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DESIGNING A THEMATIC ATLAS ON THE GEOSPATIAL IMPACT OF COVID-19

Diploma thesis

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COPERNICUS MASTER IN DIGITAL EARTH
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ANNOTATION

The main goal of this diploma thesis is to create a cartographic product in the form of a thematic atlas focusing on the impact of the COVID-19 pandemic on various aspects (e.g. social, economic, environmental)and employing appropriate cartographic and design principles. To achieve these goals, the work objectives were divided into theoretical and practical parts which focus on research and initial planning, and the actual production of the atlas respectively.

Corresponding datasets were acquired from authoritative global data sources, including the Johns Hopkins University, Oxford University, the International Monetary Fund, the World Bank, and the Copernicus Programme. Pre-processing and standardization of data were conducted first using GIS software before creating the maps and other visualizations. Various types of maps including reference maps and thematic, maps (e.g. choropleth maps, categorical maps, synthetic maps) were incorporated to provide a holistic narrative of the COVID-19 pandemic.

Post-processing and atlas layout was performed in desktop publishing software. A short usability testing in the form of a survey questionnaire and user interview was performed to assess the readability and interpretability of the atlas, as well as to identify which atlas components still need to be improved. The results of the usability testing were evaluated and necessary improvements were applied to the atlas design.

The result of the diploma thesis is a printed and digital version of a thematic atlas about COVID-19 and its implications on the social, economic, and environmental aspects. Along with the actual atlas, a streamlined methodology of atlas creation from project definition to pre-press was also defined.

KEYWORDS

cartography, pandemic, infodemic, map design, GIS

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Number of appendices: 5

This thesis has been composed by *Leonard Luz* for the Erasmus Mundus Joint Master's Degree Program in Copernicus Master in Digital Earth for the academic year 2020/2021 at the Department of Geoinformatics, Faculty of Natural Sciences, Paris Lodron University Salzburg, and Department of Geoinformatics, Faculty of Science, Palacký University Olomouc.

Hereby, I declare that this piece of work is entirely my own, the references cited have been acknowledged and the thesis has not been previously submitted to the fulfillment of the higher degree.

20 May 2021, Olomouc, Czech Republic Leonard Luz

Palacký University Olomouc
Faculty of Science
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ASSIGNMENT OF DIPLOMA THESIS

(project, art work, art performance)

Name and surname:	**Leonard LUZ**
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Field of study:	**Geoinformatics and Cartography**
Work topic:	**Designing a Thematic Atlas on the Geospatial Impact of COVID-19**
Assigning department:	**Department of Geoinformatics**

Theses guidelines

The main goal is to create a set of thematic maps about COVID-19 and its effects on the environment, society, and other related fields. The student will analyze existing data sources and maps, select interesting topics, and process them with appropriate methods of thematic cartography. Then the student will prepare a set of thematic maps in the form of a thematic atlas (publication), which will contain maps and their basic interpretation. The student will follow the principles of modern (carto)graphic design, including the use of infographics. For topics where it is possible, the student will use Copernicus Data and Information Services. After the map's creation, the student will perform a short user testing with a focus on the correct understanding of the presented information to the map user. The main results of the diploma thesis will be a set of thematic maps in the form of PDF publication and the evaluated results of the user testing.The student will attach all the collected datasets and all the animations to the thesis in digital form. The student will create a website about the thesis following the rules available on the department?s website and a poster about the diploma thesis in A2 format. The student will submit entire text (text, attachments, poster, outputs, input and output data) in digital form on a storage medium and the text of the thesis in two bound copies to the secretary of the department.

Extent of work report:	**max 50 pages**
Extent of graphics content:	**as needed**
Form processing of diploma thesis:	**printed**
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Recommended resources:

- FIELD, Kenneth. Cartography. 1st edition, 2018, Esri Press. 576 p. ISBN 9781589484399
- GRIFFIN, Amy L. Trustworthy maps. Journal of Spatial Information Science [online]. 2020, (20), 5-19 [cit. 2020-11-10]. ISSN 1948-660X. doi:10.5311/JOSIS.2020.20.654
- MOCNIK, Franz-Benjamin, Paulo RAPOSO, Wim FERINGA, Menno-Jan KRAAK and Barend KÖBBEN. Epidemics and pandemics in maps –the case of COVID-19. Journal of Maps [online]. 2020, 16(1), 144-152 [cit. 2020-11-10]. ISSN 1744-5647. doi:10.1080/17445647.2020.1776646
- MOONEY, Peter and Levente JUHÁSZ. Mapping COVID-19: How web-based maps contribute to the infodemic. Dialogues in Human Geography [online]. 2020, 10(2), 265-270 [cit. 2020-11-10]. ISSN 2043-8206. doi:10.1177/2043820620934926
- Other suitable literature available through scientific databases (WoS, SCOPUS, ScienceDirect etc.).

Supervisors of diploma thesis: **RNDr. Alena Vondráková, Ph.D.**
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CONTENT

LIST OF ABBREVIATIONS

Abbreviation	Meaning
CC	Creative Cloud (Adobe)
CFR	Case Fatality Rate
CMYK	Cyan Magenta Yellow Black (color model)
COVID-19	Coronavirus Disease 2019
CSV	Comma-Separated Values
CVD	Color Vision Deficiency
DPI	Dots per Inch
DTP	Desktop Publishing
ECDC	European Center for Disease Prevention and Control
EPS	Encapsulated Postscript
EPSG	European Petroleum Survey Group
GDP	Gross Domestic Product
GEE	Google Earth Engine
GIS	Geographic Information System
HCHO	Formaldehyde (CH_2O)
IATA	International Air Transport Association
ILO	International Labor Organization
IMF	International Monetary Fund
ISO	International Organization for Standardization
JHU	Johns Hopkins University
JPEG	Joint Picture Experts Group
NACIS	North American Cartographic Information Sociaety
NO2	Nitrogen Dioxide
OxCGRT	Oxford COVID-19 Government Response Tracker
PDF	Portable Document Format
PNG	Portable Network Graphics
RGB	Red Green Blue (color model)
SHP	Shapefile
SO2	Sulfur Dioxide
SVG	Scalable Vector Graphics
TIF	Tag Image File
WB	World Bank
WHO	World Health Organization

INTRODUCTION

One year after the onset of the Coronavirus disease 2019 (COVID-19) pandemic, the latest reports and statistics show that most countries are still grappling to control the spread of the virus. While containment measures and vaccination policies have helped reduce the cases in some countries, the global figures remain at the highest levels (WHO, 2021a). And as the pandemic continues to affect almost all aspects of society, this topic will also remain a global concern for years to come.

Being the first pandemic in the modern age, the usage of digital technology during the pandemic has also increased as compared to the pre-pandemic period (De' et al., 2020). As the data production on COVID-19 increases every day, the pandemic also highlighted the role of technology in the rapid proliferation of information about a global issue both positively and negatively. Infodemic, or the rapid spike in the volume of information due to a certain event, has become a critical issue arising together with the pandemic itself (WHO, 2020). With the large volume of digital technology users worldwide, even inaccurate and false information is also being produced and shared rapidly on different platforms, especially through social media (Liu, 2021).

Given the inherent geographical nature of pandemics in general, maps have been frequently used in communicating information for various aspects of the COVID-19 phenomenon. The most common use of maps in the pandemic is the visualization of the global distribution of cases using web maps and dynamic dashboards (Mooney & Juhász, 2020). In her paper, Griffin (2020) outlined some of the potential aspects of misinformation through maps during the COVID-19 pandemic. Several challenges in the visual representation of COVID-19 maps were also summarized by (Mocnik et al., 2020). While there have been limited studies on how largely maps contribute to the infodemic, it can be inferred that there have been inappropriate uses of maps in the depiction of the pandemic or some aspects of it.

In line with this, the thesis was developed to produce a cartographic product in the form of a thematic atlas about the COVID-19 pandemic incorporating appropriate cartographic and map design principles as the need for the proper use of maps during the pandemic has become evident. Since most of the maps generated today center on the current status of the pandemic, this atlas intends to visualize the impact of the pandemic on various aspects of society. As global datasets are being generated by various institutions independently, a consolidated source of reliable visualizations provides a holistic understanding of the pandemic that would not be otherwise possible with individual products alone.

1 OBJECTIVES

The main goal of this thesis is to create a set of thematic maps about COVID-19 and its effects on the environment, society, and other related fields. The sub-goals are to analyze existing data sources and maps, select interesting topics, and process them with appropriate methods of thematic cartography. In the practical part, the main aim is to create a set of thematic maps in the form of a thematic atlas, following the principles of modern (carto)graphic design, including the use of infographics. For topics where it is possible, Copernicus Data and Information Services will be used. After the creation of the maps, a short user testing will be performed with a focus on the correct understanding of the presented information to the map user. Along with the actual atlas, it also aims to outline a streamlined methodology on the creation of a thematic atlas about a global topic from project definition to pre-press.

To realize these goals, the work objectives were divided into theoretical and practical parts. The first part focuses on research and initial planning while the practical part concentrates on the actual production and evaluation of the atlas and its components. These goals were summarized as follows:

Theoretical goals:

- Describe the cartographic project definition
- Research on the current state of mapping during the pandemic
- Identify the atlas contents and potential data sources

Practical goals:

- Collect relevant datasets
- Harmonize and organize the gathered datasets
- Compile the atlas contents and layout
- Perform atlas usability testing

As the final output of this thesis, the atlas can serve as an easy-to-use source of information that also adheres to the principles of cartography in understanding the global impact of the COVID-19 pandemic. While the recentness of information shown has been one of the major limitations of atlases, this COVID-19 atlas focuses on documenting the global conditions one year after the pandemic has started. Given that the pandemic has not been declared over, this atlas can also be used as a basis for the succeeding editions or similar cartographic products in the future. The methodological aspect of the thesis can also be beneficial for cartographers who are concerned with the production of high-volume thematic maps for global topics (e.g. COVID-19 pandemic).

2 METHODOLOGY

Used methods

For the completion of this diploma thesis, the initial work was focused on the theoretical part starting with the cartographic project definition. The objective and project specifications were identified and the contents of the atlas were finalized following a consultation with the thesis supervisor. This was followed by preliminary research on the potential data sources as well as on scientific literature about the topic. Important issues focusing on thematic cartography and map design were explored together with the state of atlas creation specifically on global topics.

Due to the broad range of topics included in the atlas, a great deal of time was devoted to data collection and processing. The initial part of data collection was spent on the acquisition of GIS data for the reference map and the environmental topics especially since the datasets for the other topics were still unavailable until the end of January 2021. Once all the necessary datasets were obtained, data processing and harmonization using GIS software were conducted before the actual production of maps and other graphical contents of the atlas.

Map and chart design improvements (e.g. color management, color standardization, etc.) and the designing of the final atlas layout were accomplished using desktop publishing programs (DTP). A short user testing was also performed after the creation of the final atlas to evaluate the usability of the generated cartographic product. Several consultations regarding the map design were conducted together with the thesis supervisors to ensure that the final product will maximize its usability.

Used data

In the course of the atlas creation process, spatial (GIS), tabular data, and graphics data were utilized. Reliable data from official reports and publications recognized internationally were obtained and processed. In all the visualizations presented, only publicly available data were used.

GIS data

The basemap used for the reference map is a customized version of the 'Vibrant Basemap' layer created by Esri and the Vizzuality team for the Half-Earth Project. This was accessed as a tile layer through the Esri Living Atlas portal and was modified to suit the overall design of the atlas. Moreover, the base layer of the thematic maps makes use of the country/territory boundary and populated places data acquired from Natural Earth, a public domain map dataset compiled and maintained by various volunteers and is supported by the North American Cartographic Information Society (NACIS).

All the environmental datasets used in this atlas were products of the Sentinel-5 Precursor mission of the Copernicus Program. Three Offline Level 3 (OFFL L3) global products on air quality (nitrogen dioxide, sulfur dioxide, and formaldehyde concentrations) were acquired in Tag Image File (TIF) format from the Copernicus data store through the Google Earth Engine platform. These were then processed and stored as a mosaic dataset in an Esri file geodatabase.

Tabular data

The majority of the data used for the thematic overlay were acquired in tabular formats (CSV, XLSX, etc.) from authoritative data sources in their respective fields. The COVID-19 statistics, which is the most relevant for this atlas was obtained from Johns Hopkins University and Our World in Data. Tabular data on the social policies implemented by each country during the pandemic was obtained in Microsoft Excel Open XML Spreadsheet (XLSX) format from the Oxford COVID-19 Government Response Tracker (OxCGRT), a global initiative of the Blavatnik School of Government at the University of Oxford. The data for the economic topics were obtained from annual reports of major global financial institutions such as IMF and World Bank. Other statistics were manually extracted from regular fact sheets and reports of other economic institutions such as ILO for labor-related statistics and IATA for the airline industry statistics.

Graphics

Royalty-free graphic elements (e.g. icons, photos) were also used throughout the atlas. Most of these vector graphics were obtained from Freepik in Encapsulated PostScript (EPS) format while most of the icons were taken from Flaticons in Scalable Vector Graphics (SVG) format. High-resolution photos used especially for the chapter covers were downloaded from Unsplash originally in Portable Network Graphics (PNG) format.

Used software

Various software programs were used concerning data processing and graphic design. Licenses for these programs were obtained either from the University of Salzburg or from the Palacky University unless specified otherwise.

The latest version of ArcGIS Pro (v 2.8) was the primary software program used in the processing of spatial data and the production of maps in the atlas. QGIS v 3.10 was used occasionally for the visualization of some map layers. Additionally, the Google Earth Engine platform was utilized heavily especially in the acquisition and processing of global air quality datasets from Sentinel-5P.

For the creation of charts and graphs, Office 365 products including Microsoft Excel and Microsoft Word were the main program used. Web-based chart creation platforms such as Flourish, Chartle, and Polar Chart Area Generator were also utilized to create some of the charts that were not directly available in MS Excel. Several color blindness testing tools such as Adobe Color Accessibility Tool and Chroma.js Color Pallete Helper were employed. Adobe Illustrator CC 2021 (v 25.2.1) was used in creating the infographics and improving the designs of the exported maps while Adobe InDesign CC 2021 (v 16.2) was the main program used in designing the layout of the atlas. Access to the Adobe Creative Cloud environment was made possible through an Adobe CC license shared by the thesis supervisor for the completion of this thesis.

The usability testing was conducted through a combination of interviews and an online survey. The online survey tool JotForm was used to carry out the survey part as it provides several supplementary tools for monitoring the response time for each question.

Processing procedure

In the diagram below, the general steps in the creation of the atlas are outlined. The main software used especially during the data processing and graphic designing where the bulk of the work happened is also shown. A more detailed explanation of these procedures is discussed in Chapter 4 Atlas Creation.

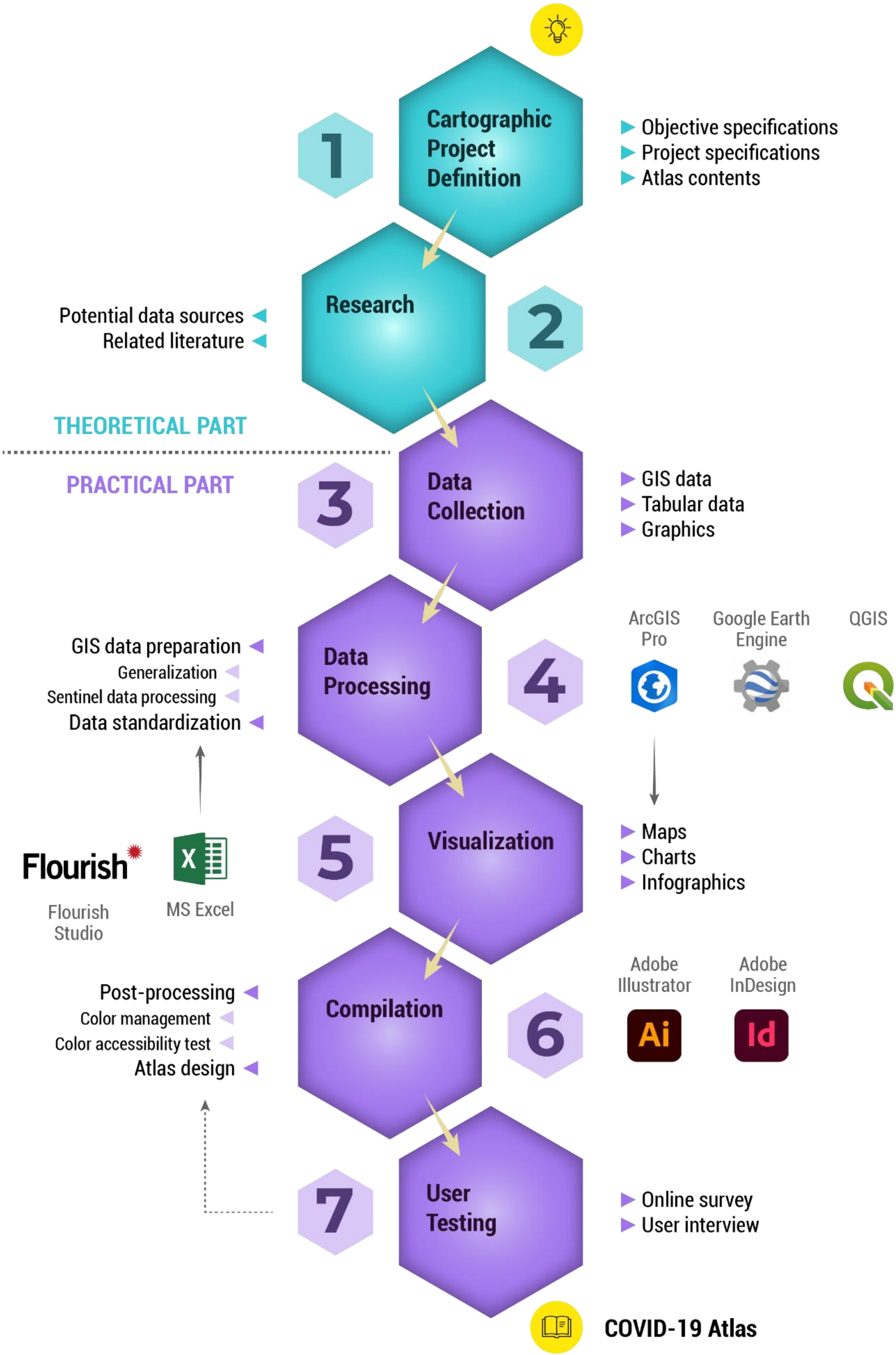

Figure 1 Workflow diagram for the atlas creation.

3 STATE OF ART

During the pandemic, understanding spatial patterns and communicating critical information has been made easy through the use of GIS technologies. The state of art chapter describes some of the particular applications of GIS during the pandemic in a broader context. Then it explains how GIS data are being presented and visualized. Furthermore, it also looks into the role of maps and geovisualizations in the infodemic and misinformation emphasizing the need to create better cartographic products. And lastly, it looks into the existence of COVID-19 atlas or other similar cartographic products presenting global topics.

Applications of GIS during the pandemic

Since the World Health Organization declared COVID-19 as a pandemic last March 2020, the role of GIS in different aspects of the pandemic cannot be emphasized enough. Not only it was used in modeling and predicting spatial patterns, but also in identifying the relationship of the growing cases to social and environmental variables. With the number of studies conducted related to the pandemic, it cannot be denied that the use of GIS has peaked during this pandemic compared to other periods since its conception.

As an inherently spatial phenomenon, the application of GIS in understanding the spread of the virus has been the topic of several spatio-temporal studies focusing on both global (Saha et al., 2020) and local patterns (X. Liu et al., 2020), (Desjardins et al., 2020), (Kim & Castro, 2020). Even at the early stages of the pandemic, how GIS can be used in modeling potential COVID-19 risk zones has been exhibited in various local settings like Italy (Giuliani et al., 2020), and China (Ren et al., 2020), which were identified as global epicenters during the first wave of the pandemic. Aside from spatio-temporal studies focusing on identifying local patterns and distribution, GIS has been widely used also in discovering key factors and spatial determinants of local transmissions in countries with a significant number of cases, such as China (Han et al., 2021) and the United States (Andersen et al., 2021).

The use of GIS in understanding the social implications of the pandemic has been demonstrated in several studies as well. In their paper, Padula & Davidson (2020) looked into the relationship between the number of nurses and COVID-19 mortality in each country and found out that a reduction in the COVID-19 mortality rate can be observed in countries with more registered nurses. In another study, the feasibility of the implementation of social distancing in the slums of Cape Town was also explored through the use of GIS (Gibson & Rush, 2020).

A lot of GIS studies were also centered on analyzing the relationship between the cases of COVID-19 and certain environmental variables, as it was initially believed that the virus may have different behaviors across varying climatic conditions. In their study, Ahmadi et al. (2020) used partial correlation coefficient tests coupled with spatial analysis to understand the relationship among several climatic parameters such as humidity, rainfall, temperature, etc., and the COVID-19 outbreak in Iran. A similar study was conducted by Tosepu et al. (2020) in Jakarta and (de Ángel Solá et al., 2020) in the Caribbean Basin. This has also been applied on a global scale wherein cities with high infection rates were analyzed to predict the potential zones at risk based on various climatic factors such as temperature, humidity, and latitude and extrapolated to the rest of the world. (Sajadi et al., 2020).

While these are just some of the most widely used applications of GIS in studying various areas related to COVID-19, Franch-Pardo, et al. (2020) consolidated several general topics of studies involving the use of GIS technologies during the pandemic. Aside from the ones mentioned above, health and social geography issues, as well as the use of data mining and web mapping technologies were also some of the most researched topics involving GIS during the pandemic.

State of COVID-19 maps

How COVID-19 data is being portrayed and shared in public is also another crucial issue not only in the point of view of cartography but also in information dissemination. If one searches for COVID-19 visualization, most of these are in the form of dashboards. One of the most widely used globally is the COVID-19 dashboard developed by the Johns Hopkins University Coronavirus Resource Center, which has been shared in various media platforms as well, especially social media, besides the online dashboard developed by the World Health Organization (Dong et al., 2020). Not only that it was the first COVID-19 dashboard to go online, but it also reflects the most updated case statistics coming from numerous country-level reports worldwide. Comparing the information recency between the two dashboards, the JHU dashboard displays updated statistics at least 12 hours ahead of what is shown in the WHO dashboard. In their paper, Kamel Boulos & Geraghty (2020) outlined some of the first web-based dashboards deployed during the early stages of the pandemic, which include the two dashboards mentioned above, as well as from other sources such as the HealthMap dashboard. Since the introduction of these dashboards, it has been widely shared and utilized by the media in reporting global cases. Even at the regional and local levels, most countries utilize map dashboards in tracking and reporting COVID-19 cases as this allows near-real-time broadcasting of information.

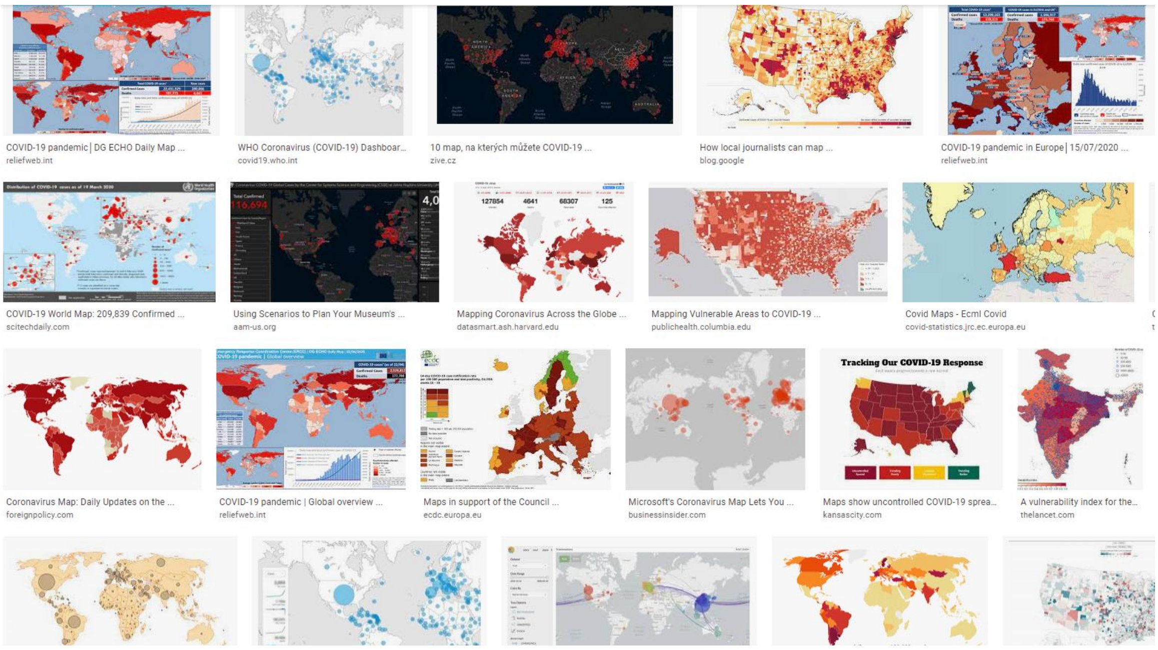

Figure 2 COVID-19 maps displayed in Google search.

Due to the dynamic nature of the pandemic, web-based dashboards have been useful not only in visualizing the spread of the virus but most importantly in the up-to-date reporting of these cases and sharing of information globally. While this is the case, static maps are also still being used for reporting. The European Center for Disease Prevention and Control, for instance, publishes static maps and charts in reporting global COVID-19 cases every 14 days (ECDC, 2021). The World Health Organization also publishes static maps as part of their weekly situational reports (WHO, 2021b). Regardless of their formats, the common denominator of these maps is their focus on showing statistics and figures like cases, deaths, and recoveries only but not on the other crucial aspects that affect how these figures are derived (e.g. testing capacities).

Maps and infodemic

As defined by the World Health Organization, infodemic is the abundance of information, especially the false or misleading kinds during a disease outbreak, that can lead to mistrust in health authorities and the responses that they implement (WHO, 2020). As the influx of digital data about COVID-19 surges, so is the amount of unverified information that is being shared on various platforms, especially social media (Tsao et al., 2021). Aside from the pandemic itself, this has been one of the most significant issues tackled by experts globally due to the potential implications in the response and attitudes of the public towards the pandemic. This misinformation in some countries during the pandemic has been the subject of several studies already, such as in the case of India (Datta et al., 2020; Islam et al., 2021). Infodemic in different social media platforms has also been explored in several studies. In their paper, Shahi et al. (2021) investigated how false information was being shared on Twitter and found out that even verified accounts belonging to celebrities and public authorities were involved in the propagation of fake or partially fake news about the pandemic. In a similar study, Guarino et al. (2021) also explored the case of information disorder in Italy during the pandemic in the social networking site Facebook.

This proliferation of misinformation is one of the consequences of the exponential rate of digital data creation coupled with ease in accessing them through different media outlets. For instance, when it comes to COVID-19 data and maps, several sources that display both global and local statistics were identified by Pászto et al. (2020). With numerous organizations reporting and sharing news of COVID-19 through maps, how they contribute to the abundance of information and in the infodemic phenomenon has been the subject of several cartographic studies as well. Sometimes, this misinformation caused by maps was not only due to the inherently incorrect data used in creating them but also to how inappropriate cartographic methods were applied to portray the correct data. During the early stage of the pandemic, Fields (2020) discussed some of the most common cartographical errors exercised by cartographers in producing COVID-19 maps especially in the use of heat maps and choropleth maps. Additional challenges in the cartographic visualization of COVID-19 data were also described by Mocnik et al. (2020) together with the potential solutions on how these cartographic issues can be solved. Griffin (2020) also reviewed in her paper the critical challenges that cartographers need to consider in creating trustworthy maps as demonstrated in various types of COVID-19 maps. In another paper, Mooney & Juhász (2020) described how web maps, in particular, contribute to the infodemic. Aside from the improper use of mapping techniques, they also found out that some of the available web-based dashboards and maps lack information on the uncertainty of data being displayed. Considering how these maps are being accessed and viewed by most people as authoritative data sources, the lack of important details about their limitations can also be deemed a contributor to misinformation. In his paper, Everts (2020) also provided a deeper analysis not only on the misuse of dashboards during the pandemic but also on the sociopolitical repercussions of how COVID-19 maps portrayed in this medium obscures some of the important social issues that need to be addressed aside from the pandemic itself.

As this surge in information affected the integrity of information, another issue that has been highlighted by this pandemic is accessibility. De' et al. (2020) emphasized that misinformation due to lack of access to a reliable source of information has also been evident during the pandemic especially in developing countries where connection to the digital world is limited. While maps are frequently shared through platforms that are accessible through social media and the internet, access for these marginalized users should also be considered.

COVID-19 and global atlases

The limited existence of COVID-19 atlas has been the principal motivation for this thesis. While individual maps, especially those that show global statistics of COVID-19 are widely available, a consolidated cartographic product presenting several aspects of the pandemic remains inadequate. In the United States, an example of a web-based COVID-19 atlas was developed by the University of Chicago's Center for Spatial Data Science (CSDS). Aside from the usual COVID-19 statistics, the atlas also visualized several topics such as testing, vaccination, community health information, and mobility. The atlas also consolidates several data sources to show near-real-time information about the pandemic along with other health-related thematic layers (UC CSDS, 2020).

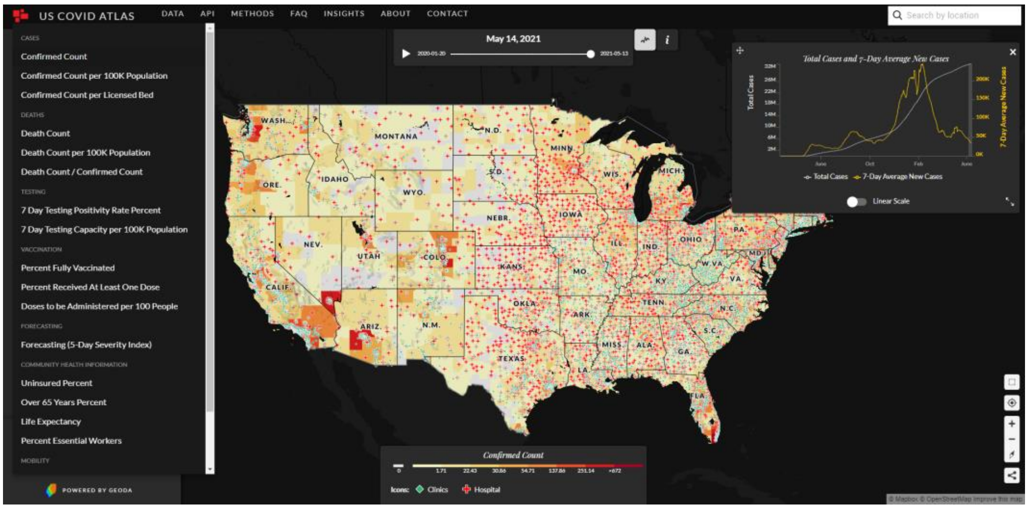

Figure 3 US COVID Atlas created by UC CSDS.

In terms of an analog atlas, there has been no published atlas yet relating to COVID-19. One of the latest analog thematic atlases visualizing a global topic is the Atlas of Sustainable Development Goals from World Development Indicators (World Bank Group, 2018). Global maps and other geovisualizations were used in this atlas to present topics based on the SDG framework. Also, the Atlas of the Human Planet is another analog atlas that portrays the distribution of human presence on the planet as captured in the Global Human Settlement Layer of the European Commission, Joint Research Centre (Paresi et al., 2017). The World Atlas Gender Equality in Education is another example of an analog atlas visualizing global trends and development in educational opportunities and literacy levels (UNESCO, 2012).

4 ATLAS CREATION

An atlas can be defined as an "intentional combination of maps and datasets" that are organized to convey a certain goal or objective (Kraak & Ormeling, 2013). Compared to a standalone map, a holistic view of a topic can be derived by integrating all of its components. Understanding the purpose is a crucial element in the creation of an effective atlas. Without the idea of its use, the presentation of the cartographic product may differ far from reality, thus propagating an atmosphere of misinformation. And when critical topics such as the COVID-19 pandemic are put as the main subject of these maps, it follows that utmost importance must be given during the conceptualization phase of the cartographic process.

To achieve this goal, the three phases of map design— map proposal, map drafting, and map compilation as outlined by Vozenilek (2014), were adopted in the creation of the atlas. During the initial phase, the objective and project specifications of the map project were defined. It was followed by the data collection phase and then the actual production of atlas contents. The data production process can be subdivided into data processing and geovisualization phases where the bulk of work was devoted to. The individual maps and other geovisualization products were compiled in the form of an atlas employing the principles of graphics design and desktop publishing. Lastly, the usability of the atlas was also tested through interviews and survey questionnaires.

4.1 Cartographic project definition

As the initial phase of the map design process, the project definition involves the formulation of the objective and project specifications. The objective specifications describe the main goals of the atlas and other relevant information that is necessary for understanding its general use. On the other hand, the project specifications describe the practical and technical aspects of the atlas. In conjunction with one another, it provides the fundamental framework for the creation of the atlas. Once the cartographic project definition has been finalized, necessary research about the topic was carried out.

4.1.1 Objective specifications

The COVID-19 pandemic, being one of the most significant global issues in the digital age, has led to a surge in the volume of data being published and consumed all over the world. By leveraging these data, this atlas aims to provide a consolidated source of information about the COVID-19 pandemic and its global socio-economic and environmental impact, one year after it happened. A substantial amount of effort was done to cover a larger user group for the atlas which is originally intended for the general public. However, the nature of the topics in the atlas is more suitable for the 'professional' niche of the public such as authorities whose works are related to the pandemic, cartographers, and other groups that may be interested in the issue. The resulting product is an analog atlas which was also exported into a digital format as a view-only electronic atlas.

Given the broad nature of the topic, the volume of information presented in the atlas was influenced mostly by the data availability and the overall project implementation timeline. Although this is the case, a variety of subtopics concerning the socio-economic and environmental impact of the pandemic were still incorporated. Only the significant issues related to the theme were selected to balance the overall workload and the level of insights that were presented to the users.

Table 1 Objective specifications

Specification	Description
Target users	Primary: professional public (e.g. authorities working on related fields, cartographers) Secondary: general public
Way of atlas manipulation	Analog atlas for general use, a digital atlas for web
Volume of conveyed information	Limited by data availability and project implementation timeline

4.1.2 Project specifications

The project specifications provide a concrete description of how the contents, especially the maps are organized in the atlas. This also serves a crucial role during the implementation stage as it helps ensure the uniformity of contents in the atlas. In this section, the technical specifications of the atlas were defined which include the properties of the maps, an overview of the procedures and the technologies used, as well as the organizational and financial considerations during the creation process.

Table 2 Project specifications

Specification	Description
Title	COVID-19 Atlas: An Illustrated Guide to the Global Impact of the COVID-19 Pandemic
Thematic focus	Visualization of the global state of COVID-19 with emphasis on its direct or indirect impact on socioeconomic and environmental aspects
Atlas dimensions	A3 Landscape (420×297 mm) or (16.5×11.7 in)
Map projections	World map: World Wagner VII Africa: Africa Albers Equal Area Conic Asia (Western part): Asia North Albers Equal Area Conic Asia (Eastern part): Asia Lambert Conformal Conic Caribbean: North America Albers Equal Area Conic Europe: Europe Albers Equal Area Conic North America: North America Albers Equal Area Conic Oceania: GDA 1994 Geoscience Australia Lambert South America: South America Albers Equal Area Conic
Map scale	*Reference maps* World map: 1:90,000,000 Africa: 1:55,000,000 Asia (Western part): 1:35,000,000 Asia (Eastern part): 1:50,000,000 Caribbean: 1:15,000,000 Europe: 1:35,000,000 North America: 1:45,000,000

	Oceania: 1:60,000,000 South America: 1:45,000,000 *Inset maps* Europe: 1:40,000,000 Western Asia: 1:22,000,000 Caribbean: 1:18,000,000 Oceania: 1:110,000,000
Methods of visualization	Thematic methods: Area symbol method and point symbol method
Map symbology	Map Data Visualization Report (MDVR) was developed, shown as Appendix 2 of this thesis
Data sources	The complete list of datasets used and sources can be found in Table 3
Technology of compilation	Print-ready Portable Document Format (PDF) in CMYK color model, Web-friendly PDF for the electronic version
Organizational and financial considerations	The atlas was developed with the assistance of the thesis supervisor. Aside from the cost of printing the final product, there are no other financial limitations addressed in the development of the atlas.

4.2 Data collection

Only authoritative and internationally recognized data sources relating to each topic were used in this atlas. All the maps and graphics in the atlas utilized data that are either in the public domain or has a Creative Common Attribution 4.0 International (CC BY 4.0) license. Under this license, the data can be used, distributed, and reproduced in any medium, as long as the source and authors are credited (Creative Commons, 2021). The graphic elements, on the other hand, were covered by the licensing policies of their respective sources which operate similarly to the CC BY license.

4.2.1 GIS data

Besides the ancillary map elements, a thematic map is generally composed of two main components, a basemap, and a thematic overlay (Dent et al., 2009). In collecting the datasets needed in the creation of each map, the first phase of data collection was focused on the spatial data for the basemap since this will also be used in creating the reference maps. These data include a polygon layer of the latest country/territory boundaries and a point layer showing the populated cities in the world.

Nowadays, GIS data especially global datasets can be easily obtained from numerous sources on the web. Among these datasets, the difference usually is on the recentness of both the geometry and attribute information. After evaluating all the possible sources for the country/territory boundaries, the final dataset used in the atlas was obtained from Natural Earth. Natural Earth is a public domain map dataset compiled by various volunteers and is supported by NACIS. Since these data are maintained by cartographers, different versions depending on the intended map scale are already available. The closest available map scale of 1:110,000,000 was downloaded for further processing. The populated places point layer was also downloaded from Natural Earth. The original datasets came in shapefile format with a WGS 1984 (EPSG:4326) map projection.

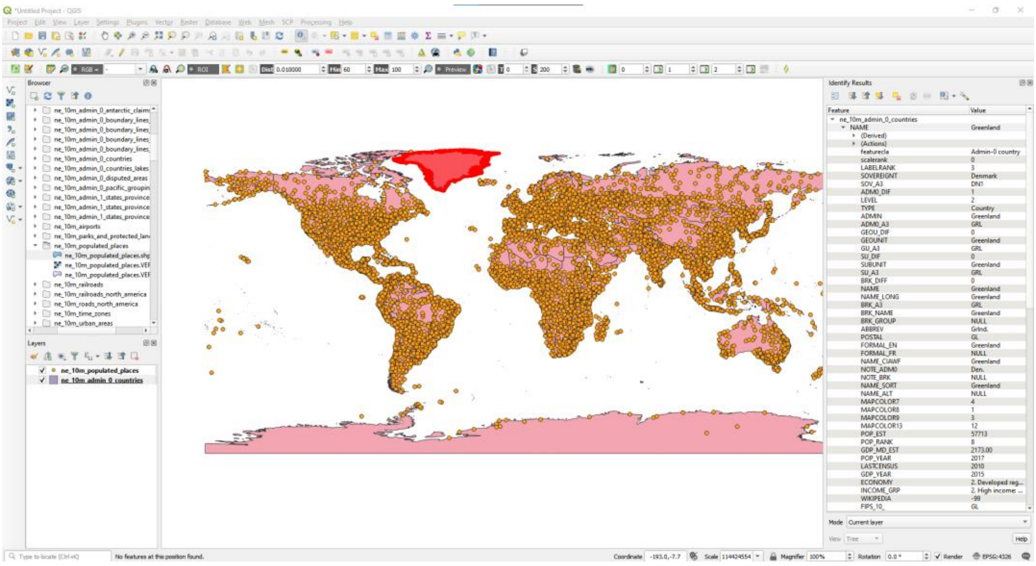

Figure 4 Small scale dataset from Natural Earth

Aside from the country boundary and populated places layers, another spatial data used in the reference maps is the Vibrant Basemap, a web map tile service from Esri Living Atlas. This tile service was used as the background layer due to its colorful and engaging depiction of the earth's surface. When combined properly with the country boundary data, a clean and simple map for reference purposes can be easily created. The original web map tile service can be accessed through this link:

https://tiles.arcgis.com/tiles/nGt4QxSblgDfeJn9/arcgis/rest/services/Vibrant/MapServer

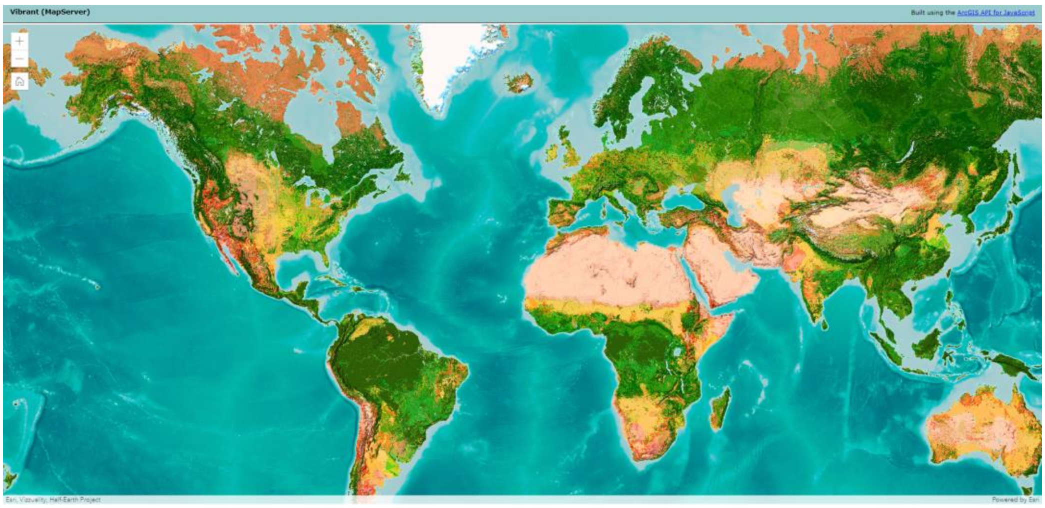

Figure 5 Vibrant basemap web map tile service

The last set of GIS data obtained is for the thematic overlay used in the environmental topics. Among the three, these datasets were the most challenging to acquire mainly due to the scope and the size of the resulting files. These raster layers showing the global concentration of three major pollutants (NO_2, SO_2, and HCHO) acquired by the Sentinel-5P observation satellite were obtained from the Copernicus Services datastore through Google Earth Engine.

Unlike other Google products which are available to the user after registration, access to the Google Earth Engine platform needs to be requested separately before it can be used and before data can be downloaded from their servers. The original raster files were downloaded as TIF with a pixel resolution of 1 km × 1 km and total file size of 69.5 gigabytes on disk.

4.2.2 Tabular data

COVID-19 dataset

For COVID-19 statistics, tabular data in CSV format was acquired from Johns Hopkins University Coronavirus Resource Center (JHU-CRC), one of the most widely-used and reliable COVID-19 information sources collating datasets on a global scale. Ever since the declaration of the pandemic, JHU-CRC has been recording daily COVID-19 statistics from every country including the new and total confirmed cases, deaths, and active cases among others. Another dataset used for COVID-19 statistics came from Our World in Data through their COVID-19 Data Explorer. This was used in the quantitative thematic maps showing the state of the pandemic as of January 2021.

Another critical dataset about COVID-19 was acquired from the University of Oxford Government Response Tracker. Similar to JHU-CRC, this institution also collects country-level data worldwide but their focus is more on the social and health containment policies implemented by each country as the pandemic progresses. These data were used mainly in the categorical thematic maps as well as on the charts included in the social impact topics.

Economic data

The data about economic indicators were obtained mostly from the latest World Economic Outlook report of the International Monetary Fund (IMF) and the World Development Indicators database by the World Bank (WB). Other datasets came from the latest Fact Sheets from the International Labour Organization (ILO) and the International Air Transport Association (IATA). While the figures for the fiscal year 2020 have been published already, most of them are still estimates using the data from the previous years. Tabular data are either in CSV and XLSX format while the reports are accessed in PDF format.

4.2.3 Graphics data

Most of the graphic elements used in the atlas were acquired from royalty-free sources on the web. These sites offer free graphic resources for non-commercial use as long as proper attributions are credited to the original authors. For the chapter covers of the atlas, photos were downloaded from Unsplash (https://www.unsplash.com/), one of the most popular websites that host freely usable images. Vector graphics in SVG and EPS formats were obtained from Freepik (https://www.freepik.com/) while icons were downloaded from Flaticon (https://www.flaticon.com/) and Flourish (https://flourish.studio/). While this is the case, additional customizations were still applied in these graphics during the design stage to match the overall theme of the atlas.

Table 3 Datasets used and their respective sources with the licensing types

Dataset	Source	License
Vibrant basemap	Esri	Public
Country boundary	Natural Earth	Public
Populated places		
COVID-19 statistics	JHU-CRC	CC BY 4.0
	Our World in Data	CC BY 4.0
COVID-19 policies per country	OxCGRT	CC BY 4.0
Volume of export	IMF	Public
Volume of import		
Gross Domestic Product (GDP) per capita		
Inflation rate		
Income level classification	World Bank	Public
Unemployment rate		
Airline industry statistics	IATA	Public
Working hours lost statistics	ILO	Public
Nitrogen dioxide concentration	Copernicus Sentinel-5P	Public
Sulfur dioxide concentration		
Formaldehyde concentration		
Vector graphics	Freepik	Freepik License (Free)
Icons	Flaticon, Flourish	Freepik License (Free)
Photos	Unsplash	Unsplash License (Free)

4.3 Data processing

The level of processing conducted varies based on the quality and format of the raw data. While the tabular data requires minimal processing, most of the GIS data acquired needed to be preprocessed first before it became applicable for map-making. This section explains the crucial steps taken in the preparation of the GIS files and the standardization of the data used.

4.3.1 GIS data preparation

Generalization

Depending on the scale and purpose of a map, the level of detail on the underlying data may also vary. In thematic maps, the base data should not distract the user during map reading so that the more important message about the topic will be easily communicated. This process of selection and simplification of detail on the map is called generalization (Tyner, 2010). Both graphical and contextual types of generalization were done in the country/territory boundaries data.

Upon plotting the raw data of country/territory boundary obtained from Natural Earth, it was observed that the geometry was too detailed for the thematic maps since a lot of small islands can still be seen which makes the map appear visually cluttered.

The coastline of some countries such as Chile, Norway, and the United States also appear too pronounced on the intended world map scale of 1:90,000,000. To address this, generalization tools, specifically the Smooth Polygon and Simplify Polygon tools in ArcGIS Pro were used. After running the tools, polygons smaller than the size threshold were removed. Small countries/territories that were not legible on the defined scale were also converted to points using the Feature to Point tool.

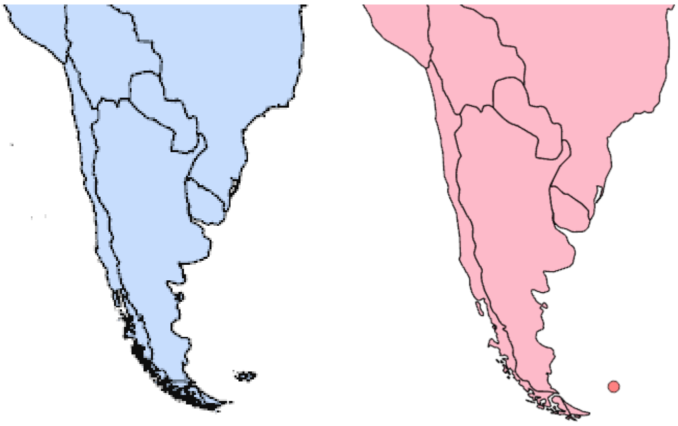

Figure 6 Ungeneralized (left) vs. generalized data (right).

Sentinel-5P data processing

Air quality data from Sentinel-5P were obtained through the GEE platform. For each pollutant, a custom script was written to get a single layer of the global average for each month. A separate script was also created to get the global average for the whole year. In summary, the script queries the GEE image collections to get the specific Sentinel-5P dataset, identify the column where the values for the pollutant concentration are stored, and set a date filter to return only the mean for a specific period. Then, using the polygon for a certain region, it clips the layer and exports the image to a defined Google Drive account.

```
SO2_per_region_01
Imports (13 entries)
  var band_viz: from 0 to 0.0002
  var africa: Table users/leonardluzgis/africa
  var ant: Table users/leonardluzgis/antarctica
  var asia: Table users/leonardluzgis/asia
  var oceania: Table users/leonardluzgis/oceania
  var sa: Table users/leonardluzgis/sa
  var na_n1: Table users/leonardluzgis/na_n1
  var na_n2: Table users/leonardluzgis/na_n2
  var eu_main: Table users/leonardluzgis/eu_main
  var eu_russia: Table users/leonardluzgis/eu_russia
  var na_n5: Table users/leonardluzgis/na_n5
  var na_n4: Table users/leonardluzgis/na_n4
  var na_n3: Table users/leonardluzgis/na_n3
var collectionSO2 = ee.ImageCollection('COPERNICUS/S5P/OFFL/L3_SO2')
.select('SO2_column_number_density')
.filterDate('2020-01-01', '2020-01-31')

var month = 'Jan'
var colmean = collectionSO2.mean()

//AFRICA
var clip_afr = colmean.clip(africa)

// Export the image, specifying scale and region.
Export.image.toDrive({
  image: clip_afr,
  description: ('SO2_Africa_'+month),
  scale: 1000,
  region: africa,
  skipEmptyTiles: true,
  maxPixels: 1e9
```

Figure 7 Sample GEE script to process mean SO_2 concentration for January 2020.

Since the interest is only on the air quality above the land surface, the resulting layer was clipped using a dissolved country boundary shapefile. Clipping the layer reduces the file size of the raster for faster downloading of the data. The results were stored in Google Drive and were downloaded as TIF files.

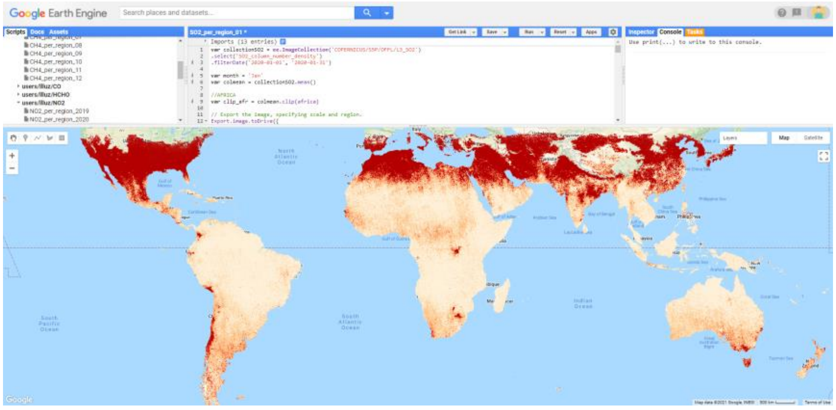

Figure 8 Visualization of a processed SO_2 concentration layer in GEE.

To easily process and symbolize the raster files in ArcGIS Pro, a mosaic dataset was created in a file geodatabase. Mosaic datasets only create a reference to the original raster files so data are not being duplicated. Due to the volume of the Sentinel-5P data, custom scripts and tools were created in ArcGIS ModelBuilder to process and store the data into the mosaic datasets. The first model automatically builds a mosaic dataset for each month and each pollutant and then adds the raster files from the input folder.

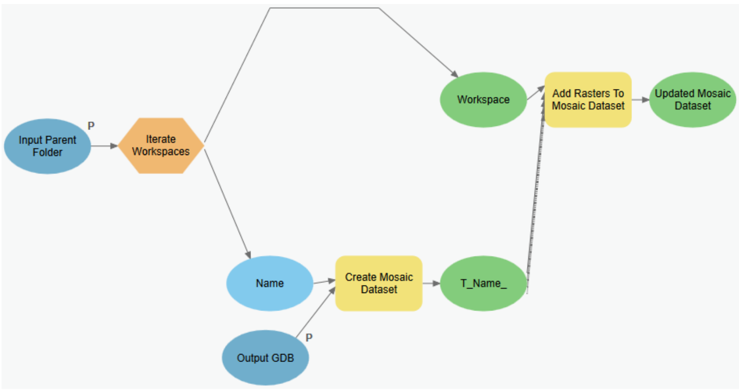

Figure 9 Model used to create the mosaic datasets and add the rasters.

The second model synchronizes the mosaic dataset, calculates the statistics, and builds the raster overviews. It was separated from the first model intentionally so it can also be used for other instances especially when a new raster is added or removed from the mosaic dataset.

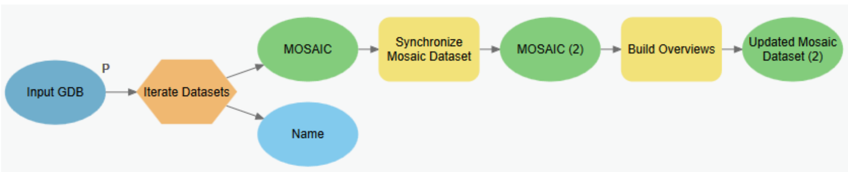

Figure 10 Model used to synchronize the mosaic datasets and build the raster overviews.

The downloaded raster files from GEE do not have a defined value for the missing data which creates an issue when symbolized in ArcGIS Pro. To address this, a custom python script was created to set the NoData values of all the raster files to Null. Rather than setting this in the raster properties individually, this tool looks at all the rasters in a certain folder and sets the NoData values to Null automatically. The script used in the tool is written below.

```
import arcpy
from arcpy import env
env.workspace = arcpy.GetParameterAsText(0)
rasters = arcpy.ListRasters()
for inRaster in rasters:
   arcpy.SetRasterProperties_management(inRaster, nodata = "1 nan")
```

4.3.2 Data standardization

Because the data were acquired from many sources and in different file formats, standardization needs to be performed. The GIS data were stored in the file geodatabase and displayed in the map using the Wagner VII or Hammer-Wagner projection. This projection is a variation of the Lambert azimuthal equal-area projection wherein, the relative area of the countries is preserved while the other elements such as shape, direction, and distance are distorted. While there were several projections used in the atlas especially for the continental and subregional reference maps, this is the main projection used in the thematic maps. The continent of Antarctica was not shown in the thematic maps since it has no native human inhabitants thus no records were available.

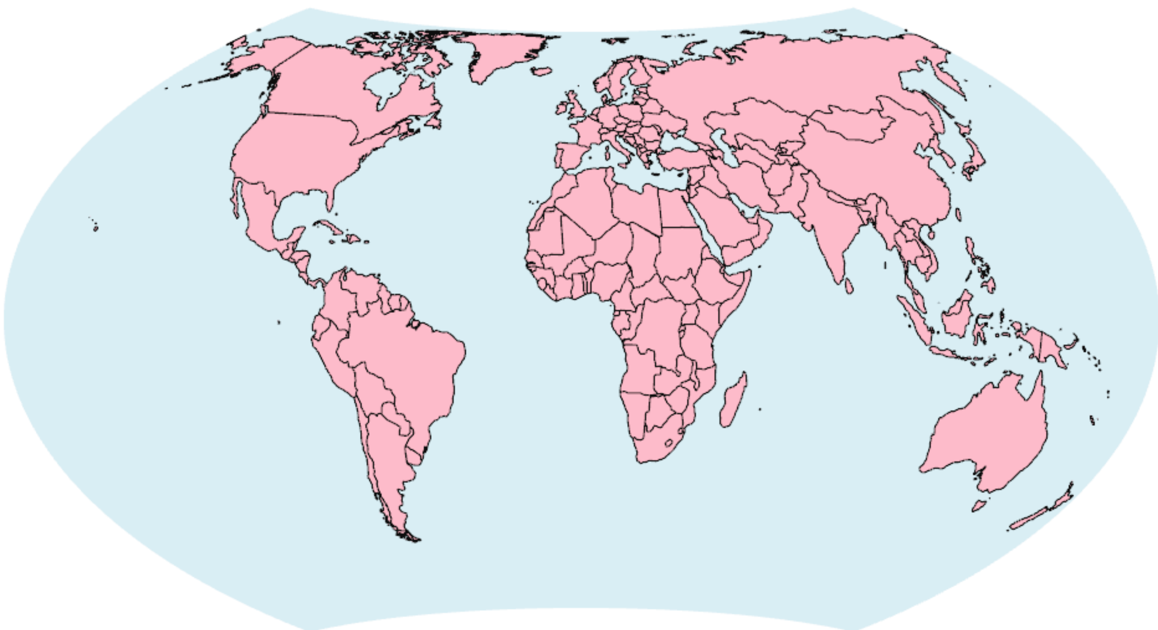

Figure 11 Generalized country boundaries displayed in Wagner VII projection.

Integrating the tabular and GIS data was done through a join operation. This requires a key field that corresponds to the matching columns from each dataset. Among all the datasets gathered, the three-digit ISO code was found out to be the most applicable unique identifier for each country/territory. Missing codes in some datasets were cross-checked and were manually entered using the latest designations from ISO. The quality of the join operation was also examined before proceeding and it was found out that the three-digit code varies for Kosovo (RKS, XKX, KOS) in the gathered datasets. The XKX version was used as a substitute code as it is the closest to the current two-digit version (XK) used by most organizations including the European Commission and IMF to identify Kosovo.

4.4 Visualization

Various forms of data visualization were used to communicate information to the users. Aside from maps, different types of charts were also created for each topic to complement the maps. Infographics were also utilized to facilitate a faster mode of communication especially for the significant topics presented in the atlas. The products derived at this stage were just drafts and post-processing was done during the compilation stage. This section describes the types of maps and charts used and how they were created.

4.4.1 Maps

All the maps used in the atlas were created in ArcGIS Pro v 2.8. The symbology was initially defined but the final CMYK values were finalized during post-processing. These maps were exported as PDF so each layer can be easily manipulated in Adobe Illustrator.

Reference Maps

Reference maps present a general picture of an area to show where things are located (Tyner, 2010). These maps were created to illustrate the political boundaries of the countries/territories and to provide users with information on the regional subdivisions used in the atlas. The scales of the reference maps were determined to cover the continents or if it is too small or too large for the map, the subregions designated by the United Nations. A total of nine reference maps were created including a world reference map and eight continental/subregional maps. Aside from the country/territory boundaries, only the Vibrant Basemap layer and a few map elements such as scale bars, north arrow, and map projection used were added to these maps to maintain the simplicity of each map so users can focus only on the names and location of countries/territories.

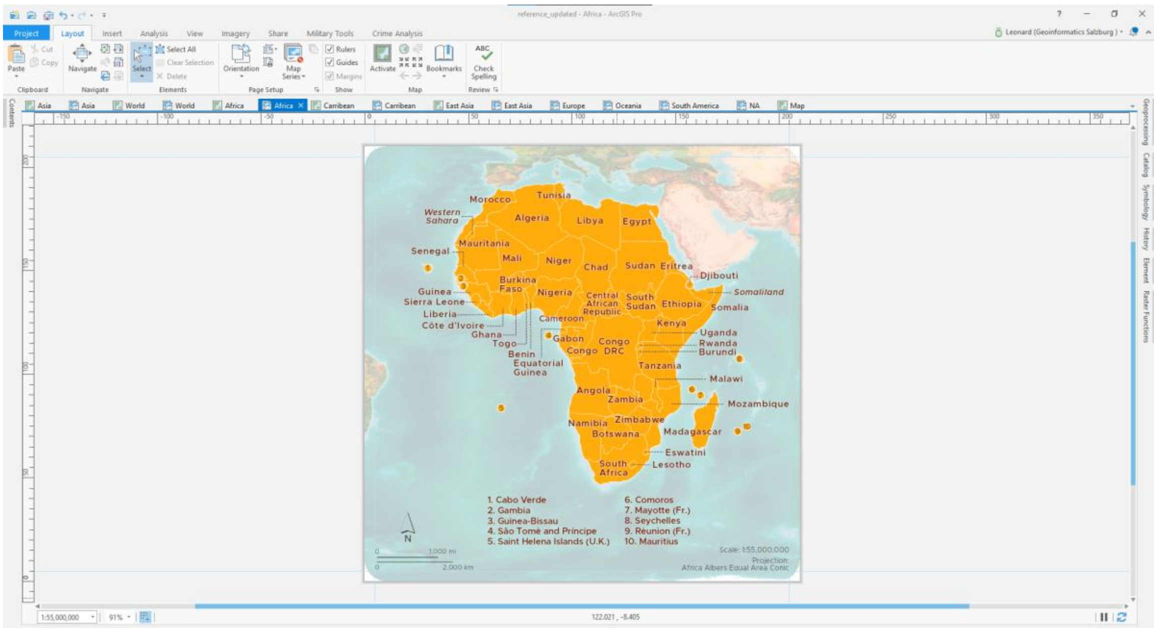

Figure 12 Africa reference map layout design in ArcGIS Pro.

Thematic Maps

Being the main focus of this atlas, several types of thematic maps were designed in visualizing the data for the identified topics. As described by Slocum et al. (2014), a thematic map is a type of map that displays the spatial pattern of a certain topic or phenomenon. Considering the global nature of the topic presented in this atlas, the maps primarily employ the area symbol method in thematic mapping although the point symbol method was also used for some of the maps. Both qualitative and quantitive (choropleth) thematic maps were produced but only ratios and percentages data were used for the latter. Most of these choropleth maps were symbolized using graduated colors with sequential and diverging schemes while graduated symbols were also employed in some topics. A combination of these methods was also applied in a limited number of maps as the author avoided the use of complex types of thematic maps for easier interpretation of the topics and efficient communication of information to the intended map users. Specific applications of these methods on the topics are discussed in Chapter 5 ATLAS CONTENTS.

The majority of the thematic maps follow a uniform map layout portraying the main map of the world and four inset maps of Europe, Western Asia, the Caribbean, and Oceania. Each inset map uses its respective coordinate system and map scale detailed in Table 2 Project specifications. The legend is placed at the top of the map with the most important categories read from left to right. No data was also disjointed from the main categories since its importance to the map is relatively low compared to the main categories.

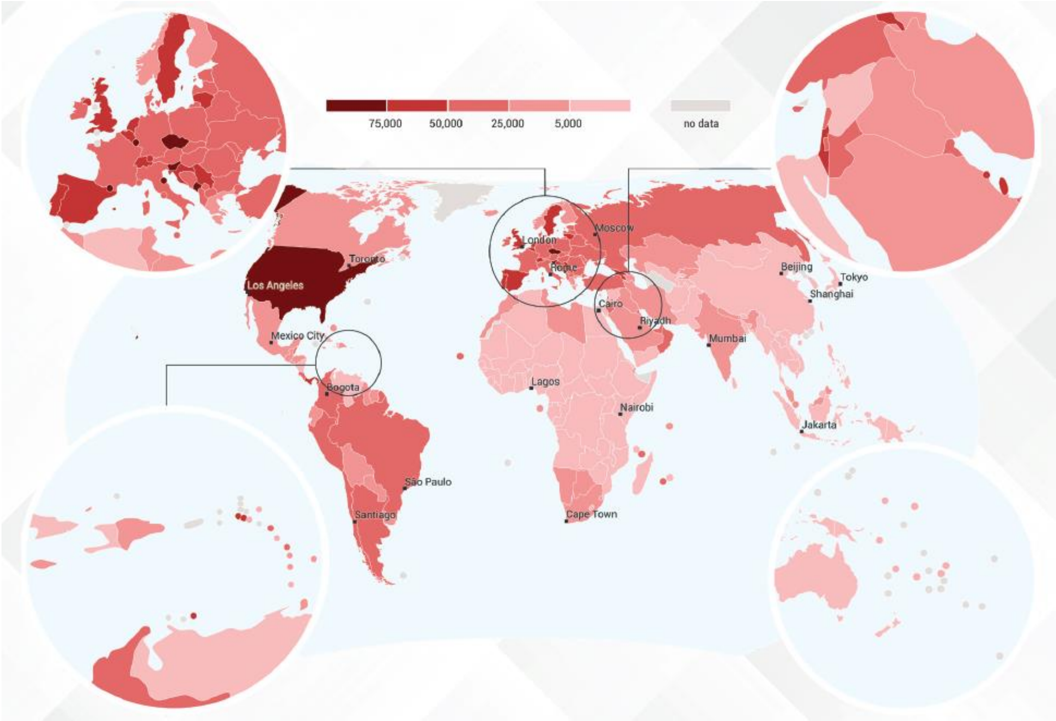

Figure 13 Confirmed cases per million map portrayed in the atlas.

Synthetic Maps

Thematic maps can be categorized as analytical, complex, or synthesis, based on the level of processing of the data being presented. Ormeling (2014) defined synthetic maps as a thematic map showing several aspects of a certain topic. In the atlas, three sets of synthetic maps were created depicting important topics on each theme (social, economic, and environmental impact). These synthetic maps were produced by combining the maps presented in the initial part of each chapter through cross typification. Rather than creating a separate chapter for these maps, they were placed on the last part of their respective chapters together with the maps from where the typification was derived so the users can still go back and check the individual maps easily. The parameters used for the typification are discussed in Chapter 5 ATLAS CONTENTS.

4.4.2 Charts

Maps were not the only type of data visualization used in the atlas. Different kinds of charts were also included to complement the maps especially in describing additional information about the topic. Basic chart types such as bar and column charts were the most common types of charts used in the atlas although other types that are not as widely used such as polar area chart and radar chart were also utilized. The majority of these charts were created in MS Excel and Flourish Studio and exported as either SVG or PNG. Described below are the types of charts and how they were used in the atlas.

Bar chart

This chart is commonly used to compare categorical data wherein the length of the bar corresponds to the value of a category. In this atlas, horizontal and vertical bar charts were used exhaustively to compare the distribution of classes portrayed on the map (e.g. how many countries implements a specific policy). A series of bar charts were also used to compare the seasonal variations on the policies implemented especially since these policies are regularly changing depending on the prevalence of cases in each country.

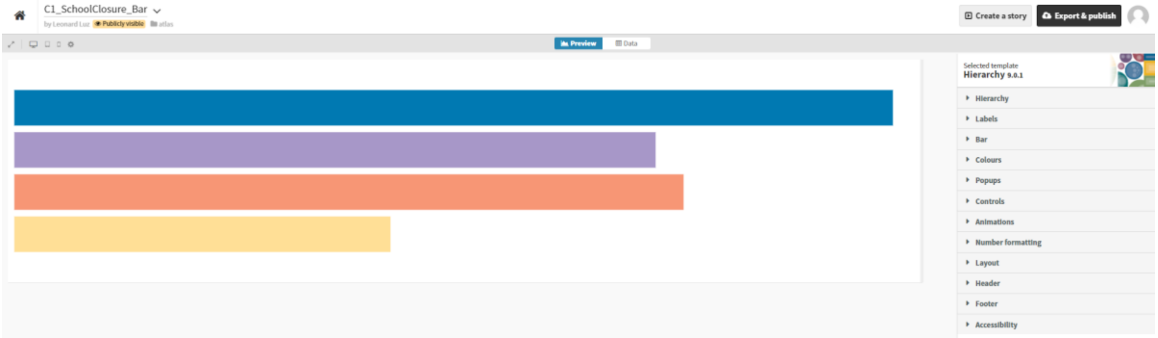

Figure 14 Sample bar chart created in Flourish Studio.

Polar area chart

Another type of chart used in this atlas for comparison purposes is the polar area chart. This chart is a contemporary variation of a pie chart wherein categories are shown as a sector of a circle in equal angles and the values they represent are portrayed by extending the radius of the sector from the center. This type of chart was used mostly in comparing if the values among the top ten/top five countries differ significantly or not since they may be part of a single class in the choropleth map. It should be noted that since each map has its unit depending on the topic presented, comparing two polar area charts within the atlas is not applicable. This type of chart was done using the Polar Area Chart Generator tool developed by Gabriel Sprenger. The output can only be exported as a low-resolution (72 DPI) PNG file so additional post-processing was conducted to improve the image quality for the atlas.

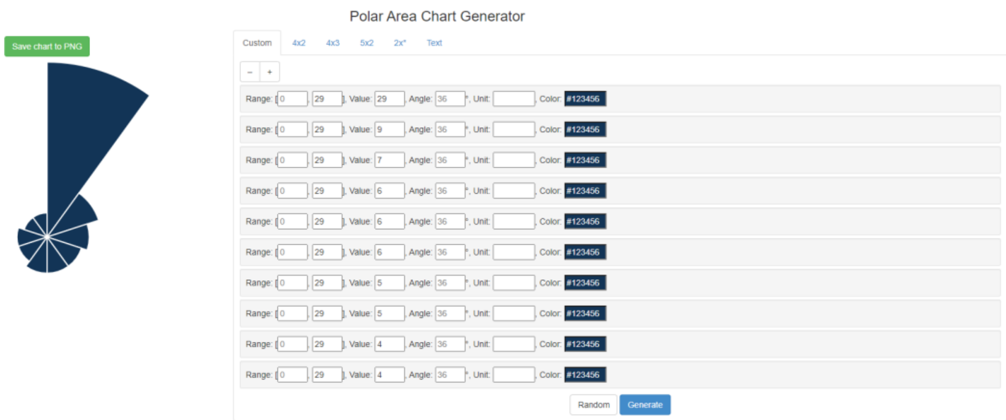

Figure 15 Sample chart from the Polar Area Chart Generator tool.

Radar chart

In some instances, the data to be compared has too many variables that cannot be displayed efficiently using a bar or a polar area chart. The third type of chart called radar chart was used in the atlas to address this. A radar chart displays three or more quantitative variables plotted on multiple axes starting from the center. This was used to show the distribution of countries for each of the social policies described in the typification of the policy strictness level map, as well as the global monthly average of the pollutants portrayed in the environmental impact chapter.

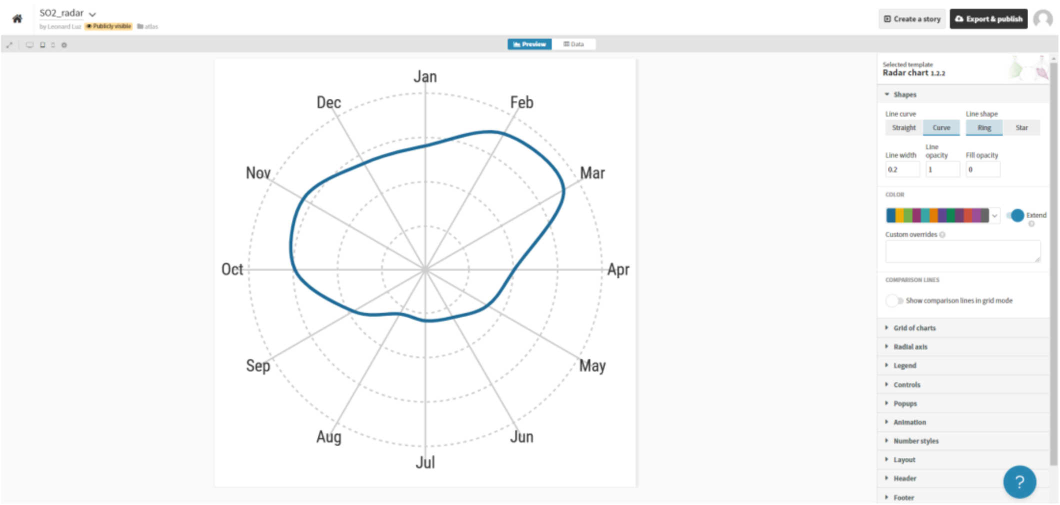

Figure 16 Sample radar chart created in Flourish Studio.

4.4.3 Infographics

The Merriam-Webster dictionary defines an infographic as a "chart, diagram, or illustration that uses graphic elements to present information in a visually striking way." (Merriam-Webster, 2021). Given that the atlas covers a broad range of topics, infographics were utilized to highlight some of the most interesting issues that may not be best depicted with maps. These topics include the current state of the COVID-19 pandemic, how the unemployment rate varies across different regions and groups, the number of working hours lost due to the pandemic, and the impact of the pandemic on the aviation sector. The infographics created for these topics made use of the charts mentioned above and contain a minimal amount of texts in the presentation of data. These infographics were also placed on the page close to the maps with the same or relevant topics. This way, the readers can gain additional insights on the topic presented on the map quickly. These infographics also provide a modern design to the atlas to make it more appealing to a wide range of audiences.

4.5 Compilation

After creating the initial drafts of the visualizations, the compilation process followed which focuses more on finalizing the designs of each map and creating the actual atlas layout using desktop publishing software programs. The principles of graphic design and desktop publishing were applied throughout the whole compilation process. Furthermore, the activities done during pre-press or the stage before the printing of a publication were also discussed here.

4.5.1 Post-processing

Color management

When working with products for printed publication, the right color space must be set while designing since the colors seen on the screen appear different on print. While digital screens use the RGB color system, a different color system of CMYK is normally used in printing (Dabner et al., 2014). It is crucial to define this setting beforehand to check how colors will appear thus avoiding unwanted color aberrations on the final printed product especially since RGB colors appear brighter than CMYK colors.

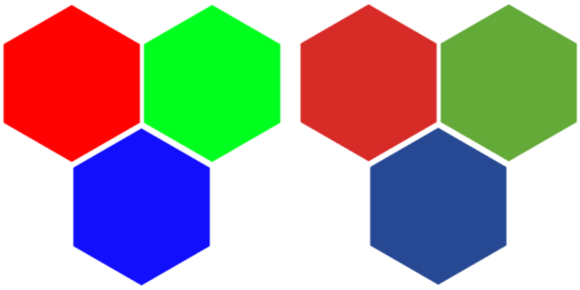

Figure 17 RGB (left) and CMYK (right) color comparison.

There are several CMYK color profiles available in desktop publishing programs. In Adobe Illustrator, Coated FOGRA39 CMYK color profile was specified since it is the usual specification used for offset printing on coated paper in Europe. FOGRA39 characterization data was developed by the German graphic technology research organization FOGRA and has been used by the International Color Consortium in developing their color profiles as well (International Color Consortium, 2021).

While the maps exported from ArcGIS Pro were already in CMYK, the exported charts use the RGB color profile so the colors appear slightly different. These color differences were corrected in Adobe Illustrator and the processed charts were exported as PDF with the associated color profile. Exporting with the color profile ensures that the color will be preserved when these maps and charts are imported in Adobe InDesign for the final layout.

Color accessibility

It is estimated that around 300 million people suffer from color vision deficiency (CVD) or color blindness. This condition affecting males predominantly is the inability to see some parts of the visible spectrum fully especially red, green, or blue lights (Colour Blind Awareness, 2021). In designing this atlas, it was ensured that the colors used in the maps and other visualizations are accessible especially to people with color blindness. In choosing colors for the symbology of each map, the Adobe Color Accessibility Tool was used to simulate the colors for the three most common types of color blindness (i.e. deuteranopia (red-green), protanopia (red-green), and tritanopia (blue-yellow)). This tool detects possible conflicts in the selected colors for each type of color blindness. Colors, as seen by people with normal vision, are displayed (top row), with deuteranopia (second row), protanopia (third row), and tritanopia (bottom row).

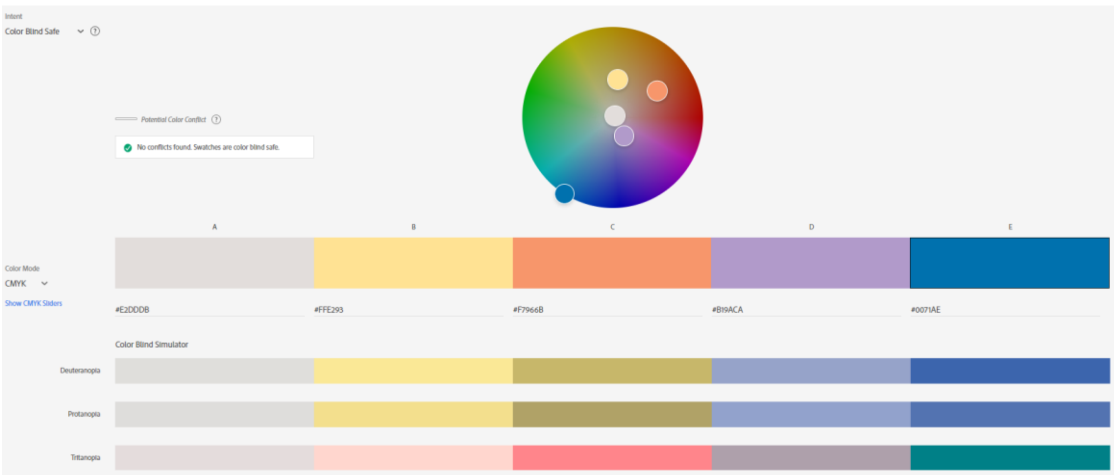

Figure 18 Adobe colors accessibility testing tool.

Documentation of these colors was also created in the form of a Map Data Visualization Report (MDVR) attached as Appendix 2 of this thesis. In addition, these colors were also saved as a color swatch in Adobe and a style file in ArcGIS. This way, the resulting color schemes can also be used by others easily.

Chart design improvements

Aside from color standardization, design improvements on the charts were also done using Adobe Illustrator. Since the created charts from MS Excel and Flourish Studio do not fit the design of the atlas in terms of font style, font color, and other elements, necessary adjustments were applied to each chart in Illustrator.

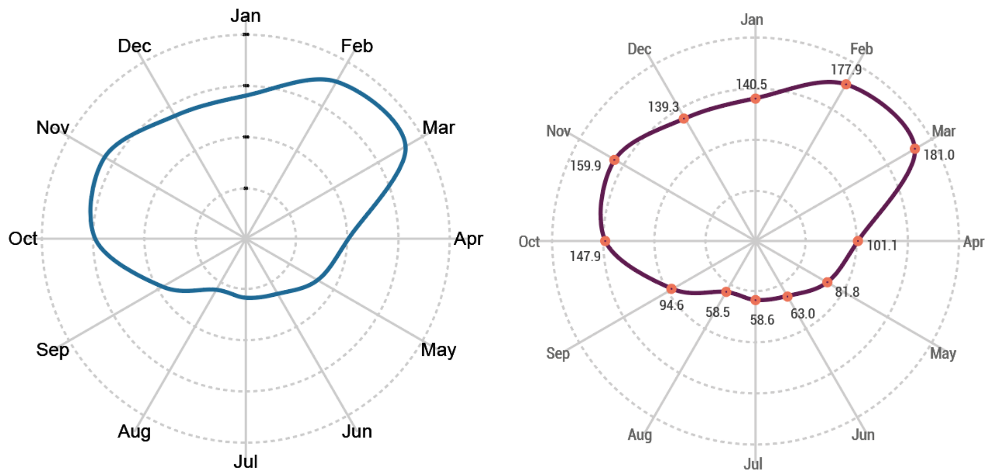

Figure 19 Original (left) and post-processed (right) radar chart comparison.

To improve the image quality of the polar area charts, the original PNG image with 72 PPI was vectorized using the Image Trace Tool in Illustrator. The Image Trace Tool follows the boundaries of the solid colors detected in the image and converts them to separate layers that can be customized individually. Colors were also adjusted to match the map symbology and other page elements.

4.5.2 Atlas Design

The compiling of the maps and the creation of the atlas layout were done in Adobe InDesign. The page size was set to A3 (297 × 420 mm) in landscape orientation. To easily distinguish the coverage of each chapter, a cover page for each was also designed. Specific colors were assigned to identify the chapters. These colors were set consistently in the chapter indicator element, the fill color of the title background, and the page number background.

To standardize the page layout, several master pages were created in Adobe InDesign. These master pages contain the page elements that need to be consistent such as the ones mentioned above. The page elements that were imported only have SVG and PDF file formats to ensure that the image quality will not be compromised during the atlas export process.

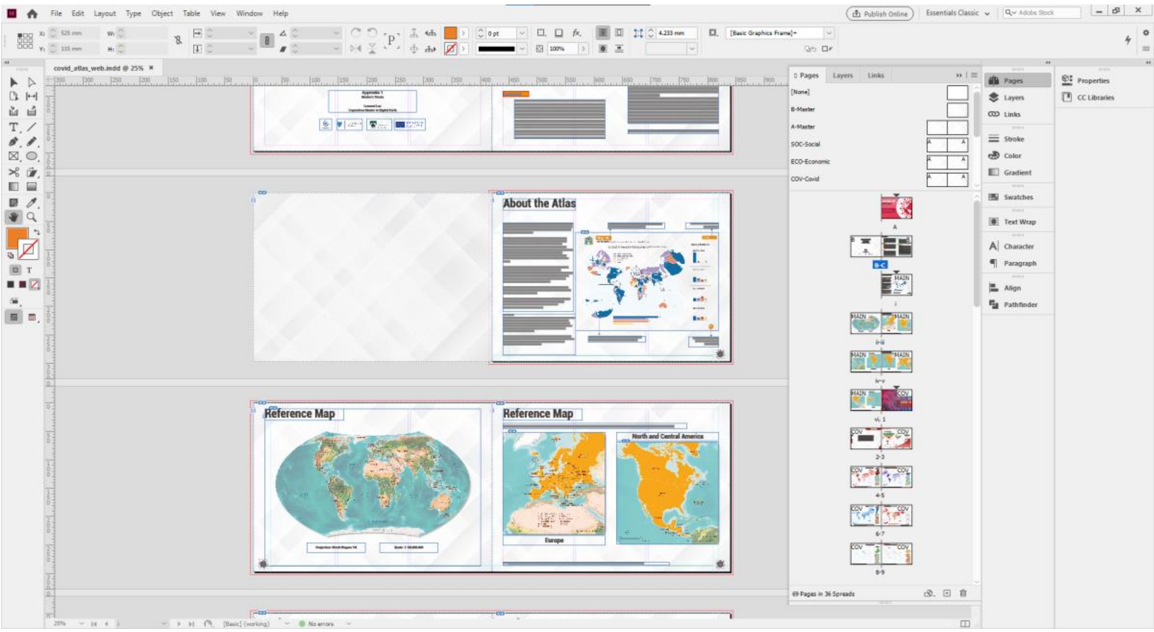

Figure 20 Atlas page layout in Adobe InDesign.

Figure 21 Atlas cover page and chapter covers.

A guide on how to use the atlas was included on the introductory page. The layout featured the main map on the left portion covering about two-thirds of the page with the supporting charts at the right and bottom. Map annotations were also included describing key facts and figures about the presented topic.

The final product was exported in Adobe PDF for web and print publication. For the print-ready version, the quality was set to 300 DPI with the printer's marks (crop and bleed marks) and slug area included. The corresponding CMYK color profile was also appended in the PDF file that is compliant with the PDF/X-1a:2001 standards. The main contents were printed in a 120 g colotech, color 4/4 paper while the front and covers were printed in 280 g colotech, color 4/0 with a spiral ring wire binding. For the web version, the images were compressed to 100 DPI, with the printer's marks and color profile removed. The hyperlinks and bookmarks were retained and the same PDF compatibility specifications were used.

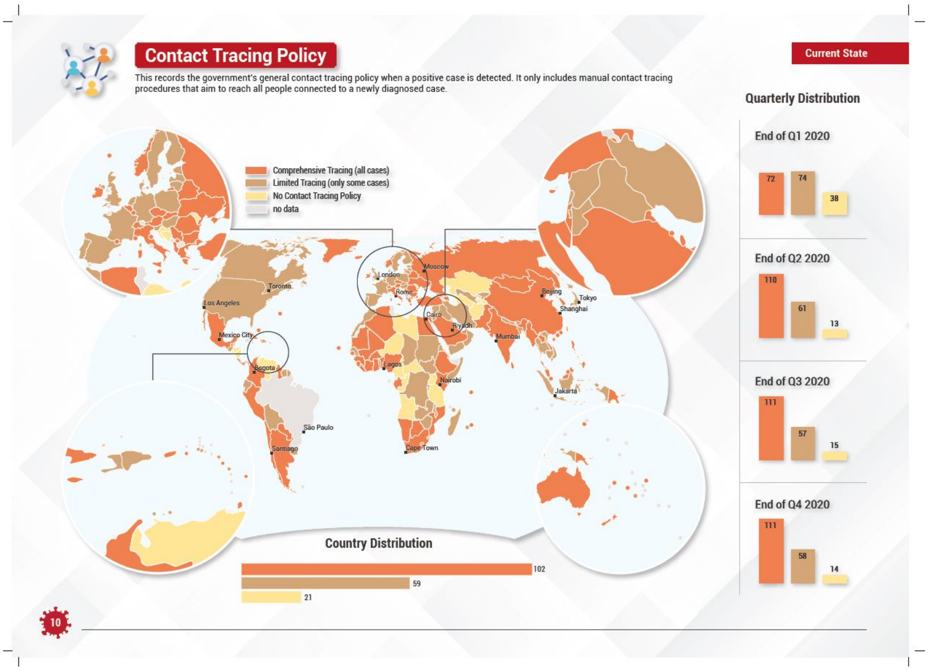

Figure 22 Sample page for the print-ready PDF with the crop and bleed marks

4.6 User testing

In map-making, it is also crucial that the cartographer considers the process of map use to ensure that the resulting cartographic is of high quality (Vozenilek, 2014). According to Kimerling et al. (2016), map reading can be defined as the process of determining what the author has depicted by translating the features into a mental image of the environment through its elements like title, symbols, and other marginalia. To evaluate if the atlas achieved its purpose, a short user testing was conducted through an online survey and interview. The target respondents were professionals working in various industries. Also, the composition of the respondents includes both GIS and non-GIS professionals with the latter comprising the majority.

The first part of the survey captures the demographics of the respondents by asking questions about the age group where they belong, sex, educational background, and if they have color vision deficiency. The survey form does not include any questions that may identify the respondents to provide anonymity.

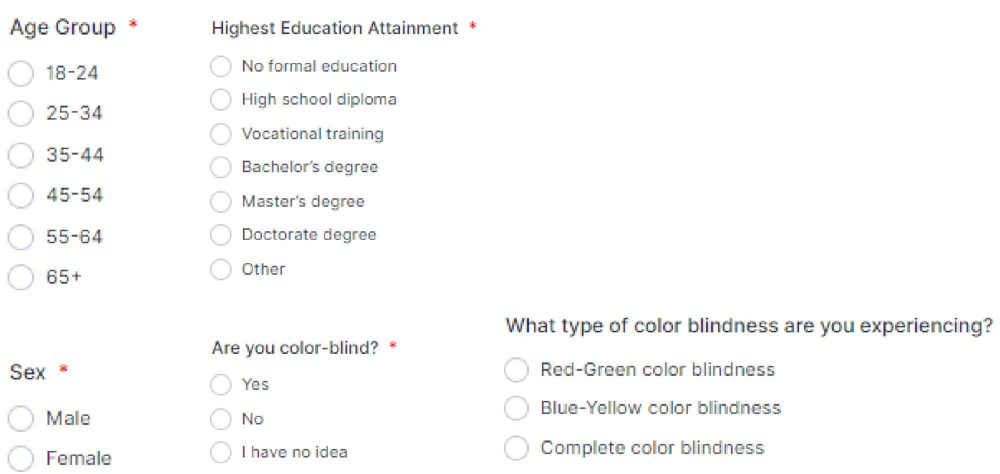

Figure 23 Demographic questions used in the survey.

For the second part of the survey, the users were asked about their thoughts on the aspects of the page and map layout, the general cartographic design, as well as the map symbols and legends. A sample of the most complex maps was selected to be evaluated for this part of the survey. Thirteen statements covering the mentioned aspects of map design were presented and the responses were measured using an agreement ordinal scale. The goal of this is to capture the general perception of the users on the important map elements that may be further improved for better map reading and interpretation (See Appendix 3).

1. How much do you agree or disagree with the following statements about the page layout? *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The page looks balanced	○	○	○	○	○
The graphic elements are logically placed on the page	○	○	○	○	○
The map and other graphics are aligned to the page and to each other	○	○	○	○	○
The title and subtitle describe the topic properly	○	○	○	○	○
The title and subtitle are suitably positioned and sized	○	○	○	○	○

Figure 24 Survey questionnaire sample format.

The last part focuses on the usability of the atlas wherein, a set of questions about the contents were asked to see how well the users can interpret the maps and related contents of the atlas. These questions were divided into easy and difficult categories. For the easy questions, the answers can be obtained by evaluating a single map and the most visible map elements while the difficult ones require examining several pages or some of the least noticeable features on the page. The results from these questions will gauge which aspects of map design need to be improved based on how well the users interpret the maps and visualizations.

After the survey, the participants were also asked for feedback on the atlas and the things that can be improved. To gain more understanding of how they approach the map interpretation, they were also asked which questions were the most difficult to answer and why. Subsequently, the results of the user testing were evaluated, and the necessary improvements were applied to the atlas.

5 ATLAS CONTENTS

There are four chapters in the atlas which also correspond to the major topics being tackled. The first chapter focuses on the global statistics relating to COVID-19 as well as the health policies implemented by different countries. In the second chapter, the social implications of the pandemic were visualized especially the social containment policies and restrictions. The third and fourth chapter focuses on the indirect impact of the pandemic on the economic and environmental aspects respectively as a result of the lockdown measures and other policies enforced.

5.1 Current state

Along with the choropleth map, a polar area chart displaying the values of the top ten countries was also shown in the atlas to easily identify the countries with the highest confirmed cases/deaths per million. Flag icons were also shown for the top ten countries and the background color of the country names was categorized according to the continent where the country belongs. For the categorical maps, a grid of vertical bar charts was displayed showing the quarterly change in the distribution of countries in each policy. A horizontal bar chart that corresponds to the distribution of countries was also added at the bottom of the main map. Additionally, the colors on the charts matched the symbology used in the map.

5.1.1 Total confirmed cases/deaths per million

Total confirmed cases/deaths per million correspond to the cumulative number of those who have contracted COVID-19/deaths that were attributed to the disease respectively, relative to the population. Based on the source data, the population estimates used for the normalization are based on the United Nations World Population Prospects for 2020. The normalized data was displayed instead of the raw values since the visualization used is a choropleth map. Only five categories were used following Peterson's Five Shade Rule stating that the human eye normally can detect only five shades of the same hue (Peterson, 2009). To divide the categories, a natural break classification rounded up to the nearest thousands was used for an easier symbol interpretation.

5.1.2 Case Fatality Rate

The Case Fatality Rate (CFR) is the ratio between the confirmed deaths and confirmed cases. It is used mainly as an indicator of the severity and a tool for public health policy planning. However, this figure should be dealt with caution as it can be interpreted inaccurately especially if there is a significant lack of resources to detect the confirmed cases and the deaths which are used in calculating this value (Noushad & Al-Saqqaf, 2021). In the atlas, a map note about this was also added to discourage the users in comparing CFR of countries with different testing capacities.

5.1.3 COVID-19 testing

Testing Policy

Since most of the statistics were based on COVID-19 testing, a visualization of how each country was conducting the tests was also included in the atlas. This information is crucial in interpreting other maps such as the ones mentioned above.

The testing dataset records the government policy on who has access to testing and includes only PCR (polymerase chain reaction) and rapid antigen tests which detect whether an individual is currently infected (Hasell et al., 2020). The source data, which includes the testing classifications also considers the implementation capacity of a country in assigning the category in addition to the official announcement from the government such that, a lower classification may be assigned if the actual testing procedures differ from what is officially announced.

Table 4 Codes and descriptions used for testing policy map

Ordinal scale	Description
3	Open public testing (including asymptomatic)
2	Anyone showing Covid-19 symptoms
1	Only those who both (a) have symptoms AND (b) meet specific criteria (e.g. key workers, admitted to hospital, came into contact with a known case, returned from overseas
0	No testing policy

Tests per thousand

Each country reports testing data differently. Some report the number of people tested while others report the total number of tests which may result in a higher value if a person is tested more than once. This limitation is mentioned as a map note in the atlas to avoid country-level comparisons. The normalization is also based on the population estimates from UN World Population Prospects for 2020.

Positive rate

The positive rate map shows the cumulative share of COVID-19 tests that are positive since the time that the country started testing. This metric not only shows how adequately countries are testing but also helps in understanding how the virus is spreading together with the data on confirmed cases. For instance, a high positive rate could indicate that a country is only testing limited groups such as patients seeking medical attention but not asymptomatic cases.

5.1.4 Contact tracing

This indicates the government's general contact tracing policy when a positive case is detected. It only includes manual contact tracing procedures that aim to reach all people connected to a newly diagnosed case. In the source data, a higher category is assigned to countries that announce a wide coverage contact tracing policy and have practical evidence on the ground about its implementation. In instances that the daily cases are rising and that there is evidence that new cases were not being reported, a lower category may be assigned (Hale et al., 2021)

Table 5 Codes and descriptions used for contact tracing policy map

Ordinal scale	Description
2	Comprehensive contact tracing (done for all identified cases)
1	Limited contact tracing (not done for all cases)
0	No contact tracing policy

5.1.5 Vaccination policy

Policies for vaccine delivery for different groups were also shown as a categorical map. The classification used differentiates whether the vaccine is accessible to all or several groups only. These groups include key workers, clinically vulnerable, and elderly groups. Furthermore, this is only limited to countries providing the vaccine at no or minimal cost to its citizens either through government funding or subsidy. A polar area chart showing the top ten countries in terms of vaccination per hundred people was included as an additional element to the page. Design specifications from the previous maps were also applied for the country title backgrounds.

Table 6 Codes and descriptions used for vaccination policy map

Ordinal scale	Description
5	Universal availability
4	Availability for ALL three, plus partial additional availability (select broad groups/ages)
3	Availability for ALL of the following: key workers, clinically vulnerable groups (non-elderly), elderly groups
2	Availability for TWO of the following: key workers, clinically vulnerable groups (non-elderly), elderly groups
1	Availability for ONE of the following: key workers, clinically vulnerable groups (non-elderly), elderly groups
0	No availability

5.1.6 Public information policy

This shows the government policy in terms of information dissemination on COVID-19 measures. The classification includes the presence of coordinated public information campaigns or public officials urging cautions only. These campaigns include launching a centralized website dedicated to pandemic response, an official press release of health protocols, and social media announcements from the government's health department (Hale et al., 2021).

Table 7 Codes and descriptions used for public information policy map

Ordinal scale	Description
2	Coordinated public information campaign
1	Public officials urging caution about COVID-19
0	No public information campaign

5.2 Social impact

In this chapter, the containment measures and social policies implemented by each country are visualized. This includes international travel controls, school, and workplace closures and policies about public gatherings. In the last part, a synthetic map of the policies summarized using cross typification implemented is shown. For most policies, the classification may not apply at all sub-national levels and a country's classification is assigned if at least some sub-national regions have implemented them. (Hale et al., 2021).

This limitation is also indicated in the atlas as a map note. The maps in this chapter were visualized as categorical maps and a consistent color scheme was applied for topics with similar classifications. For policies with fewer classifications, the hues of the main color scheme were slightly adjusted to maintain consistency in the symbolization. Furthermore, the classifications used in the maps were based on the original dataset. Aside from the synthetic map, all the other maps were symbolized using the values from the source data. The explanations on how these were coded by the data owner are discussed in the succeeding sections.

5.2.1 International travel controls

This indicates the policies implemented by each country for foreign travelers only and excludes returning citizens. The classifications include total border closure, ban, or quarantine from high-risk areas, and screening of passengers upon arrival. The policy also relates to restrictions on incoming travelers to the jurisdiction of the coded country/territory and not on outbound travelers.

Table 8 Codes and descriptions used for international travel controls map

Ordinal scale	Description
4	Ban on all regions or total border closure
3	Ban arrivals from high-risk areas or some regions
2	Quarantine arrivals from high-risk areas
1	Screening arrivals
0	No measure

5.2.2 Restrictions on gatherings

This policy shows the cut-off size for the gatherings allowed in most parts of the country/territory. The strictest classification is also assigned if any gathering outside of the house is restricted. For instances where a policy only relates to limiting the number of people allowed based on the capacity of an indoor facility and there is no clear cut-off point, the lowest classification of 'no measure' is assigned.

Table 9 Codes and descriptions used restrictions on gatherings map

Ordinal scale	Description
4	Restrictions on gatherings of 10 people or less
3	Restrictions on gatherings of 11-100 people
2	Restrictions on gatherings of 101-1000 people
1	Restrictions on very large gatherings (the limit is above 1000 people)
0	No restrictions

5.2.3 School closure policy

This policy captures the closure of educational institutions from primary schools to universities. Childcare, nurseries, language courses, and driving schools, which are not considered educational institutions were not captured in this map, but in the map for workplace closures instead. The classifications used by the provider of the source data were based on policies allowing the presence of students on the school grounds for actual face-to-face classes (examinations not included). For instance, if only teachers are allowed for class preparation, the category is still set to close. The classification also disregards school holidays so the classification for countries with school holidays covering the cut-off date of 31 January 2021 was set to the strictest level.

Table 10 Codes and descriptions used on school closure policy map

Ordinal scale	Description
3	Require closing (all levels)
2	Require closing (only some levels or categories)
1	Recommend closing
0	No measures

5.2.4 Workplace closure policy

The classifications used for workplace closure policy were based on whether the closing of businesses is being required for all or some sectors and workers or if the policy is based on recommendations only. The policy excludes workers and workplaces considered essential during the pandemic such as healthcare facilities, groceries, take-out food, hardware stores, and legal services. If businesses are allowed to operate but in limited capacities (e.g. outdoor seats, 20% capacity, etc.), the 'recommend closing' category is assigned instead of 'required closing.

Table 11 Codes and descriptions used on workplace closure policy map

Ordinal scale	Description
3	Require closing (or work from home) all-but-essential workplaces
2	Require closing (or work from home) for some sectors or workers
1	Recommend closing (or work from home)
0	No measures

5.2.5 Working hours lost

To complement the map about the workplace closure, an infographic about the total global working hours lost was created. This infographic displays the distribution of working hours lost per region (based on ILO classification) relative to the last quarter of 2019, as well as global estimates for 2021. The infographic was also inserted in between maps to reduce the monotony of seeing maps only while reading the atlas.

5.2.6 Public events cancelation

Related to the restrictions on public gatherings, the classifications on the cancelation of public events were based on the implementation level of the policy rather than the cut-off size. If mass gatherings (e.g. political protests) can still proceed but with strict social distancing policy, a lower classification (recommend canceling) is applied. The same classification is also applied if venues for public events are still open but are operating in limited capacities only.

Table 12 Codes and descriptions used on public events cancelation map

Ordinal scale	Description
2	Require canceling
1	Recommend canceling
0	No measures

5.2.7 Public transportation closure policy

The classifications used for public transport closure are also based on whether the policies are mandatory or recommended only by the government. When public transportation still operates but strict social distancing is enforced, the classification is coded as 'no measure'. The classification is set to 'recommend closing' if there are significant reductions in the means or routes of transport, as well as the volume of the public vehicles allowed to operate. The strictest classification is assigned if total shutdowns of services are enforced to align with other movement restrictions or if public transportation is only allowed for essential workers.

Table 13 Codes and descriptions used on public transportation closure policy map

Ordinal scale	Description
2	Require closing (or prohibit most citizens from using it)
1	Recommend closing (or significantly reduce volume/route/means of transport available)
0	No measures

5.2.8 Stay-at-home orders

This policy indicates whether the citizens are restricted to leave the house or if similar containment measures are applied although it does not capture if these measures are being followed in reality. Restrictions such as curfews are categorized as 'some restrictions'. The same classification is also applied if citizens are allowed to go out for non-essential trips during non-curfew hours, or if they can still leave the house for even a certain duration (e.g. one hour a day) only. The strictest classification is applied if citizens are restricted to leave the house for multiple days at a time (i.e. can only leave on a specific day of the week).

Table 14 Codes and descriptions used on stay-at-home orders map

Ordinal scale	Description
3	Require not leaving the house with minimal exceptions
2	Require not leaving the house with some exceptions
1	Recommend not leaving the house
0	No measures

5.2.9 Internal movement restriction

This indicates whether domestic traveling (e.g. other cities or regions) are monitored or not. The strictest classification is applied in cases where for instance, interstate highways/waterways are closed or when a negative test result is required to enter.

The strictest category is also applied if intensive checking of quarantine procedure is being conducted upon arrival. On the other hand, a lower classification is applied if voluntary quarantines are imposed or if traveling to neighboring cities is discouraged.

Table 15 Codes and descriptions used on internal movement restriction map

Ordinal scale	Description
2	Internal movement restrictions in place
1	Recommend not to travel between regions/cities
0	No measures

5.2.10 Facial covering policy

The classification used for this policy is mainly based on the extent to where the wearing of a mask is required. The strictest classification is applied if masks are required every time people leave their houses regardless if they are at a public place or not. If masks are required in all or some public areas only, a lower classification is applied.

Table 16 Codes and descriptions used facial covering policy map

Ordinal scale	Description
4	Required outside the home at all times regardless of location or presence of other people
3	Required in all shared/public spaces outside the home with other people present or all situations when social distancing not possible
2	Required in some specified shared/public spaces outside the home with other people present, or some situations when social distancing not possible
1	Recommend
0	No measures

5.2.11 Containment policies strictness level

The integration of the thematic maps on policies to indicate the strictness level implemented on each country was portrayed in the form of a synthetic map. This map was created by summarizing seven maps of containment measures (school closure, workplace closure, public event cancelation, public transport closure, stay-at-home orders, internal movement restriction, and facial covering policy) using a cross or table typification. The variation on the map classifications was addressed by standardizing the original values into three categories as follow:

- all required categories = 3
- recommended = 2
- no measure =1.

To combine the classifications of the seven maps and identify the final categories, these values were reclassified using a multiplier for each column. The sum of the reclassified values was calculated to get all the possible combinations.

Table 17 Original and reclassified values used for each category

Original value	School closure	Workplace closure	Public event cancelation	Public transport closure	Stay-at-home orders	Internal movement restriction	Facial covering policy
4							3000000
3	3	30			30000		3000000
2	3	30	300	3000	30000	300000	3000000
1	2	20	200	2000	20000	200000	2000000
0	1	10	100	1000	10000	100000	1000000
Multiplier	*1*	*10*	*100*	*1000*	*10000*	*100000*	*1000000*

The resulting combinations were grouped and the final classification of strictness level was assigned depending on how many policies have required, recommended, and no measure values. This method was deemed applicable since the original classifications follow an ordinal scale. Furthermore, this classification also assumes that each policy has equal importance on the determination of the strictness level.

Table 18 Category assignment and descriptions (strictness level)

Combination	Category	Description
3333333	Level 8	Require measures for all policies
All combinations with **four to six** 3s	Level 7	Require measures for most policies
All combinations with **three** 3s	Level 6	Require measures for some policies
2222222	Level 5	Recommend measures for all policies
All combinations with **four to six** 2s	Level 4	Recommend measures for most policies
All combinations with **three** 2s	Level 3	Recommend measures for some policies
All combinations with **four to six** 1s	Level 2	No measure for most policies
1111111	Level 1	No measure for all policies

Figure 25 General workflow for cross typification.

5.3 Economic Impact

This chapter provides visualizations of the impact of the COVID-19 on macroeconomic indicators as a result of lockdown policies and containment measures implemented by each country. Choropleth maps were created showing the relative change for five indicators including export, import, GDP per capita, inflation, and unemployment. A synthetic map was created to show the general trend on the three major indicators. Moreover, categorical maps showing policies of each country on providing financial relief during the pandemic were also generated. It should be noted that there were no correlational studies conducted during the creation of this atlas to quantify the impact of the COVID-19 cases or the lockdown measures on the indicators displayed.

5.3.1 Income classification

To provide additional insights and context on the maps to be presented, a categorical map showing the income of classification of countries for 2020 by the World Bank was included in the atlas. Along with the map is a list of countries/territories categorized according to their respective classifications. The purpose of this is to serve as a reference for the other visualizations so the users can compare how each income group was affected.

5.3.2 Change in volume of export and import

International trade also suffered during the pandemic as border closures and travel restrictions were put in place. This has become evident in the statistics on global export and import as published in the World Economic Outlook for 2020. According to the source data description, the values on export and import were expressed as a percent change relative to the previous year wherein, the price of goods and services were held constant so the change is only based on quantity (International Monetary Fund, 2020).

To visualize this, choropleth maps with divergent color schemes were used symbolizing the decrease or increase in export and import. A symmetric type of divergent scheme was used for the maps with the class breaks modified to the nearest tenths for easier interpretation. A polar area chart with two major sections for the top and bottom five countries was also added to supplement the map. The polar charts for both maps have the same scale so users can use them as a guide for comparison. The background fill of the country names was also colored based on the symbology used for income classification. To provide more guidance about the trend, a small arrow was added beside the country names colored according to the map and chart symbology.

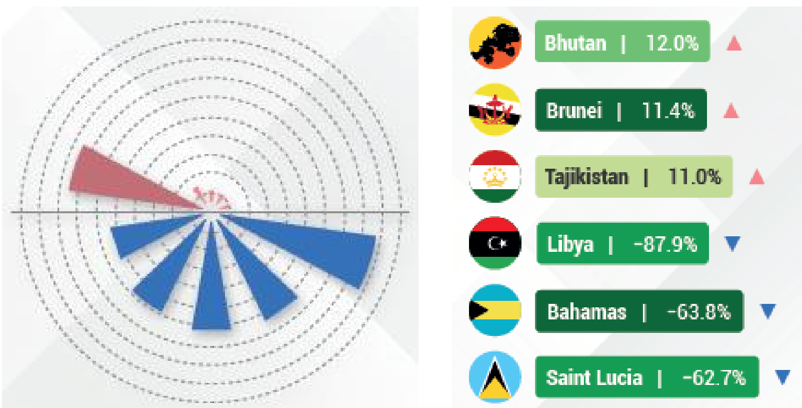

Figure 26 Two-section polar area chart (left) and the presentation of country labels (right).

5.3.3 Change in GDP per capita, inflation, and unemployment

Aside from export and import, the trend in three major economic indicators; Gross Domestic Product (GDP) per capita, inflation, and unemployment were also visualized. This change was expressed as percent change relative to the previous year using the formula:

$$\textit{Percent Change} = \frac{\textit{(new value-old value)}}{|\textit{old value}|} * 100$$

For the choropleth maps, an asymmetric divergent color scheme was used due to the inherently big gaps in the classification using natural breaks caused by the outliers in the data.

The topic of unemployment was given more attention as workplace closure policies were imposed. In addition to the map, an infographic showing the distribution of unemployment per region was added as a separate page in the atlas. The infographic also shows the distribution of unemployment based on sex and age group.

5.3.4 Trend in major economic indicators

To summarize the maps on the major economic indicators, a synthetic map was created based on the typification of the trend exhibited. The typification workflow (see Figure 25) used in the strictness level synthetic map was also applied but the values were reclassified based on the nature of change exhibited. For instance, an increase in unemployment and inflation rates signify a negative change since the effect of this type of trend on the economy is also negative, while an increase in GDP per capita indicates a positive change. The resulting synthetic map shows the number of indicators that have undergone either a positive or negative change for each country/territory.

Table 19 Original and reclassified values used for each economic indicator

Original value	**GDP per capita**	**Inflation Rate**	**Unemployment Rate**
>0	2	1	1
<0	1	2	2
0	0	0	2

Since there were only a few categories, concatenation was done instead of summing the reclassified values. Then the long descriptions for the resulting combination were assigned. 'Insufficient data' was used as a classification for records with missing data in at least one of the columns.

Table 20 Category assignment and descriptions (trend in economic indicators)

Combination	**Description**
111	Negative change in three factors
112, 121, 211	Negative change in two factors
221, 122, 212	Positive change in two factors

5.3.5 Income support policy

Income support indicates the policy of a country/territory when it comes to providing direct cash payments, or income subsidy to people who lose their jobs or cannot work as a result of workplace closures. This was portrayed as a categorical map with the symbology based on the percentage of the lost salary being covered. Based on the description from the data source, this only captures payments to formal sector workers or those who are employed with contracts and pay taxes (Hale et al., 2021). Similar to the other categorical maps, a grid of bar charts indicating the quarterly distribution of countries in each category was also added in the atlas.

Table 21 Codes and descriptions used on income support policy map

Ordinal scale	**Description**
2	Government is replacing 50% or more of lost salary (or if a flat sum, greater than 50% median salary)
1	Government is replacing less than 50% of lost salary (or if a flat sum, less than 50% median salary)
0	No income support

5.3.6 Debt/contract relief policy

Aside from income support, some governments also implement debt or contract relief policies. This map shows if the government is freezing financial obligations during the COVID-19 pandemic, which may include stopping loan repayments, preventing basic services like water from stopping or banning eviction.

Table 22 Codes and descriptions used on debt/contract relief policy map

Ordinal scale	**Description**
2	Broad debt/contract relief
1	Narrow relief, specific to one kind of contract
0	No debt/contract relief

5.3.7 Impact on the aviation sector

Strict travel restrictions and a decline in the demand among travelers have significantly affected the aviation industry among others. This was visualized as an infographic which includes the net profit loss per region, the overall decrease in the number of flights, and global change in revenue compared to the previous year. The estimated CO_2 emission reduction is also displayed in connection to the decrease in the total number of flights.

5.4 Environmental Impact

The last chapter of the atlas focuses on the impact of the pandemic on the environmental aspect, especially on the global concentration of the three major pollutants; nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and formaldehyde (HCHO). The data acquired from the Sentinel-5P satellite only measures the amount of pollutants in the atmosphere and not ground-level concentrations. Also, since other natural factors such as temperature and seasonal variations are affecting the concentration of these pollutants, the values on the maps do not necessarily imply that the change is solely due to the lockdown measures imposed during the pandemic. There were no correlational studies conducted during the making of this atlas about the level of pollutants and the imposed lockdown measures. The maps produced in this chapter may be used for initial investigation but not for deriving conclusions about the impact of the pandemic on the air quality or level of pollutants in general.

5.4.1 Global concentration of pollutants

The global concentrations of the three pollutants were portrayed in the form of unclassed graduated color maps. The raster data shows the global mean from 1 January to 31 December of 2020 for all three maps. To show the monthly variations, a radar chart with the monthly average was added beside the main map. This chart can be helpful specifically in conjunction with the other maps in the social impact chapter to see if the decrease in value coincides with the period when stricter measures were imposed.

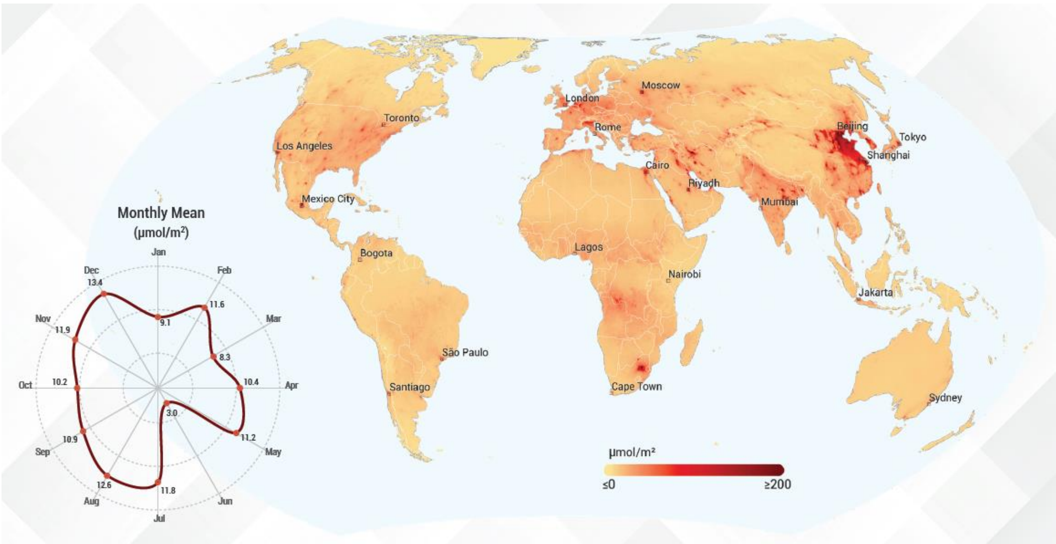

Figure 27 Unclassed graduated color map and a radar chart showing NO_2 concentration

5.4.2 Time-series maps

Aside from the global annual mean, a series of maps showing the monthly average for the three pollutants was also included in the atlas. This may help visualize the areas with a high concentration on a specific period to gain insight into the possible effect of the imposed measures. As mentioned, other variables might affect the level of monthly concentration so these maps may be used only as supplementary materials for further in-depth studies.

5.4.3 Change in annual concentration

To visualize how the concentration of these pollutants changes relative to the previous year, a choropleth map with symmetric divergent color scheme was also used for the symbology. In creating these maps, a hexagon tessellation was generated first using the Generate Tesselation tool in ArcGIS Pro with the country/territory boundary layer to show the local variations, especially within big countries. The area of the major hexagons (excluding those at the edges) measure 50,000 sq. km which was assigned based on the area of the smallest country displayed as a polygon. The annual means for 2019 and

2020 were calculated for each hexagon using the Zonal Statistic as Table tool in ArcGIS Pro. The results were appended to the hexagon tessellation polygon layer using a join operation and the hexagon ID as the primary key. The change in concentration was expressed as percent change using the formula:

$$\textit{Percent Change} = \frac{\textit{(new value-old value)}}{|\textit{old value}|} * 100$$

Along with the choropleth map, a graduated symbol map showing the concentration for 2020 was also added as a map overlay. This serves as a reference to the concentration of pollutants as a result of the change indicated by the choropleth map.

5.4.4 Trend on the concentration of three major pollutants

The synthetic map created for the environmental aspect summarizes the trend on the concentration of the three major pollutants described. Following the typification workflow used in the other synthetic maps, the percentage change values were reclassified first wherein an increasing trend indicated by the positive values was given a new value of 1 while the decreasing trend indicated by the negative values was given a new value of 2.

Table 23 Original and reclassified values used for each economic indicator

Original value	**Change in NO_2**	**Change in SO_2**	**Change in HCHO**
>0	1	1	1
<0	2	2	2
0	0	0	2

These reclassified values from each column were concatenated and the long descriptions for the resulting combinations were assigned. The category descriptions indicate only the number of pollutants that have undergone a certain trend. In the atlas, a map disclaimer was added stating that the map only indicates the trend for these pollutants and not the actual air quality of the area.

Table 24 Category assignment and descriptions (trend in economic indicators)

Combination	**Description**
111	Increasing for three pollutants
112, 121, 211	Increasing for two pollutants
221, 122, 212	Decreasing for two pollutants
222	Decreasing for three pollutants

6 RESULTS

In this section, the final atlas specifications were described along with the other supplementary products derived during the atlas creation process. The results of the user testing were also explained and. Subsequently, the results from the testing were used as a basis to update some of the atlas contents before the final publishing. The components that were not revised due to time constraints were mentioned as the potential aspects for future improvements in the atlas.

6.1 Atlas specifications

In connection with the objectives of this thesis, a thematic atlas visualizing the socioeconomic and environmental impacts of the COVID-19 pandemic was created applying the principles of modern cartography and graphic design (see Appendix 1). The thematic atlas comprising of 80 maps, 52 charts, and four main infographics provides an integrated source of information in understanding the various aspects of the pandemic besides the usual statistics shown by most maps produced today. This includes social, economic, and environmental aspects covering the topics of containment policies enforced, changes in major economic indicators, and level of pollutants among others (see Chapter 5 ATLAS CONTENTS).

Table 25 Total number of visualizations used in the atlas

Visualization type	**Count**
Reference maps	9
COVID-19 thematic maps	9
Social impact thematic maps	10
Economic impact thematic maps	9
Environmental impact thematic maps	43 (36 are from time series)
Infographics	4

Two types of PDF files were exported for the digital and analog versions of the atlas. While the digital, web-friendly version only has 126.6 MB file size, the print-ready version that was sent to the publishing house has a total file size of 729.1 MB as it contains a higher image resolution and other press-related elements such as color profiles and crop marks, and registration marks. The analog version measures 297 × 420 mm and contains a total of 70 pages.

In conjunction with the actual atlas, a general workflow for atlas creation was also outlined in this thesis (see Chapter 4 ATLAS CREATION). This workflow covers the initial phase of cartographic project definition up to the pre-press stage and user testing. Also, supplementary outputs include the ArcGIS STYLE file and the Adobe color swatch containing the color-blind safe color schemes used in the atlas. A Map Data Visualization Report (see Appendix 2) which contains the symbology specifications used in the maps was also included.

6.2 Results of usability testing

For the user testing, a mix of professionals mostly with non-GIS backgrounds was asked to participate. A total of 25 respondents from various age groups and educational backgrounds answered the survey. There is a good balance in terms of the sex of respondents but the majority of them came from the 25–35 age group, or the young professionals. Aside from the age group, the educational backgrounds of these respondents also reflect the target audience which is composed of those with bachelor's and master’s degrees. The survey questionnaire used was attached in the thesis text as Appendix 3.

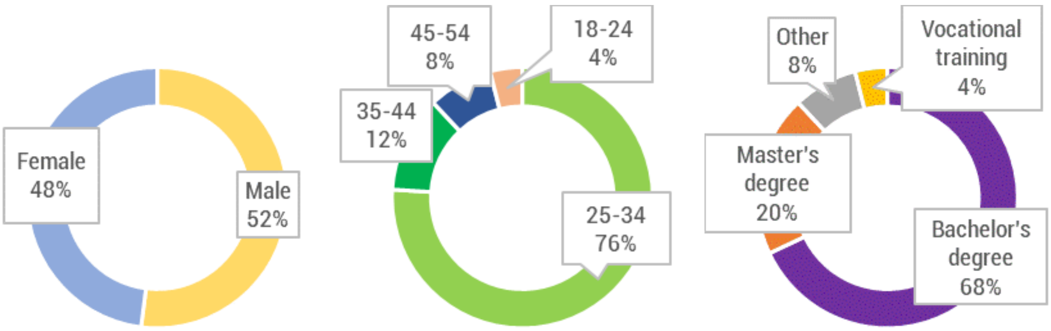

Figure 28 Demographics of the respondents in terms of sex (left), age group (middle), and education (right).

In general, positive feedback was received in terms of the layout of all three sample pages. Disagreements were noticed for the page alignment and page balance, especially for the first and second sample map respectively. Since these statements were concerned with the design preference and the majority of the responses were positive, the page layout on the atlas was retained as it is.

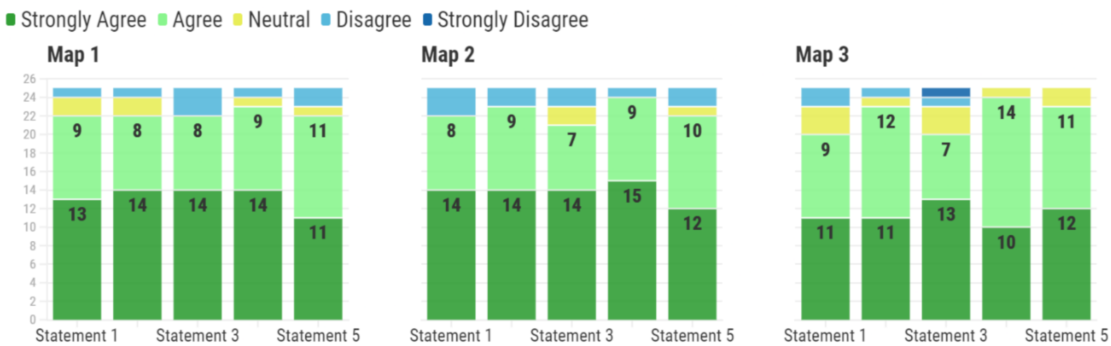

Figure 29 Agreement to the statements about the page layout.

For the cartographic design, disagreements and neutral responses were noted when it comes to the legibility of the map symbols and the labels. This is true especially for the second map about the strictness level which uses dark hues that create low contrast causing the map labels to become difficult to read. Necessary adjustments on the maps with similar symbology were applied.

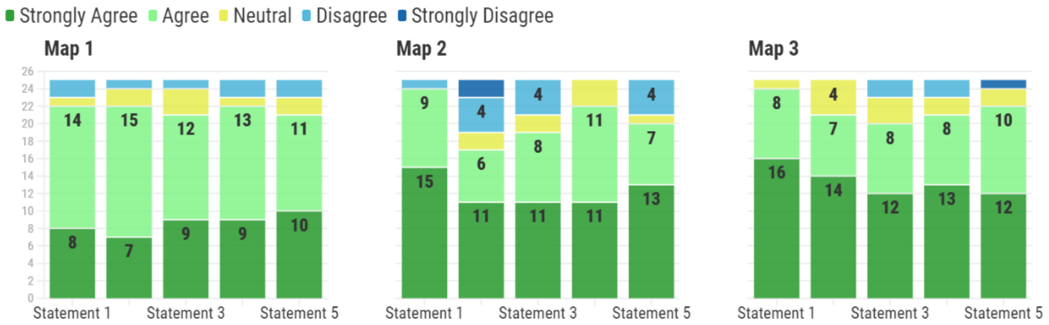

Figure 30 Agreement to the statements about the cartographic design.

Lastly, the responses when it comes to the completeness and the accurate depictions of the symbols in the legend were also positive. The majority of the respondents agreed that the symbols were properly and accurately depicted in the map legend. While these statements can be subjective, it is still crucial to obtain the general responses and sentiments of the potential users so that improvements in the initial design can be applied, especially in areas where the users expressed disagreements and neutrality.

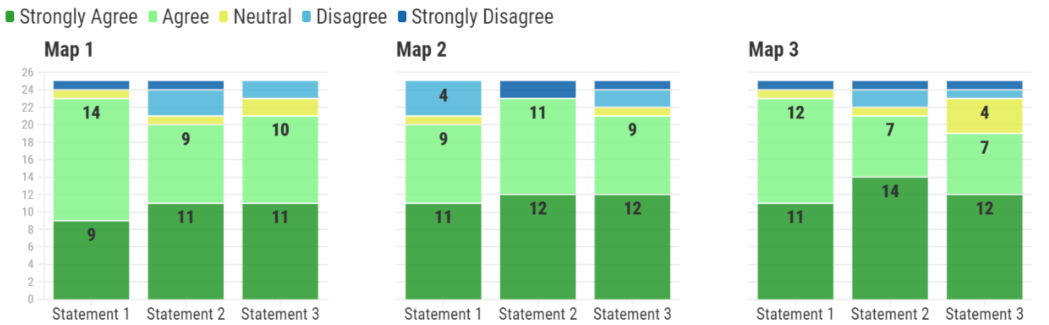

Figure 31 Agreement to the statements about the map labels and symbology.

When it comes to the results of the map reading and interpretation, a high percentage of the respondents (see Figure 32), was able to get the correct answers to three out of five easy questions. While more than 80% of the respondents got the right answer to the three questions about the maps, only 36% of them got the right answer for the first question concerning the usage of legend in the infographic. Another question with a relatively low percentage (56%) of correct responses was about the use of charts in the environmental maps. Necessary adjustments to these elements were applied to make them more visible on the map and to highlight their importance so users can easily interpret the presented visualizations.

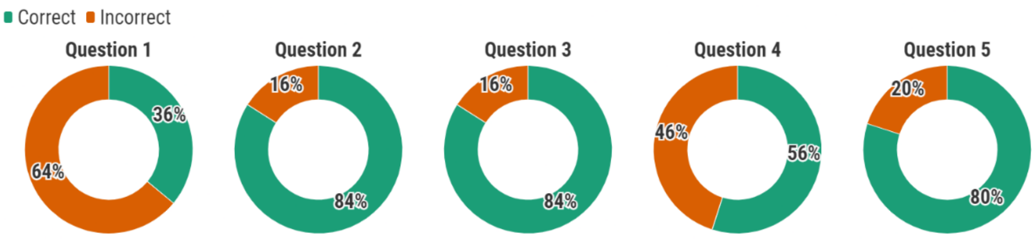

Figure 32 Percentage of respondents who got the correct and incorrect answers (easy questions).

In comparison to the first set of questions, the difficult ones that require integrating at least two maps from the atlas had a lower rate of correct answers. Although three out of five questions were correctly answered by more than 50% of the respondents, the two most difficult questions were only answered correctly by 36% and 8% of the respondents. The question with the lowest correct answer requires the users to compare the colors between a point and a polygon feature to get the correct answer. For the other question, the users are expected to identify the location of two countries on a map and compare the corresponding categories for each which will require them to check the reference maps on the atlas. Upon examining the concerned map elements that were not properly used to answer these questions, the necessary adjustments on the atlas were also applied. More descriptions on the important pages such as the reference map page were added such that the users will have an idea that those will be used for the succeeding parts of the atlas. Supplementary map annotations and explanations about the presented topics were also included to help the users understand the presented visualizations easily.

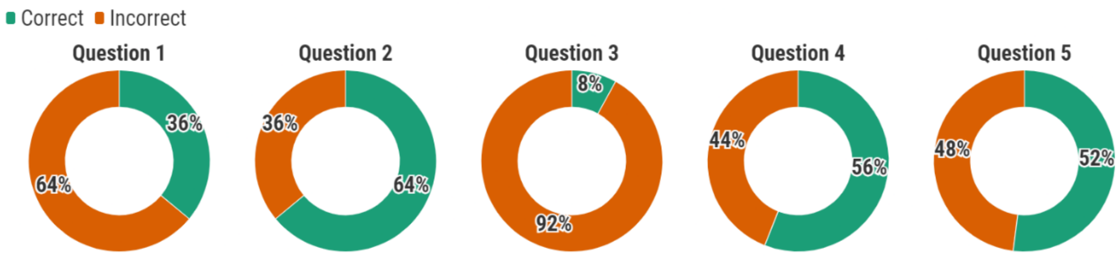

Figure 33 Percentage of respondents who got the correct and incorrect answers (difficult questions).

For the overall test results, 64% of the respondents were able to score a grade of 50% and above. Raising the passing grade to 60% and 70% reduces this value to 52% and 44% respectively. This result has been affected significantly by the results when it comes to the difficult questions that require integration of several maps in the atlas. Interestingly, 72% of the respondents were able to get a score of 60% and above for the easy part, but only 44% for the difficult questions. Whether this is due to the interpretability of the atlas, the map reading capacity of the respondents, or some other factors is another topic for future studies in map interpretation.

While these ratings may not be as high as expected, it should be noted that several factors (e.g. time spent, prior geographic knowledge, attitude towards the survey, etc.) may influence these. For instance, the number of correct answers obtained by the respondents may be correlated to the time spent in answering the test. While correlation does not signify causation, it is still important to know how these two variables are related specifically if the number of the correct answer is dependent on the time spent in answering the questions.

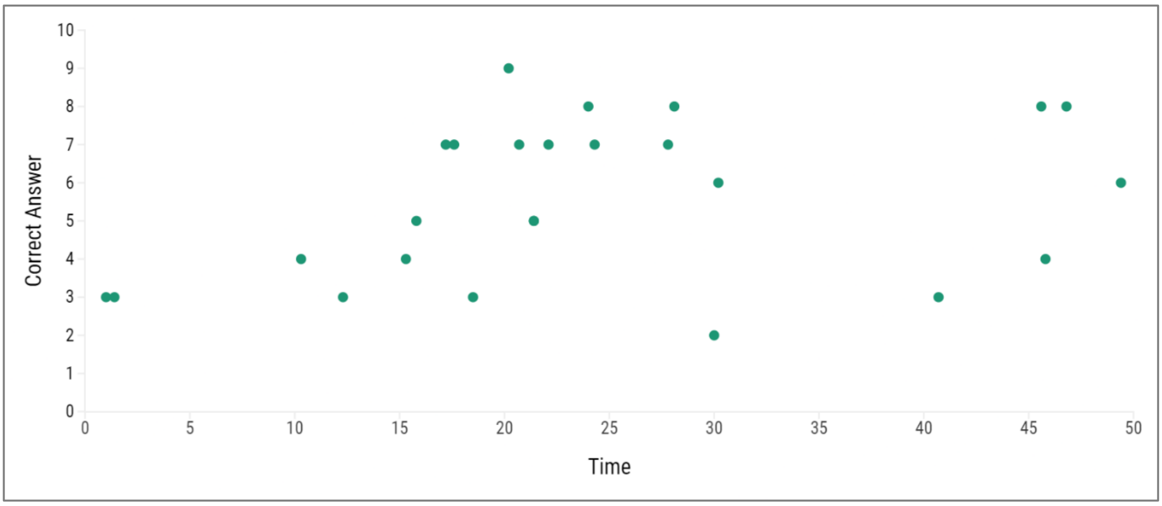

Figure 34 Scatterplot of time spent (X-axis) and number of correct answer (Y-axis).

Since the duration spent to answer the questions is known, the correlation coefficient was also calculated to check if there is a correlation between the time spent and the number of correct answers. The Pearson's product-moment correlation coefficient was derived using the formula:

$$r = \frac{\sum(x_i - x_{ave})(y_i - y_{ave})}{\sqrt{\sum(x_i - x_{ave})^2 * \sum(y_i - y_{ave})^2}}$$

The time spent and the number of correct answers were found to be positively correlated, $r(23) = .34$, $p = .128$. Though the coefficient indicates a positive correlation, by normal standards, this correlation is weak. This means that there is a low likelihood that the number of correct answers is related to the time spent by the respondents. As mentioned, time spent is just one possible reason and there could be several. This test was just conducted to see the relation between these two variables for further studies.

The results of the atlas quiz were gauged to see also which map and page elements need to be further improved. This has been deemed useful in improving the interpretability of the visualizations and the quality of the atlas in general. Considering that this is the first interaction of the atlas and the user, the performance by the respondents still indicates that the atlas is a viable mode of presenting information about the COVID-19 pandemic, although a more robust form of user testing can still be employed in the future to support this. Ultimately, involving the potential map users in the creation process not only provides a holistic approach to map production but most importantly, helps improve the quality of the resulting cartographic work.

7 DISCUSSION

While creating the atlas, several issues and workarounds were taken into consideration especially during the data processing and compilation stages. The documentation and resolution of these issues are explained in this section. Furthermore, other key decisions made related to the process of atlas creation were outlined here.

Map projections

Among the most common map projections used for world map creation, Wagner VII was selected as this serves the purpose of the map well in terms of aesthetics and area preservation. Since the major shape distortions can be found only in the polar areas, the overall depictions of the countries may not appear as unrealistic as compared to the usual world maps using Mercator projection. In addition, since this was based on the Lambert azimuthal equal-area projection, it is applicable for small-scale thematic maps that illustrate area characteristics (Esri, 2021c). For the reference and inset maps, the applicable equal-area projections for the respective region were used instead of Wagner VII to provide a more accurate depiction of the country's sizes.

Generalization

In conducting the graphical generalization of the country/territory boundaries, the primary tools used in ArcGIS Pro were the Smooth Polygon and Simplify Polygon tools. The main difference between these two tools is that Smooth Polygon removes the sharp angles in a polygon while Simplify Polygon removes insignificant vertices of a feature but still retains its general shape (Esri, 2021a). To get a more desirable result, these two tools were both utilized following a Smooth-Simplify-Smooth procedure. The original polygon layer was generalized first using the Smooth Tool with 75 km smoothing tolerance and Polynomial Approximation with Exponential Kernel (PAEK) as the smoothing algorithm. Compared to the Bezier Interpolation, the PAEK algorithm provides a better result as the vertex calculation is based on weighted averaging of all the coordinates along the source line (Esri, 2021b). After smoothing, the Simplify Tool was run to reduce the number of vertices and the complexity of the features. Simplification tolerance was set to 10 km and the Retain critical points (Douglas-Peucker) algorithm was used for the simplification. A minimal tolerance value was used since this particular algorithm is sensitive to larger values which can result in a coarse simplification. Since the result of the simplification contains features with sharp edges, the Smooth Polygon tool was run for the second time using the simplified polygon as the input. Several values were tested as smoothing and simplification tolerance but in the end, the combination of 75km-10km-50km as tolerance values was used respectively as this gives a more desirable generalization of the features without too much compromise on the shapes of the countries.

Small islands were also removed to reduce the map load. A threshold of 3,800 sq. km was used as the minimum size of features to be retained such that, significant islands such as Hawaii, Galapagos, and Canarias will still be displayed. Countries/territories that are smaller than the threshold value were converted to points using the Feature to Point tool in ArcGIS Pro. Moreover, the continent of Antarctica which has no native human population was not displayed in the thematic maps.

Sentinel-5P data processing

Datasets from Google Earth Engine can be displayed directly in GIS software such as QGIS using a plugin. However, the layers can only be displayed as a tile layer so statistics cannot be calculated. This is the main reason why the Sentinel-5P datasets were downloaded from GEE as TIF files instead of displaying them using the plugin. In downloading data from GEE, Google set a limit on the size of the raster file that can be exported to Google Drive which prohibits the exporting of the whole global dataset to one single raster especially for rasters with high spatial resolution. To resolve this, several partitions were created using the boundaries of each continent. The global datasets were clipped using these boundaries so they can be exported. These individual files were organized in a file geodatabase using mosaic datasets so they can be easily symbolized (see Chapter 4.3.1 GIS data preparation). Also since high-volume datasets were being processed, most of the processing tasks were run using custom models made from ModelBuilder.

Color schemes

Aside from using color-blind safe colors, several aspects of color interpretation were also considered in symbolizing the maps in the atlas. Although color interpretations can be deemed subjective, there are also universal characteristics of colors that if used in maps, can help in the better interpretation of the presented phenomenon (Dabner et al., 2014). For the symmetric divergent color schemes, warm hues (e.g. red, orange) were used to symbolize an increasing trend while cooler hues (e.g. blue, purple) were used to show a decreasing trend. The portrayal of 'no data' with a gray color was also standardized throughout the atlas. For the categorical maps, the least important category (e.g. no measure, no policy) was symbolized using yellow color for better color contrast as this has the lowest visual weight among colors. This way, the more important categories will be highlighted when reading the main map and the map legend. When it comes to the map legend, the most important categories were put on top for vertical legends and on the left for horizontal legends so map readers can perceive them easily.

Atlas layout and design

Information hierarchy is a crucial aspect that characterizes an atlas (Kraak & Ormeling, 2010). In the presentation of the atlas contents, the most important information was shown at the beginning. How the chapters were structured also reflects the relative importance of the topic to the general idea that the atlas presents. Since the direct impact of the pandemic can be seen in the social aspects, this was shown first in the atlas as compared to the economic and environmental aspects where the pandemic has mostly indirect impacts. Within the chapters also, the most significant topics were presented first before the others. The sequence of the topics was organized such that a causal relationship can be established by the readers even in the absence of explicit indicators from the atlas.

Suggestions for future works

As the world continues to stop the pandemic, the topics presented in this atlas can still be expanded along with the incoming data. Maps with a larger scale can be included for the most critical aspects to provide more insights and a better understanding of the local trends and disparities. In the availability of new data, more analytical and synthetic maps can be produced as well, delivering more information to the users. While this atlas incorporates a balance between form and aesthetics, the structure can be further improved to capture a broader audience in the future. Further correlational studies can also be conducted to reinforce the visualizations instead of only presenting them.

8 CONCLUSION

In line with the limited existence of a consolidated cartographic product and the budding map issues about the COVID-19 pandemic, this diploma thesis was developed to create a thematic atlas focusing on the direct and indirect impact of the COVID-19 pandemic on society and the environment, employing proper cartographic and design principles.

In creating the atlas, a cartographic project definition was formulated first to structure the objective and project specifications. GIS and tabular datasets were then acquired from global data sources to create various types of visualizations such as maps, charts, and infographics. This atlas utilizes data from various authoritative sources for global datasets such as the Johns Hopkins University Coronavirus Resource Center (JHU-CRC), the Oxford COVID-19 Government Response Tracker (OxCGRT), the World Bank (WB), the International Monetary Fund (IMF), and the Copernicus Programme.

The content of the atlas was divided into four main chapters focusing on the current state of the pandemic, its social implications, as well as the indirect impacts on the economy and environment. Before the maps were created, pre-processing and standardization of the data were done using GIS software. Reference maps and several types of thematic maps (e.g. choropleth maps, categorical maps, synthetic maps) were utilized to provide a holistic narrative of the COVID-19 pandemic.

Desktop publishing software was used in the post-processing of the maps and charts. Color accessibility testing was also conducted to ensure that the color schemes used in the atlas are distinguishable even for people with color vision deficiencies. Based on the project specifications, the atlas layout was designed following the principles of graphic design.

A short usability testing was also performed through a survey questionnaire and user interview to assess the interpretability and readability of the atlas. Aside from this, the testing was also conducted to identify which atlas components can be further improved to enhance its overall readability. Upon gathering the results of the user testing, necessary improvements were applied to the atlas design ensuring that map use has been incorporated into the creation of the cartographic product.

The result of the diploma thesis is a printed and digital version of a thematic atlas about COVID-19 and its implications on the social, economic, and environmental aspects. Along with the actual atlas, a streamlined methodology of atlas creation from project definition to pre-press was also defined.

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APPENDICES

Appendix 1 (free)	**COVID-19 Atlas**
Appendix 2 (bound)	Map Data Visualization Report
Appendix 3 (bound)	Survey Questionnaire
Appendix 4 (free)	Poster
Appendix 5 (free)	DVD

DVD Structure Description

Root Folder	**Subdirectory**
Thesis Text	
Input_Data	
	GIS
	Tables
Output_Data	
	Atlas
	Charts
	Maps
ArcGIS style file	
Adobe color swatch	
Web	assets
	images
	documents

APPENDICES

Appendix 2

COVID-19 Atlas
Map Data Visualization Report (MDVR)

Atlas Chapters

- Current Status
- Social Impact
- Economic Impact
- Environmental Impact

Page Number Fill

C18 M100 Y90 K8

C0 M50 Y100 K0

C71 M15 Y0 K0

C75 M0 Y100 K0

C58 M47 Y44 K33

Fonts Used

Roboto Bold
Roboto Regular
Roboto Light

Roboto Bold Condensed
Roboto Condensed
Roboto Condensed Italic

Font Colors

C70 M63 Y62 K58

C0 M0 Y0 K75

World Reference Map

city ▪ C75 M65 Y60 K80 size 4 pt

boundary outline color C0 M0 Y0 K0

outline width 0.5 pt

gridlines opacity 15%

			land	water	dash template
0 deg	line width	2 pt	C0 M40 Y94 K0	C73 M14 Y0 K0	6 4
20 deg	line width	1.5 pt	C0 M40 Y94 K0	C73 M14 Y0 K0	
10 deg	line width	1 pt	C0 M40 Y94 K0	C73 M14 Y0 K0	
5 deg*	line width	1 pt	C0 M40 Y94 K0	C73 M14 Y0 K0	
	opacity*	85%			

Continent Reference Map

country point size 11 pt

country polygon C0 M39 Y94 K0

outline color C0 M0 Y0 K0

outline width 0.5 pt

Thematic Maps

city ▪ C75 M65 Y60 K80
size 4 pt

country boundary C0 M0 Y0 K0
outline width 0.5 pt

no measure C0 M10 Y50 K0
no data C10 M10 Y10 K0

Current State

Europe C80 M12 Y52 K0
North America C8 M43 Y100 K0
Asia C56 M31 Y93 K12

South America C22 M91 Y91 K14
Africa C47 M94 Y29 K9
Oceania C54 M4 Y21 K0

Cases per Million

C31 M100 Y98 K45
C16 M93 Y85 K6
C7 M73 Y53 K0
C2 M52 Y31 K0
C0 M33 Y15 K0

Deaths per Million

C78 M93 Y7 K1
C62 M61 Y3 K0
C45 M44 Y0 K0
C30 M30 Y0 K0
C25 M18 Y0 K0

Case Fatality Rate

C91 M58 Y0 K0
C84 M43 Y0 K0
C75 M22 Y0 K0
C38 M8 Y0 K0
C24 M7 Y0 K0

Testing Policy

C19 M73 Y42 K7
C0 M60 Y45 K0
C0 M30 Y60 K0

Tests per Thousand

C67 M100 Y17 K6
C38 M100 Y4 K1
C14 M89 Y0 K0
C1 M52 Y11 K0
C2 M32 Y21 K0

Total Tests (million)

size 40pt
size 30pt
size 20pt
size 10pt

C69 M0 Y97 K0
outline width 1.5pt

Positive Rate

C82 M65 Y13 K1
C83 M42 Y7 K0
C70 M2 Y26 K0
C54 M0 Y34 K0
C28 M0 Y40 K0

Contact Tracing Policy

C0 M60 Y70 K0
C16 M36 Y56 K4

Vaccination Policy

C85 M37 Y81 K33
C81 M21 Y82 K5
C71 M0 Y71 K0
C58 M0 Y60 K0
C33 M0 Y44 K0

Public Information Policy

C87 M32 Y67 K23
C44 M0 Y55 K0

Social Impact

International Travel Controls

- C0 M80 Y79 K0
- C0 M50 Y40 K0
- C19 M37 Y0 K0
- C40 M0 Y11 K0

Restrictions on Gatherings

- C59 M80 Y29 K6
- C26 M86 Y40 K19
- C9 M78 Y72 K1
- C9 M40 Y70 K1

Social Policy Color Scheme 1

- C87 M47 Y9 K1
- C37 M42 Y1 K0
- C1 M51 Y58 K0

Social Policy Color Scheme 2

- C71 M65 Y0 K0
- C2 M38 Y67 K0

Facial Covering Policy

- C87 M47 Y9 K1
- C75 M73 Y1 K0
- C37 M42 Y1 K0
- C1 M51 Y58 K0

Containment Policies Strictness Level

- C75 M73 Y1 K0
- C65 M69 Y0 K0
- C44 M68 Y0 K0
- C25 M72 Y11 K0
- C11 M70 Y16 K0

- C1 M64 Y24 K0
- C3 M32 Y36 K0
- C0 M20 Y49 K0
- C5 M16 Y31 K0

hatch fill
outline width **0.5pt**
x interval **12pt** y interval **6pt**
C0 M0 Y0 K0

Economic Impact

Income Classification

- C89 M35 Y99 K29
- C85 M16 Y98 K3
- C58 M3 Y78 K0
- C21 M1 Y53 K0

Volume of Export

- C80 M54 Y0 K0
- C64 M31 Y0 K0
- C40 M20 Y0 K0
- C0 M38 Y22 K0
- C0 M60 Y30 K0
- C19 M65 Y38 K6

Volume of Import

- C88 M33 Y25 K30
- C75 M22 Y22 K0
- C55 M12 Y13 K0
- C0 M40 Y40 K0
- C0 M60 Y40 K0
- C0 M75 Y58 K0

GDP per Capita

- C87 M45 Y14 K2
- C78 M25 Y7 K0
- C60 M15 Y6 K0
- C27 M9 Y5 K0
- C0 M34 Y81 K0
- C0 M70 Y85 K0

Inflation Rate

- C55 M45 Y0 K0
- C0 M16 Y15 K0
- C0 M36 Y32 K0
- C0 M65 Y56 K0
- C6 M88 Y73 K0
- C26 M94 Y79 K25

Unemployment Rate

- C76 M22 Y0 K0
- C44 M9 Y0 K0
- C0 M22 Y37 K0
- C0 M31 Y51 K0
- C0 M52 Y74 K0
- C3 M77 Y96 K0
- C25 M84 Y99 K21

Effects on Major Economic Indicators

C73 M62 Y0 K0
C83 M40 Y0 K0
C76 M0 Y81 K0

Economic Policy

C85 M44 Y20 K5
C71 M0 Y28 K0

Environmental Impact

Nitrogen Dioxide Concentration

Critical color stops

C31 M100 Y95 K43
C11 M100 Y98 K3
C2 M8 Y49 K0

Sulfur Dioxide Concentration

Critical color stops

C63 M100 Y33 K39
C18 M100 Y49 K7
C1 M51 Y76 K0

Formaldehyde Concentration

Critical color stops

C35 M100 Y90 K57
C0 M69 Y96 K0
C2 M7 Y58 K0

Change in Nitrogen Dioxide Concentration

C89 M100 Y7 K1
C66 M75 Y0 K0
C45 M56 Y0 K0
C26 M40 Y0 K0
C0 M45 Y33 K0
C3 M64 Y48 K0
C9 M86 Y69 K1
C16 M100 Y100 K6

size **2 pt, 3.7 pt, 7 pt**
outline width **0.7 pt**
C0 M0 Y0 K0

Change in Sulfur Dioxide Concentration

C86 M45 Y14 K2
C78 M27 Y6 K0
C64 M14 Y8 K0
C34 M10 Y8 K0
C4 M35 Y75 K0
C7 M58 Y95 K1
C13 M78 Y99 K3
C17 M100 Y98 K7

Change in Formaldehyde Concentration

C91 M39 Y100 K40
C88 M31 Y75 K21
C79 M18 Y58 K3
C64 M3 Y50 K0
C14 M31 Y58 K3
C20 M46 Y75 K8
C24 M62 Y99 K16
C27 M81 Y99 K24

Trends in Concentration

C0 M100 Y98 K1
C2 M37 Y75 K0
C87 M49 Y5 K0
C39 M2 Y3 K0

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C0 M0 Y0 K0

country boundary
outline width **0.7 pt**
C56 M46 Y45 K34

Appendix 3
COVID-19 Atlas Survey Questionnaire

Good Day!

I am a graduate student specializing in Geovisualization and Geocommunication at the University of Palacky Olomouc. As part of my seminar thesis, I am conducting a short usability testing for a cartographic product that I developed. I would like to ask some of your time to answer these questions to the best of your knowledge.

Please use a device with a bigger display (laptop, desktop, tablet) when answering.

Thank you very much!

*required field

Age Group *

- o 18-24
- o 25-34
- o 35-44
- o 45-54
- o 55-64
- o 65+

Sex *

- o Male
- o Female

Highest Education Attainment *

- o No formal education
- o High school diploma
- o Vocational training
- o Bachelor's degree
- o Master's degree

Are you color-blind? *

- o Yes
- o No
- o I have no idea

What type of color blindness are you experiencing?

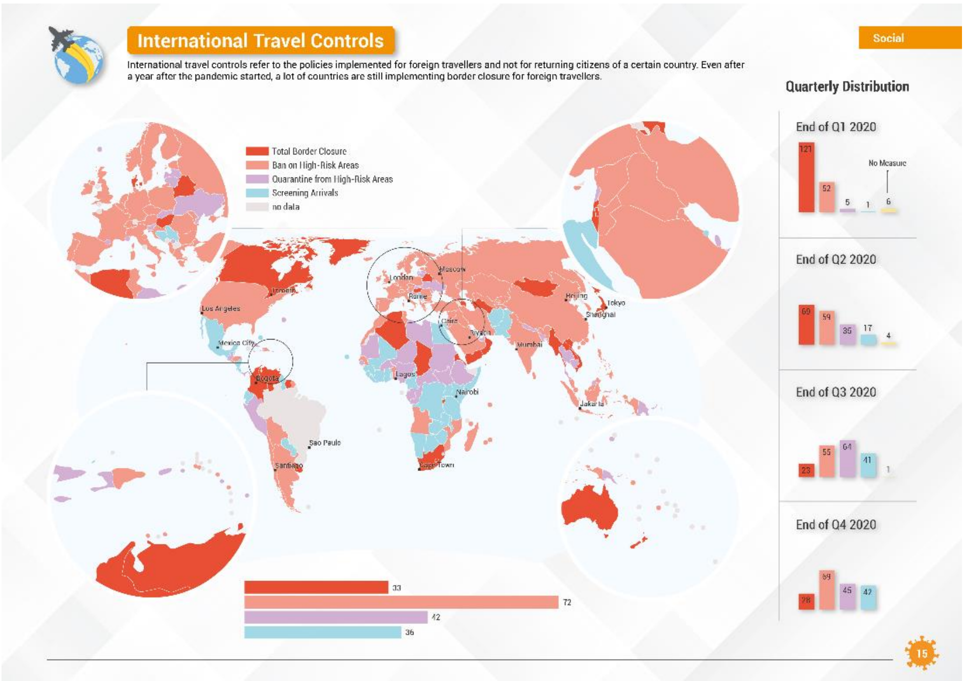
- o Red-Green color blindness
- o Blue-Yellow color blindness
- o Complete color blindness

Before proceeding to the next part, **please download** the digital version of the COVID-19 Atlas and examine it carefully.

Click to download the COVID-19 Atlas

In the atlas that you have downloaded, please go to **page 15** and examine this page.

Note: Do not use the image below as the basis for your answers to the succeeding questions.



How much do you agree or disagree with the following statements about the page layout? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The page looks balanced					
The graphic elements are logically placed on the page					
The map and other graphics are aligned to the page and to each other					
The title and subtitle describe the topic properly					
The title and subtitle are suitably positioned and sized					

How much do you agree or disagree with the following statements about the general cartographic design? *

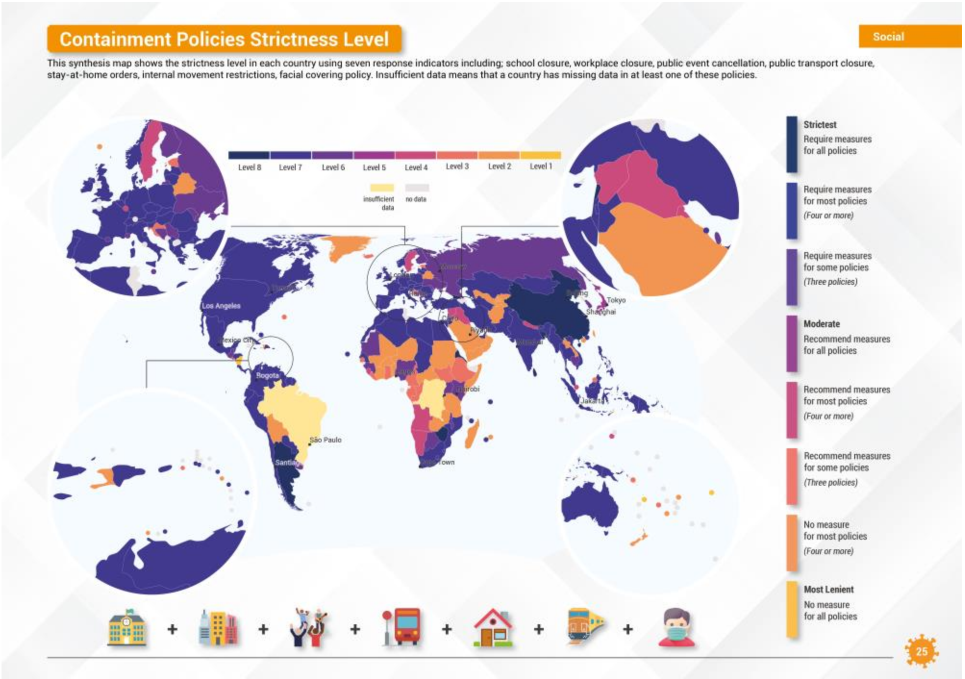
Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The main map stands out clearly from the background					
The symbols and labels on the map are legible					
The symbology for the qualitative/quantitative data was effectively applied?					
There is an appropriate visual emphasis on the important theme(s)					
There is an appropriate use of graphics, images, text blocks, and other supporting information.					

How much do you agree or disagree with the following statements about the general map legend? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
All the necessary symbols and details have been included in the legend					
The symbols in the legend appear exactly as they do on the map/graphics (size, color, etc.)					
The symbols and their descriptions are appropriately sized and positioned					

In the atlas that you have downloaded, please go to **page 25** and examine this page.

Note: Do not use the image below as the basis for your answers to the succeeding questions.



How much do you agree or disagree with the following statements about the page layout? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The page looks balanced					
The graphic elements are logically placed on the page					
The map and other graphics are aligned to the page and to each other					
The title and subtitle describe the topic properly					
The title and subtitle are suitably positioned and sized					

How much do you agree or disagree with the following statements about the general cartographic design? *

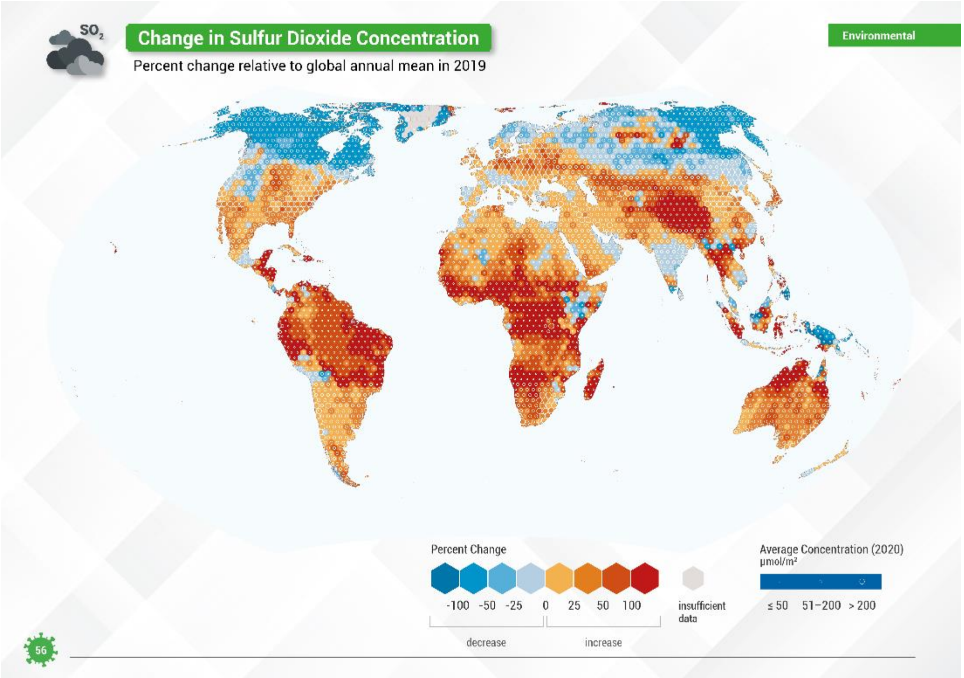
Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The main map stands out clearly from the background					
The symbols and labels on the map are legible					
The symbology for the qualitative/quantitative data was effectively applied?					
There is an appropriate visual emphasis on the important theme(s)					
There is an appropriate use of graphics, images, text blocks, and other supporting information.					

How much do you agree or disagree with the following statements about the general map legend? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
All the necessary symbols and details have been included in the legend					
The symbols in the legend appear exactly as they do on the map/graphics (size, color, etc.)					
The symbols and their descriptions are appropriately sized and positioned					

In the atlas that you have downloaded, please go to **page 56** and examine this page.

Note: Do not use the image below as the basis for your answers to the succeeding questions.



How much do you agree or disagree with the following statements about the page layout? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The page looks balanced					
The graphic elements are logically placed on the page					
The map and other graphics are aligned to the page and to each other					
The title and subtitle describe the topic properly					
The title and subtitle are suitably positioned and sized					

How much do you agree or disagree with the following statements about the general cartographic design? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The main map stands out clearly from the background					
The symbols and labels on the map are legible					
The symbology for the qualitative/quantitative data was effectively applied?					
There is an appropriate visual emphasis on the important theme(s)					
There is an appropriate use of graphics, images, text blocks, and other supporting information.					

How much do you agree or disagree with the following statements about the general map legend? *

Statements	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
All the necessary symbols and details have been included in the legend					
The symbols in the legend appear exactly as they do on the map/graphics (size, color, etc.)					
The symbols and their descriptions are appropriately sized and positioned					

For the last part, you will be asked to answer a few questions regarding the contents of the atlas. All the answers can be derived from the atlas and you can check it and go back there anytime to find them. Please try to answer all the questions **uninterruptedly** and **refrain** from using other sources (ex. Google Search) aside from the atlas.

1. **How many Asian countries/territories are included in the Top 10 of Total Cases?** *
   - ○ 4
   - ○ 3
   - ○ 2
   - ○ 1
2. **Which region has the lowest change in female unemployment rate for 2020?** *
   - ○ Africa
   - ○ Asia-Pacific
   - ○ Europe
   - ○ Middle East
3. **In which period is stay-at-home order the strictest across countries?** *
   - ○ End of Q4 2020
   - ○ End of Q3 2020
   - ○ End of Q2 2020
   - ○ End of Q1 2020
4. **In which month is the global concentration of Nitrogen Dioxide the lowest?** *
   - ○ January
   - ○ March
   - ○ June
   - ○ July
5. **As of Jan 31, 2021, what is the policy implemented by the United Kingdom for foreign travelers?** *
   - ○ Total Border Closure
   - ○ Ban on High-Risk Areas
   - ○ Quarantine from High-Risk Areas
   - ○ Screening Arrivals
6. **Between Croatia and Slovenia, which country implements a stricter overall containment policy?** *
   - ○ Croatia
   - ○ Slovenia
   - ○ Policies are the same

7. **Aside from Sweden, which European country/territory does not require the wearing of a face mask as of Jan. 31, 2021?** *
   - Norway
   - Finland
   - Estonia
   - Latvia
8. **Aside from Bahrain, which Asian country/territory offers universal availability of the vaccine to its citizens as of Jan. 31, 2021?** *
   - UAE
   - Qatar
   - Macao
   - Israel
9. **What is the income level of the country/territory with the highest gain in GDP per capita for 2020?** *
   - High
   - Upper Middle
   - Lower Middle
   - Low
10. **In South Korea, the general trend in the concentration among the three pollutants (NO_2, SO_2, HCHO) is ______?** *
   - Increasing for Three Pollutants
   - Increasing for Two Pollutants
   - Decreasing for Three Pollutants
   - Decreasing for Two Pollutants

Link to form:

https://form.jotform.com/211207234222035