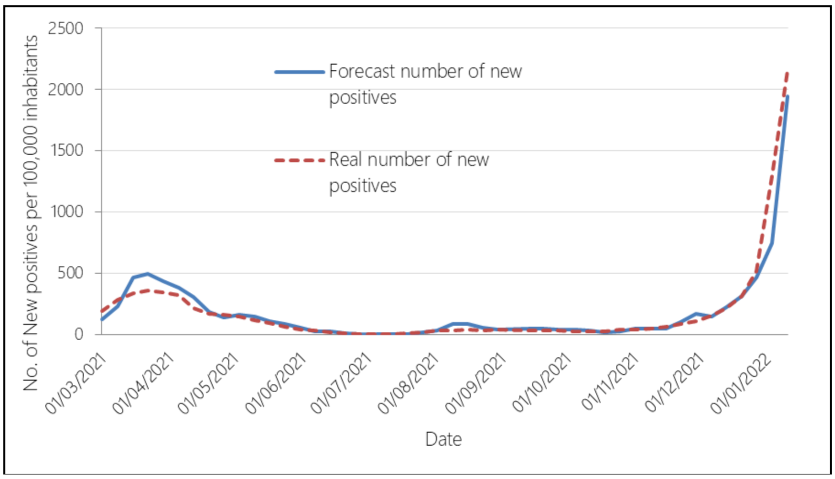

Figure 6. Forecast against real number of new positives in the Piedmont region. Source: Authors' elaboration.

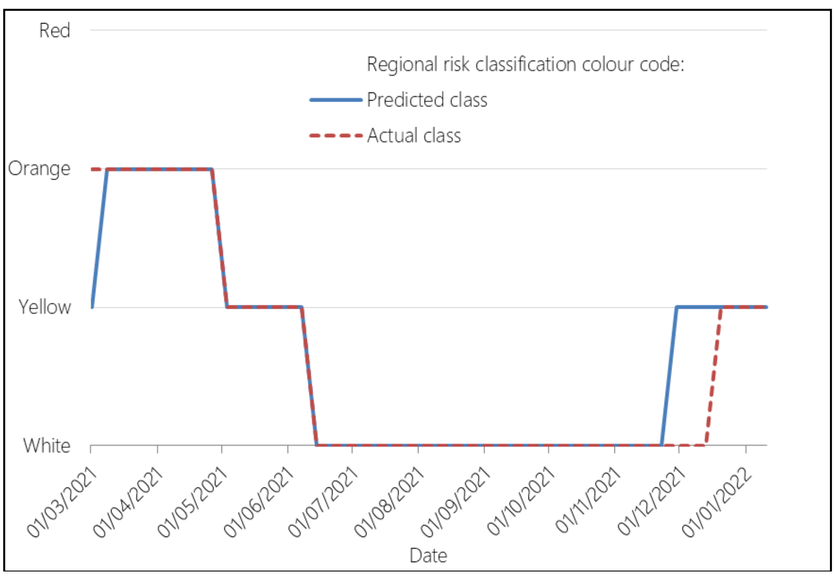

Figure 7. Regional risk classification colour code forecast time series for the Lombardy region (predicted and actual classes). Source: Authors' elaboration.

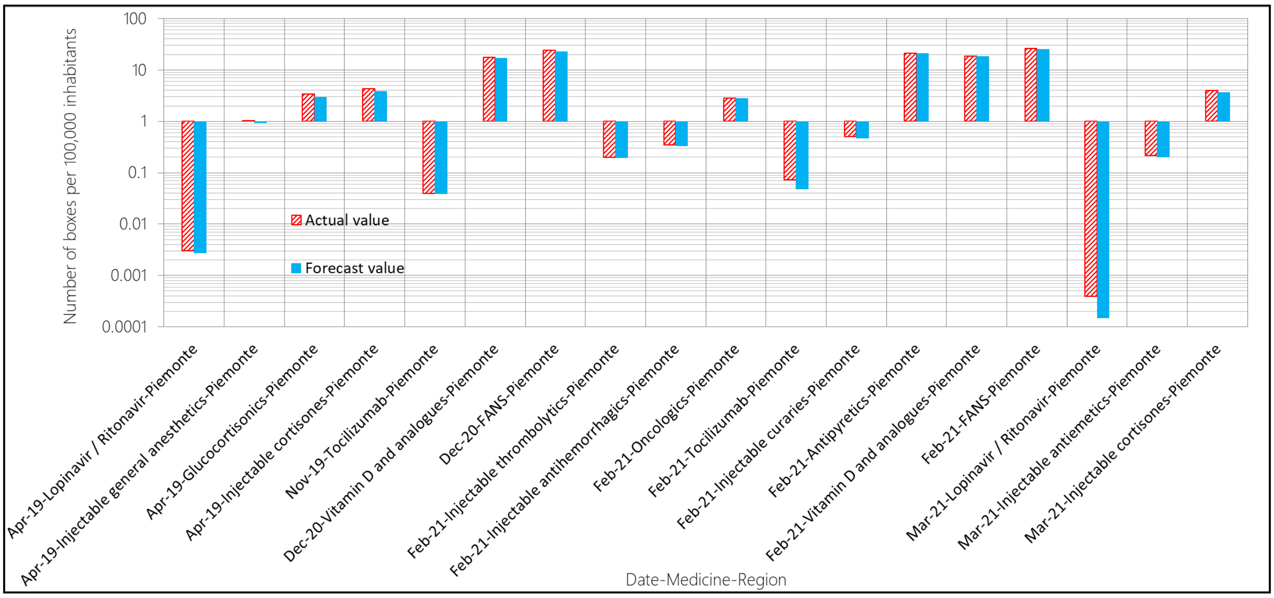

Figure 8. Forecast vs. actual pharmaceutical supplies purchases for the Piedmont region. The horizontal axis indicates the month considered, the medicines and the region. Source: Authors' elaboration.

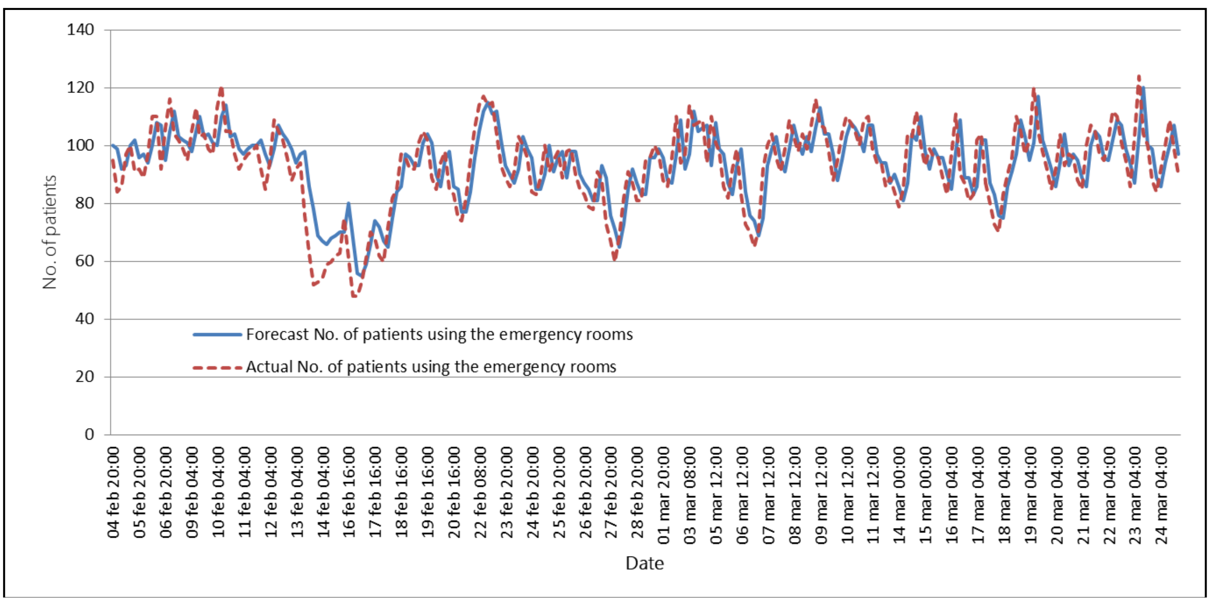

Figure 9. Predicted number of patients attending the emergency rooms vs. the actual values for Policlinico Gemelli hospital of Rome. Source: Authors' elaboration.

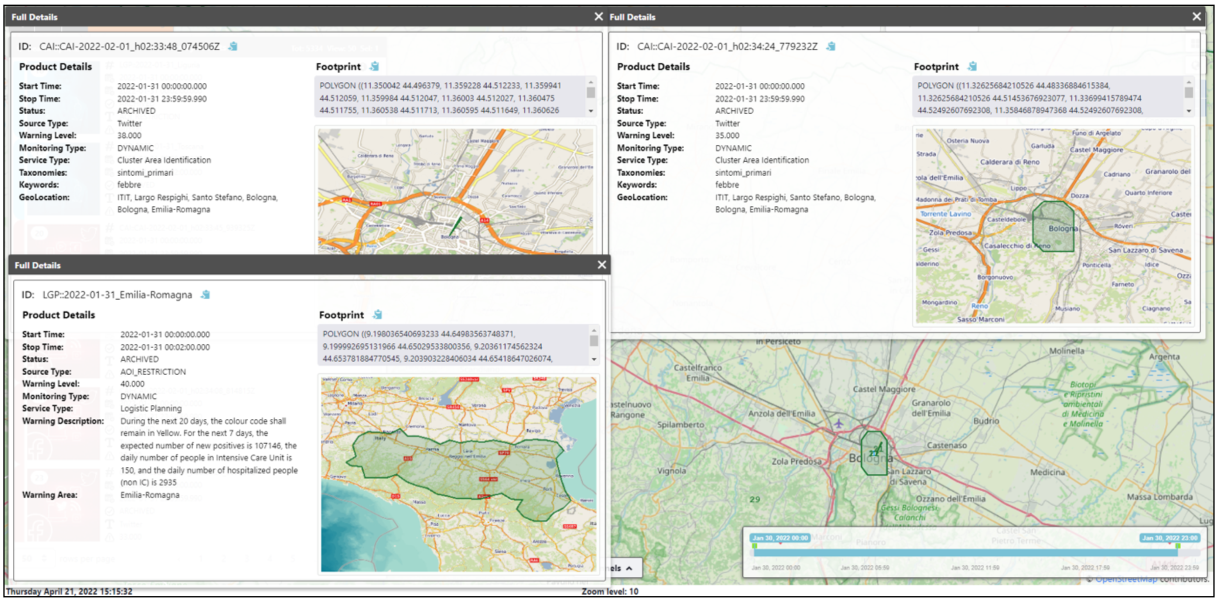

Figure 10. Use case in the Emilia-Romagna region in the last week of January 2022. The Cluster Area Identification (top two warnings in the figure) raised warnings related to the keywords “*sintomi primari*” (primary symptoms) and “*febbre*” (fever). Simultaneously, the Logistic Planning service raised a warning (bottom left corner in the figure) predicting that the region colour code should remain in yellow for the following 20 days (the forecast was actually correct). Source: Authors’ elaboration.

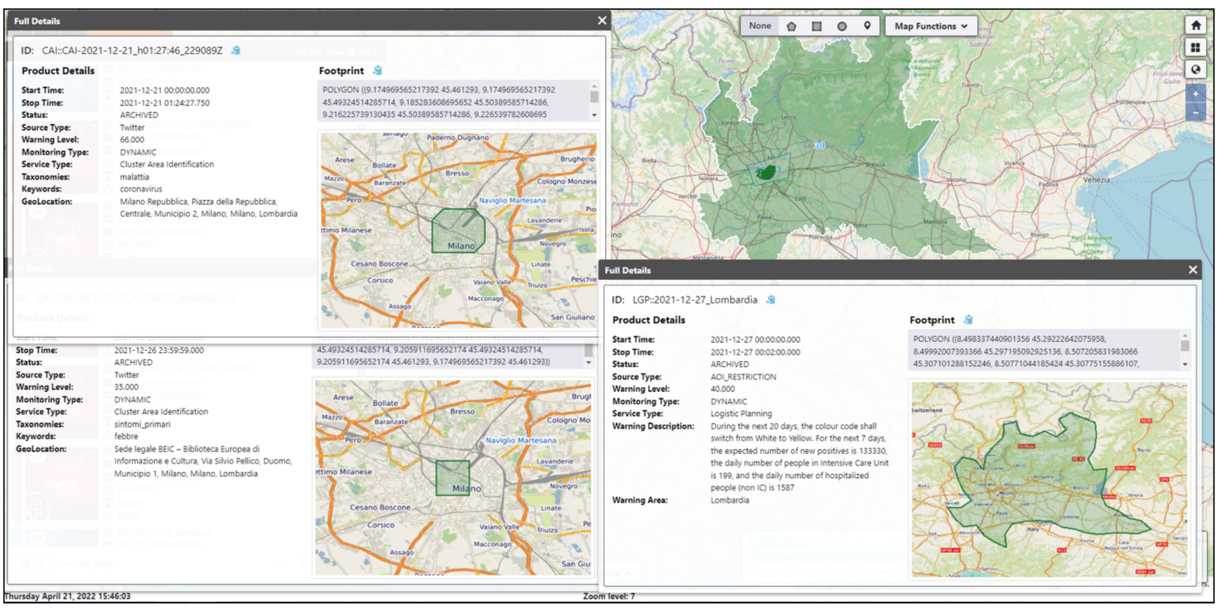

Figure 11. Use case in the Lombardy region in December 2021. The Cluster Area Identification (warnings on the left side of the figure) raised alerts related to the keywords “*sintomi primari*”, “*febbre*”, “*malattia*” (disease) and “coronavirus” on 21st and 26th December 2021. On 27th December, the Logistic Planning service raised a colour change warning (bottom right corner in the figure) predicting a switch from white to yellow: this change actually took place on 3rd January 2022. Source: Authors’ elaboration.

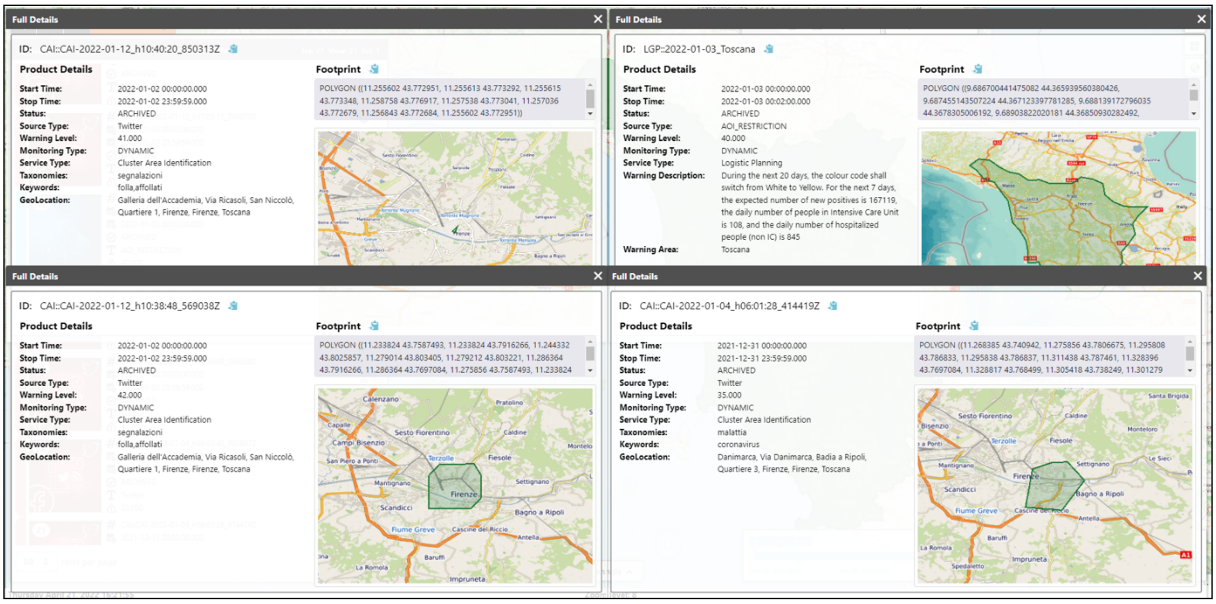

Figure 12. Use case in the Tuscany region in January 2022. The Cluster Area Identification raised alerts related to the keywords "*folla*" (crowd), "*assembramenti*" (gatherings), "*malattia*" and "coronavirus" on 31st December 2021 and 2nd January 2022. On 3rd January 2022, the Logistic Planning service raised a colour change warning (bottom right corner in the figure) predicting a switch from white to yellow: this change actually took place on 10th January 2022. Source: Authors' elaboration.

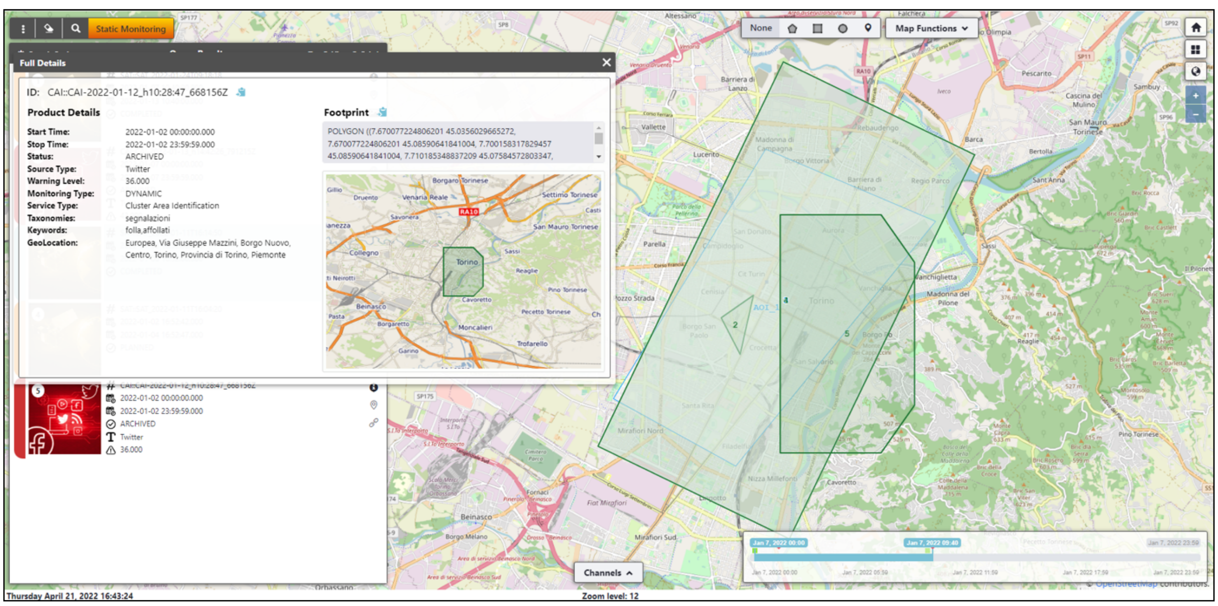

Figure 13. Use case from the Cluster Area Identification module over the area of Turin, Piedmont region, on 2nd January 2022. The system raised a warning for the keywords "*folla*", and "*affollati*" (crowded), referring to people gatherings. Source: Authors' elaboration.

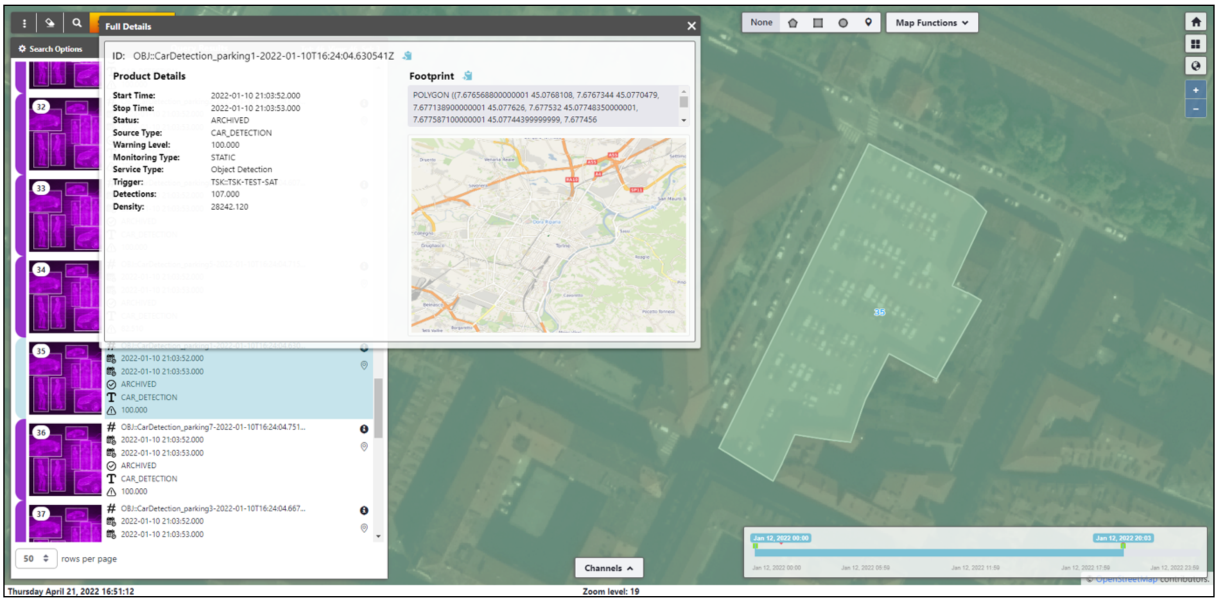

Figure 14. Use case in the Piedmont region in January 2022. The Cluster Area Identification raised an alert related to the keywords "*folla*" and "*assembramenti*" on 2nd January 2022 over the city of Turin. This triggered a satellite acquisition through the intelligent tasking service, which was acquired on January 10th and confirmed the gathering trend through analysis of parking spot occupancy. Source: Authors' elaboration.

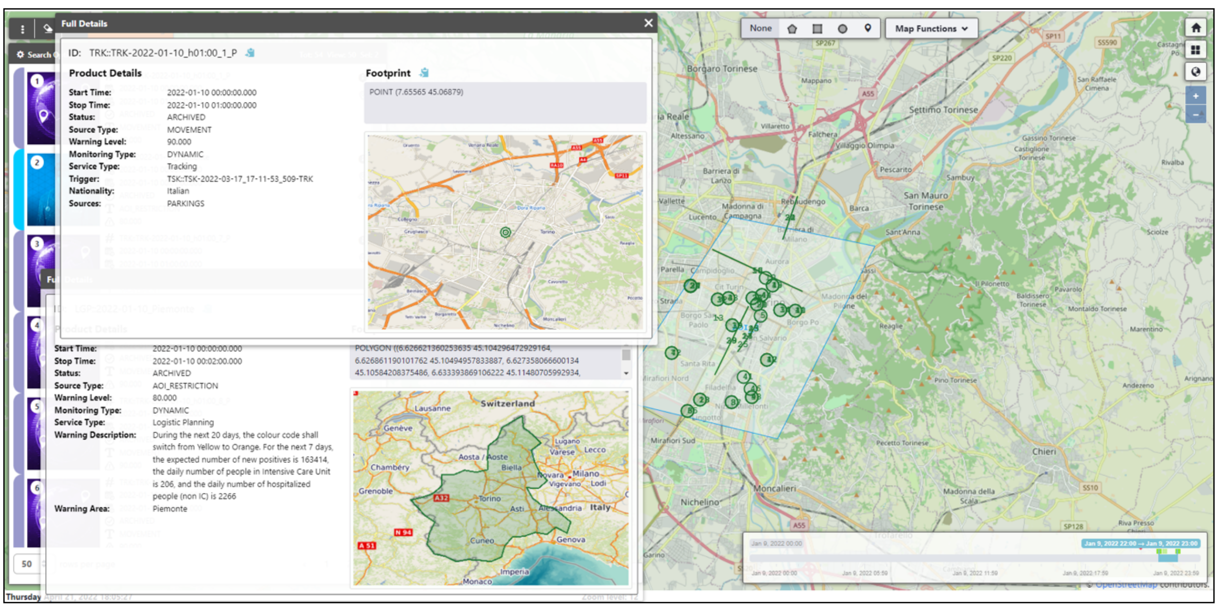

Figure 15. Use case in the Piedmont region in January 2022. On 10th January the tracking service raised several warnings related to an increase in the people movement trends. In addition, the Logistic Planning raised an alert on the same date predicting a colour code change from yellow to orange, which effectively took place on 24th January. Source: Authors' elaboration.

Furthermore, the added value of the ECO4CO – Earth Cognitive System 4 Covid-19 project, in the synergy of the various pillars and with particular reference to the Logistic Planning, is expressed by the possibility of working (with interactive queries and functions) to dynamically operate, display data, warnings, possible critical situations directly in a proactive platform able to support geospatial and temporal analysis, study and identification of critical conditions, in order to support predictive hypotheses and ad hoc intervention measures.

Figures 10 to 15 provide several use cases taken from the warnings available in the platform that show how the different subservices contribute together with different information to the pandemic management.

It is worthy of note how the Cluster Area Identification module raised several warnings that were confirmed by the Logistic Planning, regardless of the region considered (Figures 10-13).

In addition, social media monitoring through the Cluster Area Identification proved its efficiency also when combined with the Intelligent Tasking and Object Detection modules, where warnings related to people gatherings were then confirmed by parking analysis of satellite imagery (Figure 14).

Moreover, the merging of the Tracking service and Logistic planning (shown in Figure 15) proves that also the monitoring of mobile data can support the management of emergency scenarios with a high accuracy.

Particularly, Figure 10 shows a use case in the Emilia-Romagna region in the last week of January 2022. The Cluster Area Identification raised warnings related to the keywords primary symptoms and fever. In the same time, the Logistic Planning service raised a warning predicting that the region colour code should remain in yellow for the following 20 days (and the forecast was correct).

Figure 11 evidences a use case in the Lombardy region in December 2021. The Cluster Area Identification raised alerts concerning the keywords primary symptoms, fever, disease and coronavirus on 21st and 26th December 2021. On 27th December, the Logistic Planning service raised a colour change warning predicting a switch from white to yellow, and this change took place on 3rd January 2022.

Figure 12 highlights a use case in the Tuscany region in January 2022. The Cluster Area Identification raised alerts related to the keywords crowd, gatherings, disease and coronavirus on 31st December 2021 and 2nd January 2022. On 3rd January 2022, the Logistic Planning service raised a colour change warning predicting a switch from white to yellow, and this change took place on 10th January 2022.

Figure 13 shows a use case from the Cluster Area Identification module over the area of Turin, Piedmont region, on 2nd January 2022. The system raised a warning for the keywords crowd and crowded, referring to people gatherings.

Figure 14 evidences a use case in the Piedmont region in January 2022. The Cluster Area Identification raised an alert related to the keywords crowd and gatherings on 2nd January 2022 over the city of Turin. This triggered a satellite acquisition through the intelligent tasking service, which was acquired on January 10th and confirmed the gathering trend through analysis of parking spot occupancy.

Finally, Figure 15 highlights a use case in the Piedmont region in January 2022. On 10th January the tracking service raised several warnings related to an increase in the people movement trends. Furthermore, the Logistic Planning raised an alert on the same date predicting a colour code change from yellow to orange, which actually took place on 24th January.

5. Future developments for innovative solutions, an effective health system, a conscious awareness

The COVID-19 pandemic has underlined the lack of an adequate preparedness at global scale to tackle the ongoing emergency, has wrought havoc in the health and economic systems of countries worldwide and has brought about the need to define controlling measures under difficult conditions due to urgency, uncertainty and panic. The pandemic has also reiterated how the world is interconnected, has shown the importance of discussing and sharing actions, and has highlighted the relevance of a transparent decision-making system, characterized by correct information among communities (Aliyu, 2021). In fact, rapid, updated and correct information of the population is a crucial requirement to raise the awareness to carry out correct behaviour and actions and avoid the spread of incorrect data, information and preventive guidelines, in a circuit of fear and harmful misinformation. People, who are vehicles of diffusion, can even unwittingly become superspreaders or accelerators of the infection, while if properly educated and sensitized, they can play an essential role in preventing and reducing transmission episodes. Moreover, webApps, dashboards and geotechnological platforms can facilitate the process of a conscious diffused awareness, meeting a shared need for knowledge and knowing how to behave.

The COVID-19 pandemic has also highlighted (Malik et al., 2021, pp. 4, 6-7) how the availability of a large amount of high-quality big data is fundamental for a profitable implementation of AI in the management of the disease and for an innovative use of geotechnologies. Therefore, some online platforms and webApps have been developed to provide free access to data on COVID-19 coming from multiple sources, but a great effort must still be made to really support an effective response system in real and near real time. Meanwhile it has been evidenced that: "An AI framework having predictive analytics capabilities was built and applied to clinical data to provide support to clinical decision making. The predictive models could learn from previous health-related data of Covid-19 patients to predict which patient will develop severe symptoms that is, acute respiratory distress syndrome or who will require intensive care unit facility". In addition: "The AI-based technologies may also contribute to detecting clusters of cases and predicting the future course of the disease spread through modelling in a city, state and country by analysing all previous data collected during the course of Covid-19 pandemic".

Thus, these result-driven geotechnologies can be used and enhanced "for proper screening, analyzing, prediction and tracking of current patients and likely future patients" (Vaishya et al., 2020, p. 337), just as specific applications, as for example Google Trends (GT), can provide a useful support to "define the proper timing and location for practicing appropriate risk communication strategies for affected populations" (Husnayain et al., 2020, p. 221).

According to an extensive literary review, six key use cases can be identified regarding the potential added value provided by Artificial Intelligence, Machine Learning techniques and connected applications, that is to say: "forecasting infectious disease dynamics and effects of interventions; surveillance and outbreak detection; real-time monitoring of adherence to public health recommendations; real-time detection of influenza-like illness; triage and timely diagnosis of infections; and prognosis of illness and response to treatment" (Syrowatka et al., 2021, p. 1).

In the framework of specific applications useful to bolster up actions aimed at containing huge problems and social dramas due to the spread of diseases, the relevance of rigorous processes of geocoding in a GIS environment has been underlined in order to monitor and predict – through constantly updated dynamic point and choropleth maps – the evolution of the phenomena and their distribution, making it possible to identify details and spatial-temporal aspects that would otherwise be unrecognisable. Moreover, the need to devise and refine a *Homogenous Centralised System for Dynamic Geoprocessing and Geolocalised Diffusion Models in response to Emergencies* has been discussed, because the importance is commonly detected of having platforms into which merge data – guaranteeing requirements of safety and confidentiality – with specific formats and able to organize comparable and superimposable databases that can be integrated in a GIS environment. In this way and by using ad hoc tools for geospatial and geostatistical analysis, it is possible to conduct studies of density, recognizing critical zones and the areas requiring an intensification of interventions, services and medicines (Pesaresi, 2020).

A systematic review has also gathered into six thematic groups specific examples of GIS applications and geospatial analysis regarding COVID-19, identifying studies and elaborations about (Ahasan et al., 2022):

- *environment*, assessing the relationship between various meteorological elements (temperature, humidity, precipitation, wind-speed, daylight hours, solar radiation) and the possible transmission of the virus;
- *socio-economic and cultural*, considering as relevant factors, potentially associated with a higher COVID-19 incidence or mortality rate, gross domestic product (GDP), demographic and household compositions, population density, aspects concerning accessibility, vulnerability index, poverty and unemployment rates;
- *population health surveillance*, developing multicriteria decision-making indexes to evaluate the risk and resilience of the healthcare systems, and devising epidemic prediction models for spatial-temporal analysis, in order to foresee the potential number of positives and deaths due to the pandemic diffusion;
- *spatial transmission*, predicting possible clusters and transmission, also in the light of potential human mobility, public transportation, travel limitations, commercial traffic, as key factors in the era of globalization and international interconnection;
- *computer-aided spatial and statistical analysis and modeling*, looking to identify the potential highest risk place and the contexts subject to major increase which require particular surveillance and specific interventions, or simulating the possible spread of COVID-19 and understanding the spatial distribution pattern;
- *big data, social media and mobile data*, where i.e.: data mining and ML models were applied to analyze the twitter information related to symptoms of users or other aspects related to COVID-19, and was similarly done with social media posts; radar data were utilized to monitor traffic patterns in zones with a high number of vehicle movements; a Geo-AI based program characterized by an instant messaging app or analogously smart apps using big data analytics were used to trace the contacts of positives in real time, in order to contain the spread of COVID-19.

Meeting the need to test innovative and profitable geotechnological and interdisciplinary solutions for an effective health emergency response system, the ECO4CO – Earth Cognitive System 4 Covid-19 project has made it possible to integrate simulation and geolocalisation models, Artificial Intelligence and Machine Learning techniques, GIS applications, refined algorithms and satellite resources, for ad hoc data elaboration and real and near real time mapping. Moreover, the ECO4CO project has made it possible to synergically operate using retrospective data coming from different sources to improve and refine algorithms with the aim to support predictive hypothesis and forecasting scenarios.

The logical sequence of the key pillars, starting from Cluster Area Identification, and passing through Intelligent Satellite Tasking, Object Detection, Tracking, up to Logistic Planning, has made it possible to test different services and solutions useful also in terms of future emergencies.

The statistical corrective measures adopted and the rigorous analyses conducted for increasing the accuracy of the automatization processes have served to devise a reference system able to support decision-making, considering as some prime key factors the number of Emergency Department admissions, medicinal stock availability, the number of daily infections, recoveries and fatalities, and predicting a possible change in region colour coding for the COVID-19 classification. A similar set of variables, processed in the system with a high level of accuracy, makes it possible to assist clinical teams and healthcare authorities in the planning of interventions and measures useful to tackle health emergencies, looking to the future.

In addition, the procedures adopted make it possible to have a basis for further tests with other variables, in order to be less unprepared in case of new needs.

Acknowledgements

This paper results from the project "ECO4CO – Earth Cognitive System 4 Covid-19 project" co-funded by the European Space Agency (ESA contract N° 4000133199/20/NL/AF) and developed in collaboration by Telespazio S.p.A, e-GEOS S.p.A, Leonardo S.p.A, LINKS Foundation (formerly ITHACA), CherryData S.r.l and Sapienza University of Rome.

Paragraph 1 of this paper develops and looks in depth at some considerations made in the contribution "Pesaresi C., *Riscopriamo la geografia. La pandemia minuto per minuto*, Touring Club Italiano, 2022".

References

1. Ahasan R., Alam M.S., Chakraborty T. and Hossain M.M., "Applications of GIS and geospatial analyses in COVID-19 research: A systematic review", *F1000Research*, 9, 1379, 2022.
2. Akinwumiju A.S., Oluwafemi O., Mohammed Y.D. and Mobolaji J.W., "Geospatial evaluation of COVID-19 mortality: Influence of socio-economic status and underlying health conditions in contiguous USA", *Applied Geography*, 141, 102671, 2022, pp. 13.
3. Aliyu A.A., "Public health ethics and the COVID-19 pandemic", *Annals of African medicine*, 20, 3, 2021, pp. 157-163.
4. Alsharif W. and Qurashi A., "Effectiveness of COVID-19 diagnosis and management tools: A review", published online 2020 (*Radiography*, 27, 2021, pp. 682-687).
5. Atek S., Pesaresi C., Eugeni M., De Vito C., Cardinale V., Mecella M., Rescio A., Petronzio L., Vincenzi A., Pistillo P., Bianchini F., Giusto G., Pasquali G. and Gaudenzi P., "A Geospatial Artificial Intelligence and Satellite-based Earth Observation Cognitive System in Response to COVID-19 Emergency", *Acta Astronautica*, 2022, pp. 18.
6. Atek S., Pesaresi C., Eugeni M., Gaudenzi P., De Vito C., Cardinale V., Mecella M., Rescio A., Petronzio L., Vincenzi A., Pistillo P. and Vora A., "An Earth Observation Cognitive System in Response to Sars-Covid-19 Emergency", *Proceedings of the International Astronautical Congress – IAC* (Dubai, United Arab Emirates, 25-29 October 2021), 2021, pp. 1-11.
7. Azevedo L., Pereira M.J., Ribeiro M.C. and Soares A., "Geostatistical COVID-19 infection risk maps for Portugal", *International Journal of Health Geographics*, 19, 25, 2020, pp. 8.
8. Barbieri D., Giuliani E., Del Prete A., Losi A., Villani M. and Barbieri A., "How Artificial Intelligence and New Technologies Can Help the Management of the COVID-19 Pandemic", *International Journal of Environmental Research and Public Health*, 18, 7648, 2021, pp. 10.
9. Brunialti T., Dai Prà E. and Gabellieri N., "Malattie infettive e cartografia per l'analisi e il monitoraggio: il progetto di mappatura del COVID-19 in Trentino", *Bollettino della Associazione Italiana di Cartografia*, 170, Special Issue, 2020, pp. 19-36.
10. Carballada A.M. and Balsa-Barreiro J., "Geospatial Analysis and Mapping Strategies for Fine-Grained and Detailed COVID-19 Data with GIS", *ISPRS International Journal of Geo-Information*, 10, 602, 2021, pp. 27.
11. Casti E., Adobati F. and Negri I (Eds.), *Mapping the Epidemic. A Systemic Geography of COVID-19 in Italy*, Elsevier, 2021.
12. Chee M.L., Ong M.E.H., Siddiqui F.J., Zhang Z., Lim S.L., Ho A.F.W. and Liu N., "Artificial Intelligence Applications for COVID-19 in Intensive Care and Emergency Settings: A Systematic Review", *International Journal of Environmental Research and Public Health*, 18, 4749, 2021, pp. 15.
13. Chen C., Jyan H., Chien S., Jen H., Hsu C., Lee P., Lee C., Yang Y., Chen M., Chen L., Chen H. and Chan C., "Containing COVID-19 Among 627,386 Persons in Contact With the Diamond Princess Cruise Ship Passengers Who Disembarked in Taiwan: Big Data Analytics", *Journal of Medical Internet Research*, 22, 5, e19540, 2020.

14. Chen G., "A Gentle Tutorial of Recurrent Neural Network with Error Back-propagation", *ArXiv*, abs/1610.02583, 2016.
15. Dangermond J., De Vito C. and Pesaresi C., "Using GIS in the Time of the COVID-19 Crisis, casting a glance at the future. A joint discussion", *J-READING (Journal of Research and Didactics in Geography)*, 1, 9, 2020, pp. 195-205.
16. Grekousis G., Wang R. and Liu Y., "Mapping the geodemographics of racial, economic, health, and COVID-19 deaths inequalities in the conterminous US", *Applied Geography*, 135, 102558, 2021, pp. 10.
17. Husnayain A., Fuad A. and Su E.C.-Y., "Applications of Google Search Trends for risk communication in infectious disease management: A case study of the COVID-19 outbreak in Taiwan", *International Journal of Infectious Diseases*, 95, 2020, pp. 221-223.
18. Iyanda A.E., Boakye K.A., Lu Y. and Oppong J.R., "Racial/Ethnic Heterogeneity and Rural-Urban Disparity of COVID-19 Case Fatality Ratio in the USA: a Negative Binomial and GIS-Based Analysis", *Journal of Racial and Ethnic Health Disparities*, 2021, pp. 14.
19. Kamel Boulos M.N. and Geraghty E.M., "Geographical Tracking and Mapping of Coronavirus Disease COVID-19/severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) Epidemic and Associated Events Around the World: How 21st Century GIS Technologies Are Supporting the Global Fight Against Outbreaks and Epidemics", *International Journal of Health Geographics*, 19, 8, 2020.
20. Kanga S., Meraj G., Sudhanshu, Farooq M., Nathawat M.S. and Singh S.K., "Analyzing the Risk to COVID-19 Infection using Remote Sensing and GIS", *Risk Analysis*, 41, 5, 2021, pp. 801-813.
21. Kim S.J. and Bostwick W., "Social Vulnerability and Racial Inequality in COVID-19 Deaths in Chicago", *Health Education & Behavior*, 2020, pp. 1-5.
22. Lessler J., Azman A.S., McKay H.S. and Moore S.M., "What is a Hotspot Anyway?", *The American journal of tropical medicine and hygiene*, 96, 6, 2017, pp. 1270-1273.
23. Lyu T., Hair N., Yell N., Li Z., Qiao S., Liang C. and Li X., "Temporal Geospatial Analysis of COVID-19 Pre-Infection Determinants of Risk in South Carolina", *International Journal of Environmental Research and Public Health*, 18, 9673, 2021, pp. 17.
24. Malik Y.S., Sircar S., Bhat S., Ansari M.I., Pande T., Kumar P., Mathapati B., Balasubramanian G., Kaushik R., Natesan S., Ezzikouri S., El Zowalaty M.E. and Dhama K., "How artificial intelligence may help the Covid-19 pandemic: Pitfalls and lessons for the future", *Reviews in medical virology*, 31, 5, 2021, pp. 1-11.
25. Murgante B., Borruso G., Balletto G., Castiglia P. and Dettori M., "Why Italy First? Health, Geographical and Planning Aspects of the COVID-19 Outbreak", *Sustainability*, 12, 5064, 2020, pp. 44.
26. Naudé W., *Artificial Intelligence against COVID-19: An Early Review*, Bonn, IZA (Institute of Labor Economics) DP N. 13110, 2020, pp. 14.
27. Pesaresi C., "A geographical and crosscutting look at the COVID-19 pandemic in an international framework. Introduction", *J-READING – Journal of Research and Didactics in Geography*, 2, 9, 2020, pp. 13-19.
28. Pesaresi C., *Riscopriamo la geografia. La pandemia minuto per minuto*, Touring Club Italiano, 2022, http://www.touringmagazine.it/articolo/5556/riscopriamo-la-geografia-la-pandemia-minuto-minuto.
29. Pesaresi C., Pavia D. and De Vito C., "Three geotechnological proposals to tackle health emergencies and the monitoring of infectious diseases. Inputs from the COVID-19 pandemic for future preparedness", *Bollettino della Associazione Italiana di Cartografia*, 170, Special Issue, 2020, pp. 58-75.
30. Pesaresi C., Pavia D., De Vito C., Barbara A., Cerabona V. and Di Rosa E., "Dynamic space-time diffusion simulator in a GIS environment to tackle the covid-19 emergency. Testing a geotechnological

application in Rome", *Geographia Technica*, 16, Special Issue, 2021, pp. 82-99.

31. Podda C. and Scanu G., "Trattamento spaziale dei dati pandemici: la cartografia del COVID-19", *Bollettino della Associazione Italiana di Cartografia*, 170, Special Issue, 2020, pp. 37-57.
32. Schmidt F., Dröge-Rothaar A. and Rienow A., "Development of a Web GIS for small-scale detection and analysis of COVID-19 (SARS-CoV-2) cases based on volunteered geographic information for the city of Cologne, Germany, in July/August 2020", *International Journal of Health Geographics*, 20, 40, 2021, pp. 24.
33. Shi F., Wang J., Shi J., Wu Z., Wang Q., Tang Z., He K., Shi Y. and Shen D., "Review of Artificial Intelligence Techniques in Imaging Data Acquisition, Segmentation, and Diagnosis for COVID-19", *IEEE Reviews in Biomedical Engineering*, 14, 2021, pp. 4-15.
34. Syrowatka A., Kuznetsova M., Alsubai A., Beckman A.L., Bain P.A., Craig K.J.T., Hu J., Jackson G.P., Rhee K. and Bates D.W., "Leveraging artificial intelligence for pandemic preparedness and response: a scoping review to identify key use cases", *npj Digital Medicine*, 4, 96, 2021, pp. 1-14.
35. Vaishya R., Javaid M., Khan I. and Haleem A., "Artificial intelligence (AI) applications for COVID-19 pandemic", *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, 14, 4, 2020, pp. 337-339.
36. Wang S., Ding S. and Xiong, L., "A New System for Surveillance and Digital Contact Tracing for COVID-19: Spatiotemporal Reporting Over Network and GPS", *JMIR mHealth and uHealth*, 8, 6, e19457, 2020.
37. Werner P.A., Kęsik-Brodacka M., Nowak K., Olszewski R., Kaleta M. and Liebers D.T., "Modeling the Spatial and Temporal Spread of COVID-19 in Poland Based on a Spatial Interaction Model", *ISPRS International Journal of Geo-Information*, 11, 195, 2022, pp. 21.
38. Wu C., Zhou M., Liu P. and Yang M., "Analyzing COVID-19 using multisource data: An integrated approach of visualization, spatial regression, and machine learning", *GeoHealth*, 5, 2021, pp. 14.
39. Zhang S., "Challenges in KNN Classification", *IEEE Transactions on Knowledge and Data Engineering*, 2021.