IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE FOR CREATING MAPS

MASTER'S THESIS

submitted in partial fulfillment of the requirements for the degree

of

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PARIS-LODRON UNIVERSITY SALZBURG (PLUS)

Faculty of Digital and Analytical Sciences

Department of Geoinformatics

and

PALACKÝ UNIVERSITY OLOMOUC (UPOL)

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submitted by

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With the support of Erasmus+ programme of the European Union. This Master's Thesis has been developed in the framework of the Erasmus Mundus Joint Master Degree (EMJMD) "Copernicus Master in Digital Earth", jointly coordinated by Paris-Lodron University Salzburg, Department of Geoinformatics, Austria together with University of South Brittany, Computer Science Department, France and Palacký University Olomouc, Department of Geoinformatics, Czech Republic.

ANOTATION

Artificial Intelligence (AI) has started revolutionizing the field of cartography and geographic information systems (GIS). AI can help in processing huge amounts of spatial data quickly and automatically, reducing manual processes in terms of analysis, and geovisualization. ChatGPT is one of the AI-powered large language models that can be utilized alternatively to create maps. However, to incorporate the AI tool with data, it's necessary to understand how to create prompts for generating the most useful results.

The main objective of this study is to assess the capability of AI-generated maps from ChatGPT-4 and to compare the quality with a traditional cartographic technique. Map results are developed by Prompt Engineering, the crucial methodology of large language models that can enhance to produce high-quality outputs. The prompt details can affect the level of output quality, this study leverages two different prompt patterns which are indirect prompt as a basic pattern, Cognitive verifier and Question refinement as an advanced prompt. The results are evaluated on the number of attempts, errors, incorrect results, and map completeness to show how well ChatGPT-4 is in thematic map creation.

The case study utilizes the dataset from Global Wildfire Information System (GWIS) and Fire Information for Resource Management System (FIRMS), NASA that aims to create Wildfire maps in Portugal in both static and interactive maps using Python libraries such as Geopandas and Folium. The thematic methods explored include choropleth maps, dot density maps, and graduated symbol maps. The last stage of the study is performing the map evaluation according to cartographic rules. The workflow is conducted by ArcGIS Pro, Geopandas, Folium libraries and IDE tools (e.g., Google Colaboratory, Visual Studio code).

Finally, the outputs are delivered as code snippets, archive chats, and maps in HTML and PNG formats. The outputs provide a step forward in insight into how ChatGPT-4 understands thematic mapping processes and the levels of map quality that can be achieved.

KEYWORDS

ChatGPT-4, GeoAI, Prompt engineering, Large language models, Cartography, Thematic maps.

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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 fulfilment of the higher degree.

Parinda Pannoon

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ASSIGNMENT OF DIPLOMA THESIS

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Theses guidelines

The aim of the thesis is to analyse and evaluate usage of Artificial Intelligence (AI) for creating maps, including both analogue maps and interactive web maps. Student will process deep research on AI-based tools in the context of cartography, geoinformatics and geovisualisation. Then analysis and evaluation from different aspects (e.g. AI functionality, AI learning ability, cartographical rules, pricing, user availability etc.) will be made. Student will propose a complex workflow of AI usage for different scenarios, including COPERNICUS data that will be used for at least one scenario. Set of map outputs created with AI will be done, and finally comparison with traditional aproach will be processed.
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Recommended resources:

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CONTENTS

LIST OF ABBREVIATIONS

Abbreviation	Meaning
AI	Artificial Intelligence
ChatGPT	Chat Generative Pre-Trained Transformer
CSV	Comma Separated-Value
FIRMS	Fire Information for Resource Management System
GeoAI	Geographic Artificial Intelligence
GeoJson	Geographic JavaScript Object Notation
GIS	Geographic Information Systems
GWIS	Global Wildfire Information System
HTML	Hypertext Markup Language
IDE	Integrated development environment
LLMs	Large Language Models
MODIS	Moderate Resolution Imaging Spectroradiometer
NLP	Natural Language Processing
SLMs	Small Language Models

INTRODUCTION

AI has played an important role increasingly in recent years. The role of AI is multifaceted and continues to expand in various industries. In daily life and industrial operations, AI technology helps to solve complex problems and improve efficiency. Nowadays, AI is being widely leveraged due to AI's ability to analyze huge amounts of data, pattern recognition and make wise decisions.

The journey of AI started in 1956, John McCarthy introduced the concept "Artificial Intelligence" to describe an area of computer science focused on developing computers that behave like humans (Lakshmi Aishwarya et al., 2022). However, AI has been starting to grow rapidly in the mid-20th century. This is due to the growth in computing power, the availability of huge amounts of data, including the development of deep learning algorithms. The launch of the Large Language Model (LLM) of ChatGPT in late 2020 is an important step in the evolution of AI technology. ChatGPT leverages the power of LLMs to understand, generate and interact with human language in the form of an AI Chatbot or question-answering (QA). This natural language processing (NLP) capability in ChatGPT can give meaningful and relevant answers.

In the domain of Geoinformatics, AI technology has been integrated into various research areas. Machine learning and Deep learning are utilized to interpret complex geographic information, predict spatial trends, and provide insights with high accuracy. There are scientific studies that have leveraged the power of ChatGPT in map creation. For example, Tao and Xu (2023) explored making maps with ChatGPT based on ChatGPT by asking it to use external tools to read geospatial data and plot final maps. However, the use of AI to automatically create maps from human language commands is still relatively new nowadays. This leads to the question of how well AI can create maps based on cartographic rules and how good the quality between the AI-generated and human-generated maps.

The thesis explores ChatGPT-4's capabilities in creating maps using prompt engineering. AI-generated maps are compared with human-generated maps to assess their limitations and quality, including the influence of prompts on map outputs because large language models can produce different levels of detail in the map outputs. These results contribute to the development of AI's capabilities in GIS and cartography which is an alternative approach for creating maps.

1 OBJECTIVES

This master's thesis mainly aims to utilize AI for creating maps by applying different prompt patterns. AI-generated maps are compared to maps created through a conventional cartographic method. The map results are based on Python's script according to prompt engineering techniques. The case study particularly focuses on wildfire events in Portugal between 2002 and 2022.

1.1 Specific objectives

The study sets the following specific objectives to guide the research:

i. To evaluate the functional capability and learning ability of the AI in producing maps, in both static and interactive maps.
ii. To analyze and evaluate different prompt patterns that influence map outputs.
iii. To assess the map quality between maps generated by the AI and those produced through a traditional method, aiming to identify strengths and limitations.

1.2 Research questions

i. How well do AI-generated maps achieve cartographic aspects by formulating prompts?
ii. Do unstructured and structured prompts significantly influence AI-generated maps?
iii. How good is the quality of AI-generated maps compared to human-generated maps?

These research questions aim to explore AI's potential and limitations in cartography domain more broadly. By analyzing AI's capabilities along with refining prompts allows map makers to see the possibility of the alternative map-making tool.

2 STATE OF ART

This chapter outlines the relevant research and developments within the realms of GeoAI, Large Language Models (LLMs), and Prompt Engineering for creating maps including a comprehensive overview of the state of art in these intersecting fields.

2.1 Geo-Artificial Intelligence

The rapid growth of AI techniques and huge amounts of data has resulted in the combination of AI and geoinformatics technologies, which mainly aim to analyze, solve spatial problems and derive insights from geospatial data. Richter and Scheider (2022) mentioned the term GeoAI is a combination of 'geo,' as in 'geographic' or 'geography,' and 'Artificial Intelligence. The origins of Geo-AI can be traced back to its earliest days of geographic information systems (GIS) and applied statistics. In 1965, Howard Fisher at Harvard Laboratory created computer map-making software for spatial analysis and visualization research (Esri, n.d.). We can say that GeoAI has its roots in the mid-1960s. (Dardas, 2020). During the period, applications were limited by computational power, data availability and machine learning algorithms.

In recent years, GeoAI has continued to evolve rapidly, driven by advancements in AI algorithms particularly machine learning, sensor technology, and computational infrastructure. Also, spatial data are becoming more accessible, including increasing the volume of real-time sensor observations, the variety of imagery data, and geotagged text data (Li et al., 2016). These data need to be operated by GeoAI techniques such as the integration between GIS analysis and deep learning for extracting useful insight and automating processes.

According to the study of Richter and Scheider (2020), discuss the evolution of GeoAI, highlighting the influx of new geographic information and advanced machine-learning techniques that have expanded the scope of GIS research. The application of NLP in deep learning for handling geographic information from unstructured textual data and interpreting narratives about landscapes can deal with question-answering tasks related to geographic information. The authors mentioned that GeoAI can be beneficial for solving complex tasks combined with diverse data. However, this field still has challenges with model transparency issues, and reliability that come with the black box of machine learning methods.

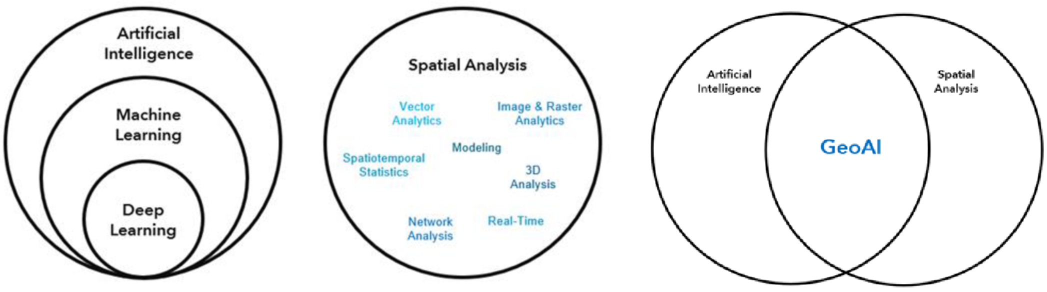


Figure 1 Integrating AI and spatial science into GeoAI. (Esri, n.d.)

Snow (2020) discussed the transformative impact of GeoAI on Esri's article that the integration of AI, deep learning, and GeoAI can improve productivity and modernize mapping processes. The author emphasizes that GeoAI at the intersection of AI and geospatial technology offers significant opportunities for improvement in remote sensing and national mapping. It facilitates complex tasks across multiple domains such as aviation, topographic mapping, and disaster response. GeoAI in mainstream industries is seen as a crucial step towards more efficient and effective mapping solutions.

In recent years, AI map products have evolved significantly, this reflects broader trends in emerging GeoAI applications. These map products encompass a wide range of applications, including autonomous routing suggestion, land use-land cover extraction, thematic map creation, and more. They leverage technologies of machine learning, large language models and generative AI to provide a large set of maps that may not be possible with traditional mapping technologies.

For example, Maps GPT is an easy-to-use artificial intelligence mapping tool, powered by Proxi. The integration of OpenAI makes the map creation process easier because a unique tool allows users to create maps with markers that meet their needs and expectations. Whether a traveler looking for directions or an activity planner looking for a location. Users can prompt their desired location and category. Then Maps GPT instantly creates an interactive map with optimized markers. This feature allows users to create maps without the need for any advanced technical knowledge because of the integration of the GPT model that receives input from natural language (TasticAI, 2023).

Another available product is Bettermaps, integrated with artificial intelligence technology and digital cartography. Bettermaps introduces automated tools for creating web maps, and improving map layouts. This platform facilitates users in map design, enhances map quality and extract map data. Through the application of AI, making maps becomes easier and high quality (Bettermaps, n.d.).

Textomap is one of the map products that utilizes the generative AI of ChatGPT to create, customize and embed maps. from prompts and questions. This AI-driven cartographic tool is instrumental in generating interactive maps from textual content by inputting natural language. The map can extract points of interest and addresses from the text input which allows users to leverage the map for several purposes such as educational purposes, and travel planning (Textomap, n.d.).

2.2. Large Language Models and Cartography Domain

Large Language Models (LLMs) are a type of artificial intelligence (AI) technology designed to understand, generate, and manipulate human language. Large language models have been trained on trillions of words with billions of parameters (Kırıkkayış, 2023) and leading to large amounts of computing power (Hong, 2023). This training enables them to perform a wide range of natural language processing (NLP) tasks, such as text generation, translation, summarization, and question-answering. The interaction of LLMs allows a machine to understand or communicate with natural language as a human word.

ChatGPT is one of the popular generative AI models in the form of a chatbot developed by OpenAI. According to Ray (2023), this generative AI has involved significant improvement, its advanced understanding and interaction capabilities allowing for accurate, contextual text processing even with nuanced inputs. Additionally, it is possible to foster more dynamic conversational experiences, broadening the scope of its application and interaction.

In the Cartography domain, Tao and Xu (2023) indicated that ChatGPT offers a useful alternative approach for mapping. It reduces the barrier to producing maps, leading to its enhanced efficiency of producing large volumes of maps and enabling an understanding of geographical spaces through spatial thinking capability. The authors highlighted utilizing ChatGPT for mapping comes with challenges, including unequal advantages and quality control across different user groups. Users need to be cautious when using ChatGPT for mapping tasks, especially regarding the unverified data sources, also the process of map improvement is not straightforward.

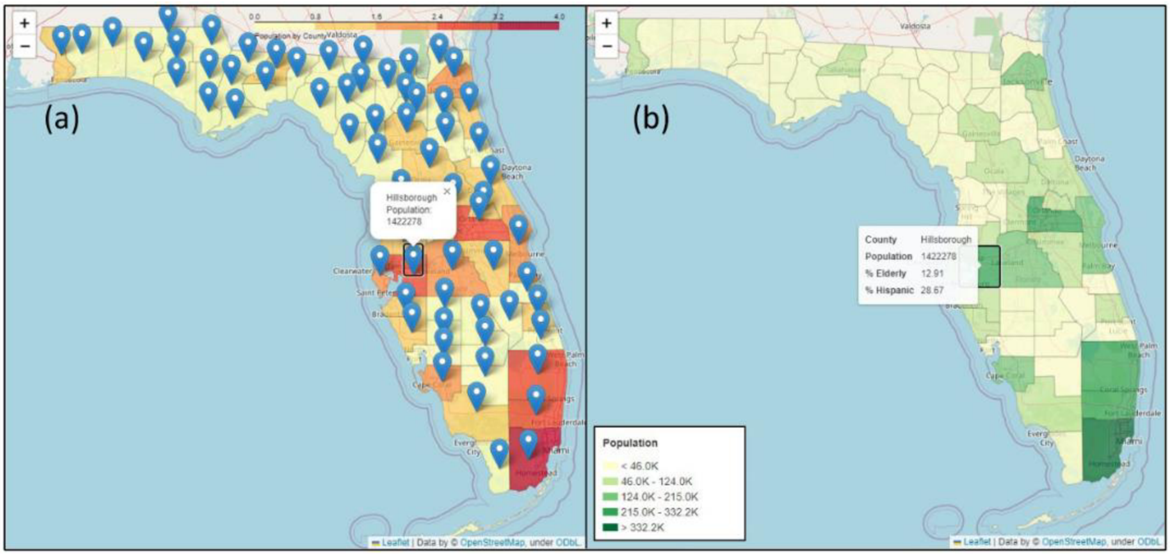


Figure 2 (a) Initial web map of Florida population before revision by ChatGPT; (b) the map after revision by ChatGPT. (Tao & Xu, 2023)

According to Li and Ning (2023), showcased the self-operating Geographic Information Systems (GIS) integrated GPT-4 API with GIS, callled AutonomousGIS. It can perform spatial analyses by accepting inputs as natural language and generating results as code, map and graph workflow. Through case studies, LLMs within GIS can generate maps successfully by automating intricate spatial analysis tasks. This integration could make GIS technologies more approachable for those without a GIS background, making a step towards the future of AI-driven autonomous GIS systems and significantly reducing manual operation time. However, there are several limitations, such as the inability to debug code that went wrong during the execution which often struggled with generating correct code in a single attempt.

2.3 Prompt engineering

Prompt engineering is the process of structuring input text for LLMs and is a technique integral to optimizing the efficacy of LLMs (Chen et al., 2023). Prompt engineering is an increasingly important skill set needed to converse effectively with large language models (LLMs), such as ChatGPT (White et al., 2023). The structure and context of given prompts can affect the desired output which we need to refine the prompt patterns to solve tasks.

According to Chen et al. (2023), discussed the following essential components for constructing a well-made prompt.

- Giving instructions: When the model is prompted with basic commands, the model will have many possibilities of the answers. This makes the results quite broad, so a comprehensive description is necessary to describe for more accurate and relevant results.
- Be clear and precise: This approach entails crafting prompts to be more unambiguous and specific, steering the model towards producing the desired outcome. When faced with vague or nonspecific prompts, the model tends to produce outputs that are broadly applicable and may not align in a particular situation. On the other hand, a prompt that is both detailed and precise allows the model to produce content that closely matches the specific demands. This is because it minimizes ambiguity, directing the model more accurately towards the intended response.
- Try several times: Due to the unpredictable behavior of Large Language Models (LLMs), executing multiple times of responses, the technique known as "resampling". This technique requires running the model several times with the same prompt to get the best output. Such a method helps in exploring the variations in the model's responses, thereby boosting the probability of achieving a high-quality result.
- Role-prompting: Role-prompting is when the model assigns a specific persona, such as performing as an expert. This strategy helps the model's response to match the expected outcome. For example, by prompting the model to assume the role of a historian, it becomes more likely to offer responses that are both detailed and contextually precise regarding historical events.

Additionally, recent studies have integrated prompt engineering methods with map creation, the study conducted by Kang, Zhang and Roth (2023) generated high-quality image maps using DALL·E 2 relied on a specific prompt format. The prompt format indicates map type, region, place, and additional descriptions. The author mentioned that this pattern allowed the LLM to create a map output corresponding to the parameters. The map type parameters vary from choropleth map, heat map, physical map, political map, and reference map. Moreover, specifying description parameters allows the map images to have a wide range of styles and colors. Although the AI model of DALL·E 2 can create realistic and diverse images from text prompts, some inaccuracies and misleading information occurred in AI-generated maps due to cartographic concepts and terminology indicated in the prompt.

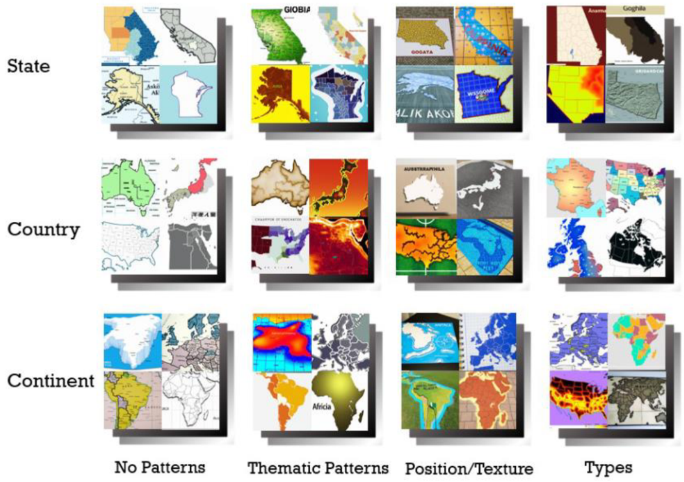


Figure 3 AI-generated maps using DALL·E 2, categorized by geographic scale and prompt type. (Kang, Zhang & Roth, 2023)

According to Juhász et al. (2023), leverage generative AI models of LLM (ChatGPT) and a multimodal pre-training method (BLIP-2) to enhance map tagging accuracy in OpenStreetMap (OSM) by analyzing street-level images from Mapillary. By providing a detailed description of the source photograph and refining prompts with additional context can increase the accuracy. The method involved constructing prompts, it started with a context message and instructed the model by a few-shot pattern in which the authors provided a small number of examples or baseline scenarios. Then the model learned from the given examples to respond properly.

3 METHODS AND PROCEDURES

This section describes the methods overview of using the AI tool to create maps. This includes the data and software used to achieve the results. The study divides the methods into two main parts, the first part is creating static and interactive maps by different prompt patterns, and the second one is assessing map quality between AI-generated and human-generated maps. The prompt details will be elaborated in Chapter 4.

3.1 Methods

This thesis leverages the large language model of ChatGPT-4, to generate maps through prompts. The first stage involves using ChatGPT-4 on geospatial data to produce thematic maps which are choropleth, graduated symbol, and dot density maps. Each map is created in both static and interactive versions using Basic and Advanced prompts. The case study is a Wildfire event in Mainland Portugal during 2002–2022. The average burned area will be visualized as a choropleth map, Fire spot numbers in each region for a graduated symbol map, and Fire spot density for a dot density map. The fire data are derived from Global Wildfire Information System (GWIS) and FIRMS NASA.

The first stage is conducted to evaluate the functional capability and learning ability of Artificial Intelligence (AI) in producing maps, as well as to assess how prompt patterns influence the map outputs. The second stage aims to assess the quality of AI-generated maps compared to human-generated maps considering the cartographical rules. The suitability criteria of cartography are set for the evaluation which reveals the map quality from AI compared to traditional methods focusing on correctness and legibility according to cartographic rules. The research combines qualitative and quantitative evaluation approaches. The statistics of incorrect results given by AI, the number of attempts, map completeness and error messages will be evaluated in the first stage. The human-generated maps are used as the references for the comparison in the second stage.

3.2 Data source

Global Wildfire Information System (GWIS)

GWIS is a joint initiative of the Group in Earth Observations (GEO) and the Copernicus Work Programs (GWIS, n.d.). GWIS provides data on wildfire trends, geographic distribution of fires, burned areas per country and sub-national level for all countries globally. The case study of the choropleth map uses average burned area data from 2002 to 2022. The data visualization on the maps such as 'Yearly Burned Area', 'Average Monthly Burned Area by Landcover', 'Fire size and Carbon Monoxide emission' are also directly downloaded from GWIS Country Profile application in CSV format.

Burned area values based on the product MODIS MCD64 A1. Average monthly fire size indicates monthly fire size per administrative area and year, showing the total burned area per fire size class for each month. Fire size (ha) is from the GlobFire database. The CO emission is derived from the Global Fire Emission Database (GFED) which combines satellite information on fire activity and vegetation productivity to estimate fire emissions. (San-Miguel-Ayanz et.al, 2020)

FIRMS NASA

The Fire Information for Resource Management System (FIRMS) provides Near Real-Time (NRT) active fire data. Moderate Resolution Imaging Spectroradiometer (MODIS) and Terra satellites, and the Visible Infrared Imaging Radiometer Suite (VIIRS) are the foundational satellite data sources to detect active fires and thermal anomalies. (NASA-FIRMS, n.d.). The graduated symbol and dot density map in this study visualized active fire information in 2022. The data was acquired from NASA, Fire Information for Resource Management System (FIRMS) from shapefile format.

3.3 Software and technical tools

3.3.1 Map generation and data visualization

- **ArcGIS Pro:** ArcGIS Pro is a GIS software developed by Esri for creating maps, managing geospatial data, and performing spatial analysis. In this study, ArcGIS Pro creates thematic maps for the traditional method. The license was obtained through the University of Salzburg.
- **Flourish:** Flourish enables users to create interactive data visualizations. The platform supports various types of visualizations, including bar charts, pie charts, scatter plots and more. The bar, line, and stacked charts are included in the map with ArcGIS Pro.
- **ChatGPT-4:** A generative AI trained to generate human-like text responses from given prompt. It is used for generating code snippets of static and interactive maps based on prompt inputs. Since it can interpret natural language input, this allows users to interact with the prompts and context of the conversation.

3.3.2 Code developing and libraries

- **Google Colaboratory (Colab):** A cloud-based platform provided by Google that offers free access to computational resources for executing and developing Python-based projects. Google Colaboratory is leveraged in processing and visualizing the code results for the static map version.
- **Visual Studio Code (VS Code):** This Integrated development environment (IDE) is a free source code editor developed by Microsoft. It is widely used by developers for writing, editing, and debugging code across various programming languages and platforms. Jupyter Notebook works with a Python environment in Visual Studio Code for creating and visualizing the interactive map version.
- **Folium:** Folium is a Python library used for creating interactive maps and visualizations. It is built on top of the Leaflet JavaScript mapping library.
- **Geopandas:** GeoPandas is an open-source Python library that extends its capabilities to handle geospatial data. It includes built-in plotting capabilities for creating maps and visualizing spatial data by leveraging Matplotlib and several Python libraries. In this study, Geopandas is the main library used for creating static maps.

- **Matplotlib:** Matplotlib is a popular Python library used for creating static and interactive data visualization such as chart or diagram. In this study, all data visualizations in the static maps are plotted by Matplotlib.
- **Plotly:** An open-source data visualization library for creating interactive data visualization. It offers a range of visualization types, from basic charts like bar charts to more complex plots like 3D plots and geographic maps. Its interactive capabilities enable the creation of data visualizations on the interactive version.

3.4 Prompt patterns

The AI-generated maps are performed by using two different patterns which are basic and advanced prompt patterns. The basic prompt pattern refers to Direct instruction also known as Zero-shot. It is the simplest type of prompt without requiring any examples. The pattern consists only of instruction directly as a question or request stating what AI should do (Patel & Parmar, 2024).

Another prompt pattern in this study is the Advanced prompt which combines Cognitive verifier and Question refinement patterns. The Cognitive verifier is used for generating map elements at the beginning of the process. The prompt can generate additional questions related to the original question which potentially can return results exactly as specified in answers. The Question refinement will be used in the last step of the map development to adjust specific details, the pattern refines the inputs or questions, reducing the gap between LLM's understanding and the user's knowledge, then the quality of both input and output can be more accurate and efficient (White et al., 2023).

3.5 Processing procedure

The data are preprocessed in ArcGIS Pro software with shapefile format and used as the input for ChatGPT-4. The preliminary outputs of the three case studies are designed and tested in ChatGPT-4 to ensure the feasibility of the AI model and Python libraries at the beginning of the research. Each thematic map is iterated five times with the same or similar prompts. The iterative method helps in exploring the variations in the model's responses and enables developers to assess limitations and try to push the boundaries of AI ability (Patel & Parmar, 2024). The outputs among five maps will be evaluated for the next step. The code snippet of the static map is executed in Google Colab since the GPU capability supports the visualization faster than the virtual machine. The interactive maps are executed within Visual Studio Code due to the large code snippets and the limitation of RAM in Google Colab.

For the mapping process, each map element is developed by one prompt at a time for the basic prompt pattern. For the advanced prompt, Cognitive verifier can generate more than one map element at a time because it provides three additional questions related to the original requirements. Question refinement is used in the last step to adjust specific details, or create some elements that are not achieved by Cognitive verifier.

The maps from the traditional method in the last stage are generated by using ArcGIS Pro software, and Flourish is utilized for data visualization. The human-generated maps are set as the reference for the suitability criteria. The reference consists of the most appropriate map specifications according to cartographic rules. By comparing maps with specifications, the strengths and weaknesses can be assessed in their quality. The more the map complies with the map's specifications or benchmark, the better the quality of the map (Vansteenvoort & Maeyer, n.d.). Then the outputs between AI and traditional methods can be evaluated according to three suitability levels. The general workflow is shown in Figure 4.

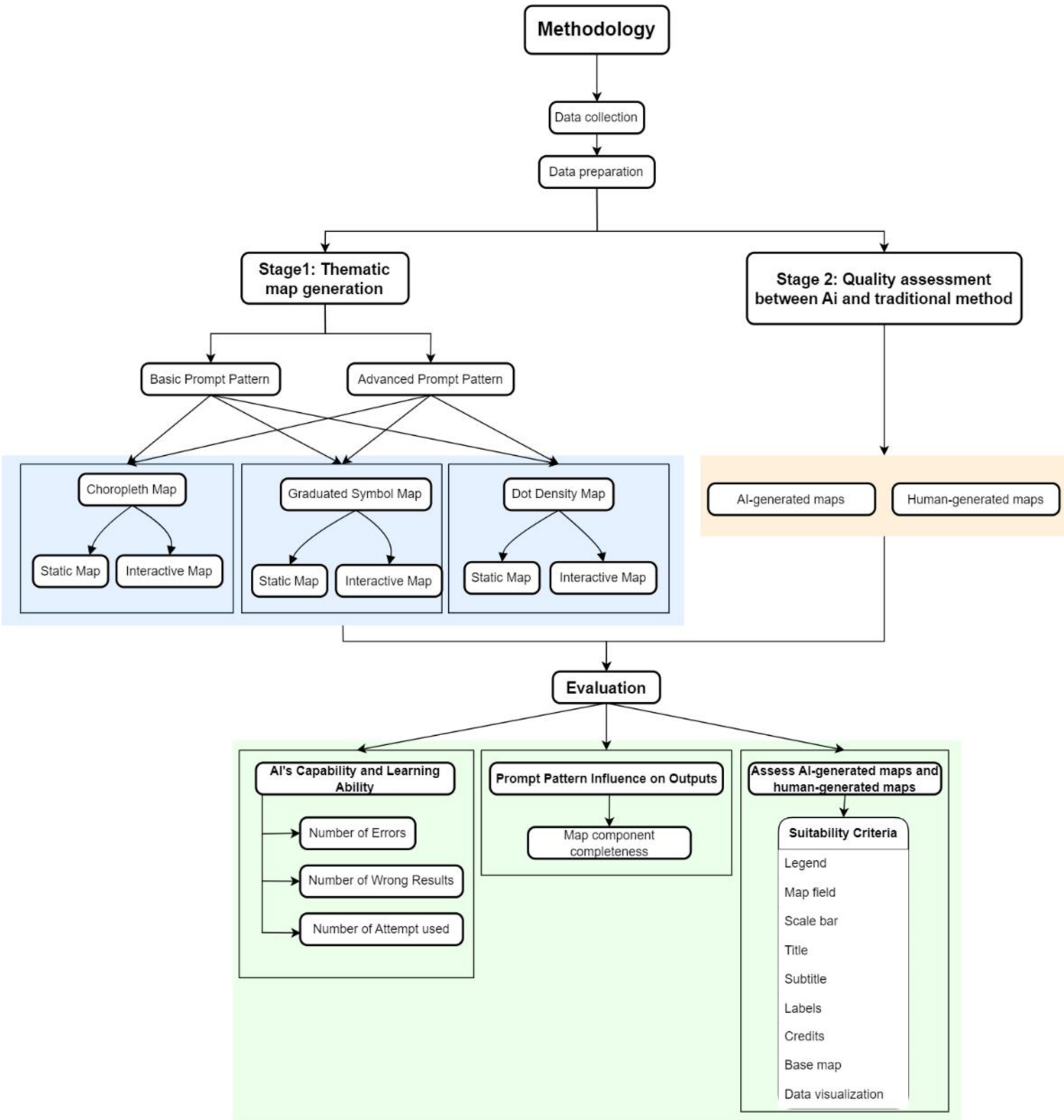


Figure 4 Workflow of the study

4 THEMATIC MAP GENERATION

4.1 Basic Prompt Pattern

The concept of basic prompt or direct instruction pattern is a method that directly tells or instructs the model to follow instructions without providing any examples. The explicit instruction should be clear to derive precise and accurate results. This pattern is also known as Zero-shot in prompt engineering. This study constructs the structure into three elements which are Instruction, Role and Task as shown in Figure 5.

The instruction provides the initial information about the given geospatial data, which enhances the LLM's understanding of the context and ensures geospatial data will be processed properly. The details in the instructions describe a list of shapefiles and the study area including years. Giving a role to LLM enables the AI to dive into a specific domain such as cartography or Geoinformatics. By acting as a persona could provide outputs that the persona would create and help in providing details to users who do not have in-depth knowledge of the field (White et al., 2023). In this prompt, the role of 'cartographer' is assigned to collect the cartographic knowledge for accomplishing a map-making task.

The role and the instruction are indicated initially at the beginning of the process in ChatGPT-4. The task is the main command to straightforwardly inform what the expected output that the LLM should perform. In this pattern, The AI keeps training what it needs to create or adjust on each element one at a time throughout the process until it gives desired map outputs.

Instructions: From the given zip file, consists of 2 shapefiles; 1. the state boundary of Portugal named "boundary", and 2. the average burned area from 2002–2022shapefile each region in Portugal.

Role: Act as a cartographer, your role is to give me a code to run in a local environment.

Task: Can you create a choropleth map of Average burned areas in each region, 2002–2022? The map should be created from Geopandas library mainly.

Figure 5 Basic prompt structure

4.1.1 Case Study 1: Choropleth map from basic prompt

The choropleth map in this study aims to visualize the average burned area in Portugal from 2002 to 2022 using Geopandas library for the static version and Folium library for the interactive version. The map is designed to show regional variations in burned areas, using a graduated-color scheme according to the extent of land affected by fires. The bar chart of 'Average burned areas yearly' is also generated in this thematic map using Matplotlib library. The chart aims to provide additional data visualization related to the burned areas in Portugal.

1. Static map

As mentioned in methods and processing procedures in Chapter 3, the study is performed in both static and interactive maps. A code snippet is executed on the Google Colab environment. Geopandas is one of the most effective libraries for creating maps in Python programming language, which extends the capabilities of the Pandas and Matplotlib libraries to allow for the handling of geographic data. This library's ease of use for creating static thematic maps is not only informative but also visually appealing.

In this study, the AI's capability of geodata processing and geovisualization can be evaluated based on the library. The fundamental map composition consists of a map field, legend, scale bar, map title and credits. The additional elements are a chart or data visualization, labels subtitle and basemap.

Map field

The choropleth map is generated by the prompt structure as shown in Figure 5. The AI usually gives the correct output for this thematic method since the choropleth map is a commonly used and easy method in Geopandas library. The graduated-color scheme is assigned in the column argument based on the burned area attribute.

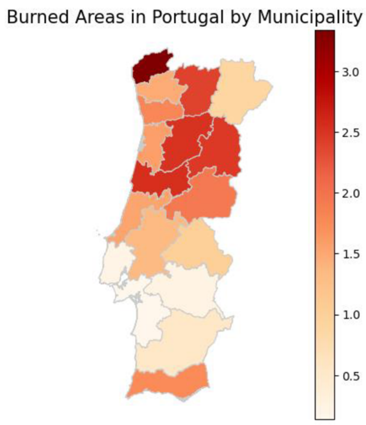


Figure 6 Choropleth map generated by basic prompt pattern

The common error in the code given by AI is that the data is not normalized by shape areas automatically. Therefore, the data either needs to be preprocessed before inputting on the ChatGPT or indicated in the prompt explicitly. Sometimes, it returns inappropriate data classification for creating discrete classes. Users need to specify the classification method to the AI (e.g., Equal Interval, Quantiles, etc.). As well as the color scheme, the AI could give a cold color tone even if the context is wildfire incidence. In this case study, orange-red shades (OrRd) are the default color when the term *'warm color scheme'* is specified in the prompt.

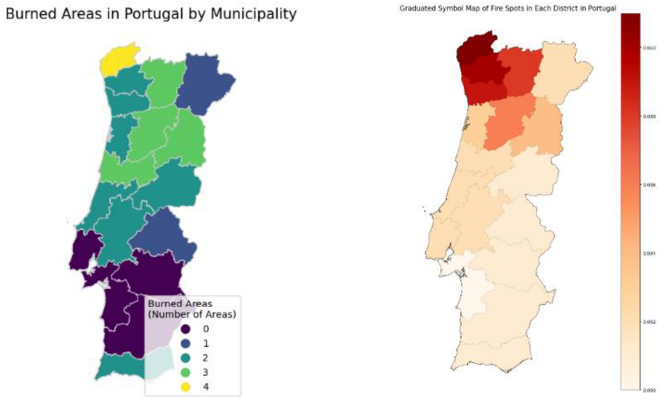


Figure 7 Inappropriate color and data classification of choropleth maps

- **Legend**

The discrete legend is predefined and uses the same warm color scheme as the map to represent the average burned area in each region. The default legend style given by AI is a continuous bar (Figure 6). To modify the legend with five classes ranging from high to low values, the useful prompt is *'change the continuous legend to a discrete legend'* as indicated in Figure 8. Adjustments to the code will be made on 'scheme' parameter determining how the data is categorized into discrete bins.

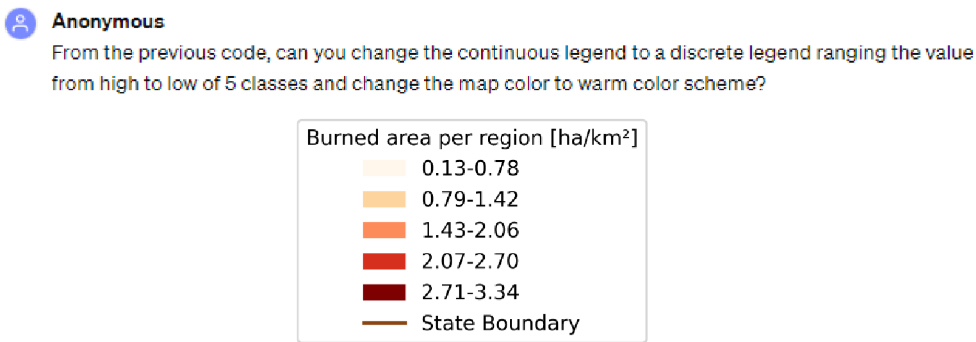


Figure 8 Refined prompt and proper legend of the choropleth map

2. Interactive map

An interactive map created using Folium offers a user-friendly way to display geospatial data. Folium enables developers to build attractive maps with interactive features using straightforward Python scripts. The interactive ability allows maps to embed additional information through popups and tooltips that users can interact with data dynamically such as a zoom button, dynamic scale bar and toggle layers to customize the view. This allows Folium library to present maps in an informative and attractive manner.

The interactive choropleth map can be generated using the same prompts as the static version, only change the library's name and specify the *'interactive'* term in the prompt as specified in Figure 9. The primary map composition consists of a map field, legend, scale bar, title and credits. The additional elements for the interactive version are the chart or data visualization, labels, subtitle, basemap, tooltips and layer control.

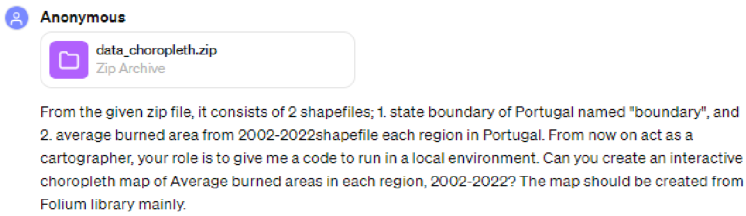


Figure 9 Basic prompt pattern for an interactive choropleth map

- **Map field**

The interactive map is barely successfully created on the first try, ChatGPT-4 often raises an error while trying to load the shapefiles, which can happen due to the complex geometries (Figure 10). The prompt language needs to be clear and concise.

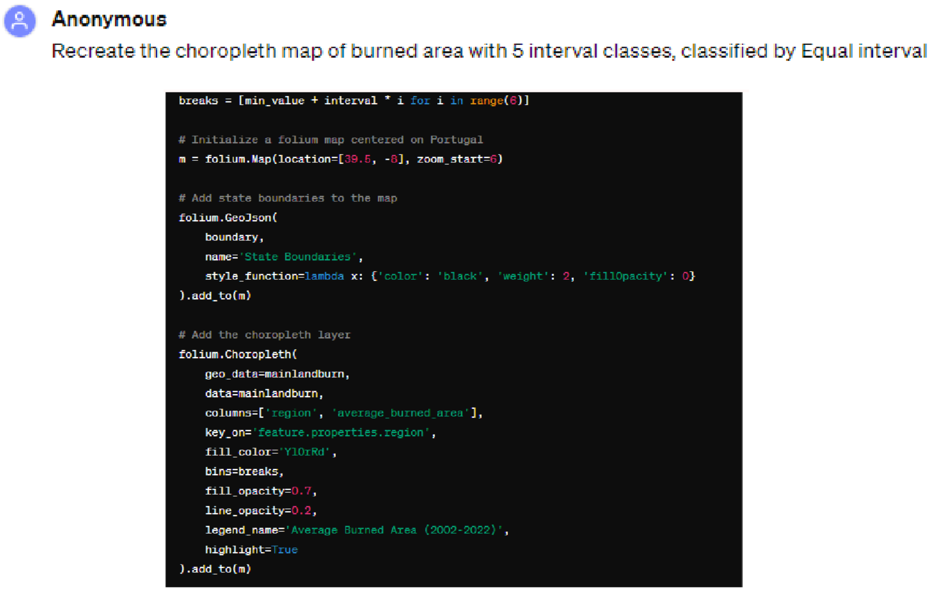


Figure 10 Basic prompt for creating choropleth map and legend

The AI adjusts library's parameters correctly from the given prompt. It calculates the minimum and maximum values of the 'burned_area' attribute to determine intervals, then creates a list of breaks that defines the 5 boundaries. The breaks are passed to the bins argument of the 'folium.Choropleth' method to specify the desired interval classes. However, the AI does not consider the data normalization since Folium requires only two data frames which are geographical coordinates of each area and burned area attributes. Therefore, the normalized data need to be processed before creating the map in ChatGPT-4.

- **Legend**

The default legend is generated by Folium's Choropleth method simply by automatically adding a legend based on the 'fill_color' parameter and the 'bins' used for classification without adding a manual legend. In addition, the legend intervals and colors always correspond with the map field. Conversely, the legend in the static map needs to be adjusted either in color scheme or legend labels several times. Therefore, the map legend for the interactive version does not require as many prompts as the static map, which the AI needs to code intricately.

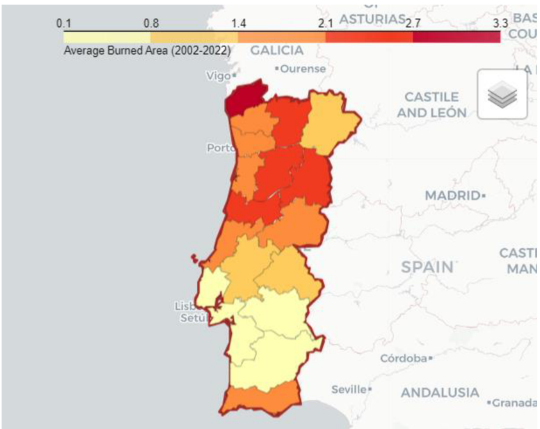


Figure 11 Completed map and legend of the interactive version

4.1.2 Case Study 2: Graduated symbols map from basic prompt

The graduated symbols map aims to visualize the number of fire spots in each area using the active fire spots from FIRMS NASA. The capability of AI can be evaluated on how well it can create graduated symbols with varying magnitudes across the areas intuitively.

1. **Static map**
   - **Map field**

To create the graduated symbols map by basic prompt pattern, implementing diverse prompting is necessary since Geopandas library has not been developed for the Graduated symbols specifically. Prompts are designed and crafted in several styles to increase the possibility of the LLM's responses for generating desired outputs. The prompts are adjusted in different words such as *'Bubble map'* or *'different circle sizes'*.

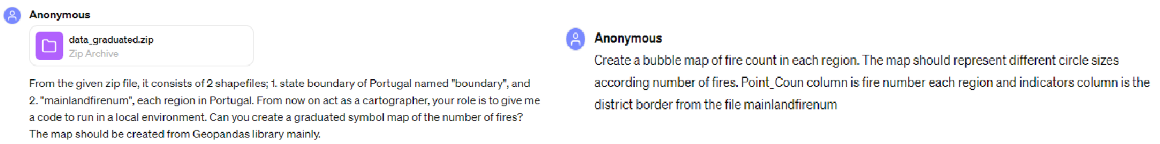


Figure 12 Prompts used for creating graduated symbols map

For this thematic method, ChatGPT-4 usually creates a choropleth or proportional map instead. The word 'bubble' is selected to create the graduated symbols map since it is a common term for the library to create different symbol sizes. However, the AI's response usually generates the symbols in proportional sizes, instead of grouping sizes by classes. Hence, the information on interval ranges and sizes should be indicated in the prompt explicitly.

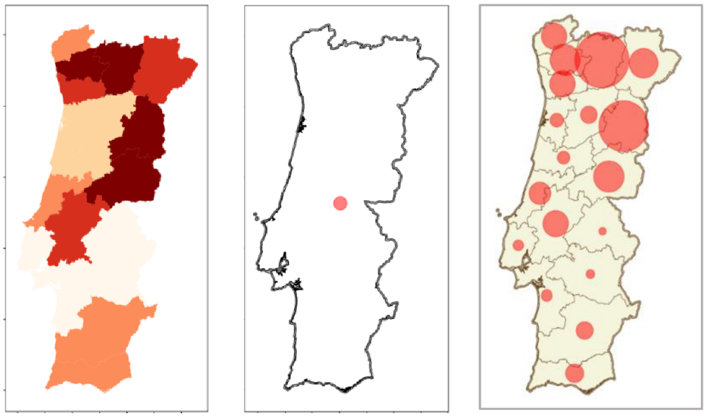


Figure 13 Possibility of graduated symbols outputs given by ChatGPT-4

- **Legend**

To match the symbol sizes in the legend, the prompts describe all requirements for the value intervals and scaling factors to ensure they visually correspond to the sizes represented on the map. However, several aspects need to be refined throughout the process such as the legend labels, classification method, overlapping issue and shapes.

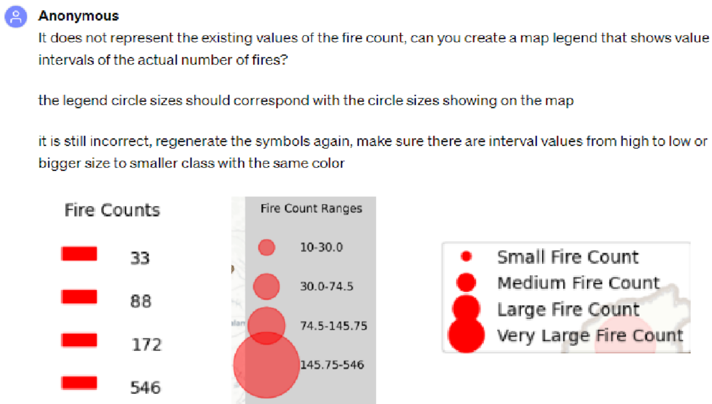


Figure 14 Prompts for creating a legend and results

2. **Interactive map**

- **Map field**

The possibility of the outputs from AI when creating the graduated symbols can be varied. The number of fires can be aggregated to a group by 'Marker Cluster' function in Folium leading to an incorrect result. To solve this problem, using the term 'bubble map' in a prompt can be helpful as explained in the Graduated symbols map for static map. Moreover, the symbols can be proportional in size instead of classified groups, so the command needs to provide the range and interval width directly (Figure 15). Then the code can calculate interval values and distinct circle sizes to match these specific intervals.

Anonymous
Reclassify the data to have only 4 different sizes by Equal interval

Anonymous
Create a graduated symbol map of counting fire spots in each district in Portugal using Folium

Anonymous
Change the intervals to the following values; first class;10-33, second class;34-88, third class; 89-172, fourth class; 173-546

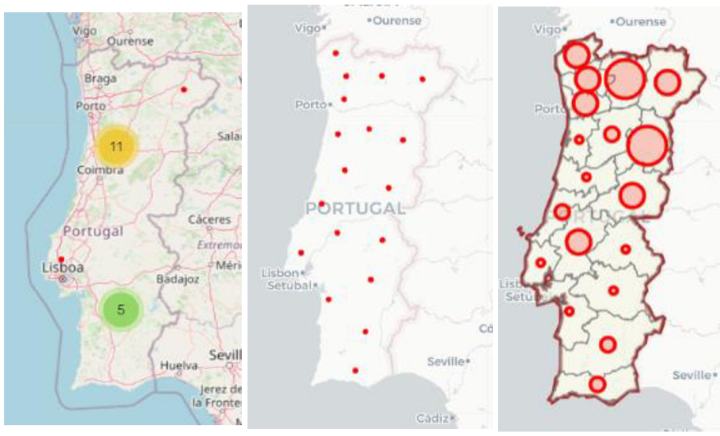


Figure 15 Refined prompts and outputs of interactive graduated-symbols map

- **Legend**

Adding a legend to a Folium map can be complicated because Folium does not have built-in support for legends with custom symbols as a choropleth map. The AI provides the solution by adding a custom legend using HTML to create circle symbols that reflect the sizes on the map. The basic prompt requires several refined prompts to solve the issue where the legend might not have displayed as expected, the prompt needs to specify the radius, color, opacity and size parameters in the HTML legend more closely to match those of the circles.

Anonymous
It failed, can you increase the legend sizes of all 4 classes to be the same as the map?

```
# Define the intervals and corresponding circle sizes for fire data again for clarity
intervals = [
    (10, 33, 5),   # First class
    (34, 88, 10),  # Second class
    (89, 172, 20), # Third class
    (173, 546, 40) # Fourth class, increased size
]

# Step 3: Create a map centered around Portugal with zoom level 7
map_center = [39.557191, -7.8536599]  # Approximate center of Portugal
m = folium.Map(location=map_center, zoom_start=7)

# Steps for adding layers (omitted for brevity)

# Adding a custom legend with adjusted SVG circle sizes to match the map
legend_html = '''
<div style="position: fixed;
bottom: 50px; left: 50px; width: 250px; height: 200px;
border:2px solid grey; z-index:9999; font-size:14px; background-color: white;
padding: 10px;">
  Fire Counts Legend <br>
  10-33   <svg height="20" width="20"><circle cx="10" cy="10" r="5" fill="r
  34-88   <svg height="30" width="30"><circle cx="15" cy="15" r="10" fill="
  89-172   <svg height="50" width="50"><circle cx="25" cy="25" r="20" fill=
  173-546   <svg height="90" width="90"><circle cx="45" cy="45" r="40" fill
</div>
'''
m.get_root().html.add_child(folium.Element(legend_html))
```

Figure 16 Prompt used and code output of graduated symbols legend

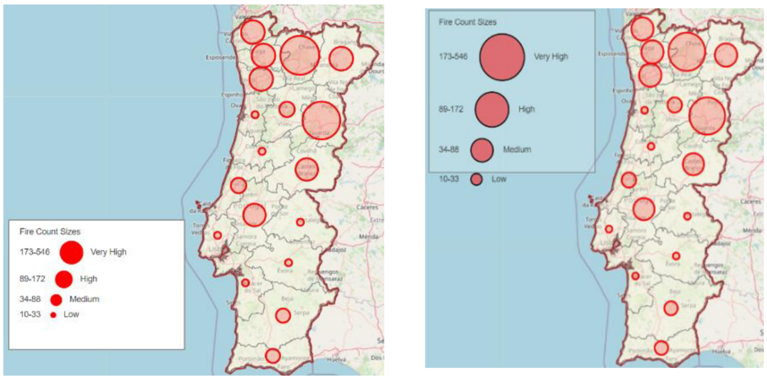


Figure 17 Improper legend sizes and colors

4.1.3 Case Study 3: Dot density map from basic prompt

The dot density map aims to visualize the fire spot distribution across Portugal using the active fire spots from FIRMS NASA. The AI's capability can be evaluated on how well it can visualize random dots to show spatial density.

1. **Static map**
   - **Map field**

Geopandas does not have a built-in function for plotting dot density maps. Using a straightforward prompt indicating only the term *'dot density'*, the LLM can return irrelevant methods such as choropleth or only map layers. To solve this problem, it is necessary to describe entire process of how the dot density is created. As indicated in Figure 18, the prompt explains how to plot the random points from the fire spot's attribute. These concise and detailed explanations can reduce the number of prompts in this thematic map.

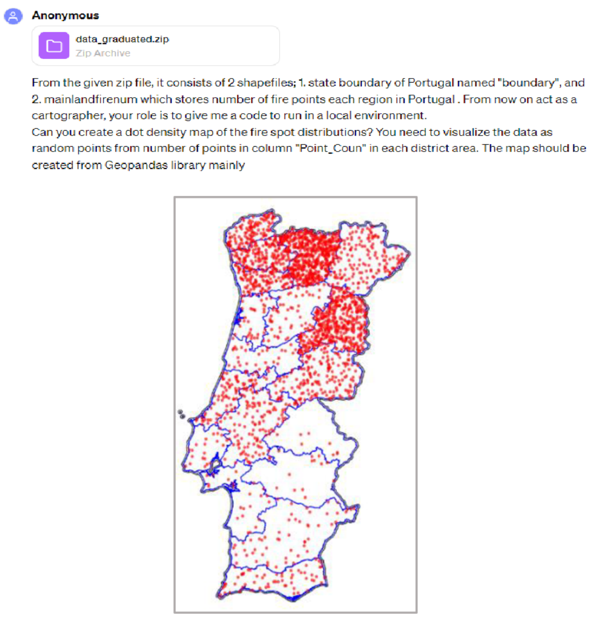


Figure 18 Prompt used and dot density map result

In addition, ChatGPT-4 can adjust the cluster pattern so that the dots are not too dense. The prompt can be specified as *'Represent values per dot unit'*, then the AI generates a 'random_points' function in which the number of dots is divided by the scale factor. The result is the correct map where each dot represents five fire points, giving a clearer visualization of fire distribution intensity across the districts of Portugal.

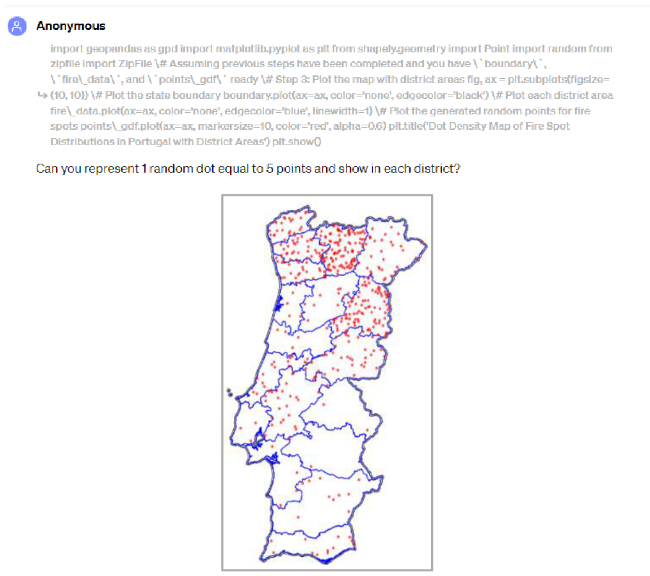


Figure 19 Prompt used and map representing five fire spots per one dot symbol

- **Legend**

In the basic prompt, to ensure the custom legend matches the size used in the plot, 'markersize' parameter in Matplotlib needs to be adjusted step by step. The legend with the actual size as the map symbol can be generated either by emphasizing in the prompt that the marker size on the map should be the same as the legend or by providing the absolute number in the parameter.

```
# Adjusting the legend marker size to be slightly smaller for accurate visual represe
legend_handle = [mlines.Line2D([], [], color='red', marker='o', linestyle='None',
                                 markersize=7, label='5 Fire spots = 1 dot')]  # Reduce
ax.legend(handles=legend_handle, loc='upper left')
```

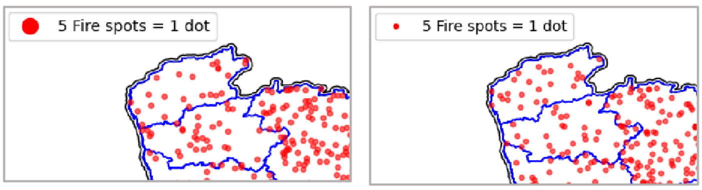


Figure 20 refined code and adjusted legend dot sizes

2. Interactive map

- **Map field**

The folium library does not have a specific functionality for creating dot density maps. The common issue is that the LLM returns the result as a Heatmap or Marker cluster. To create an interactive dot density map, the prompt is the same as the static version since Folium integrates seamlessly with Python. Therefore, the function of generating random points of the polygon's attribute can be used on the interactive map.

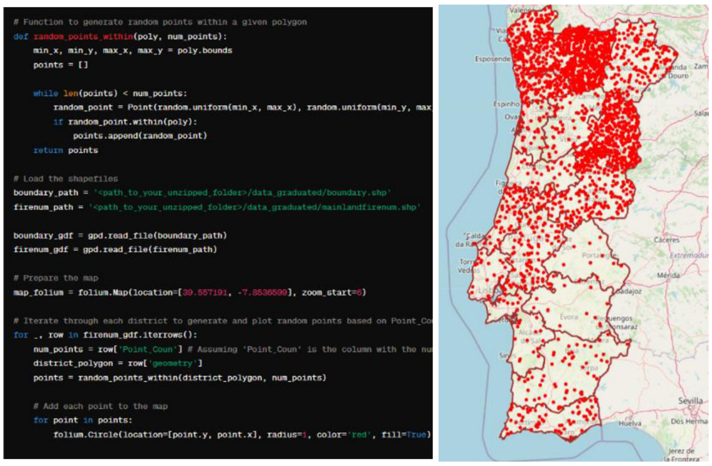


Figure 21 Correct code snippet and dot density map

- **Legend**

When ChatGPT-4 creates the dot size in the legend, it adjusts the HTML to mimic the appearance of the map symbol. However, it requires several attempts because AI generates a dot object independently from a dot on the map. This leads to issues of different color, opacity, and size which can be fixed by specifying exact values in the prompt.

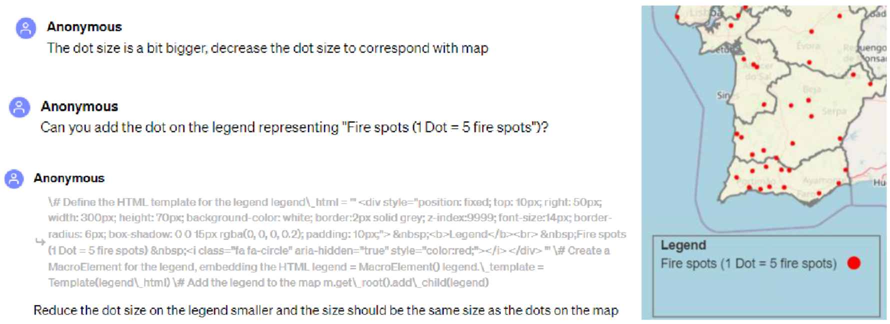


Figure 22 Refined prompts and improper dot sizes

4.2 Advanced Prompt Pattern

The advanced prompt aims to develop the quality of the map outputs. According to White (2023), the effectiveness of the responses produced by a conversational LLM depends on the quality of the prompts. The interactions between a user and LLM can be developed to enhance its ability to solve a range of issues effectively. This study applies Cognitive verifier and Question refinement to enhance the quality of the output and details which aims to reduce the user's effort in creating a map. The Cognitive verifier can provide sub-questions related to the user's command. Thereafter, the LLM is capable to combine user's answers and process them into the final outputs.

Another prompt is Question refinement which is used for refining map details such as color, placement, and text, including generating map compositions. The advanced capabilities enable them to provide refined prompts beyond simple text. The initial prompt assigns contextual statements to the advanced prompts, it is a way to describe how a user and an LLM will communicate in a prompt. For the Cognitive verifier, the LLM is asked to generate three additional questions and when it receives the answers, it needs to combine them to produce a map. The contextual refinement of the Question refinement pattern is described in a prompt whenever it is asked to adjust a map, it should suggest a better version of the prompt based on an original prompt.

Contextual statement: When I ask you a question, generate three additional questions that would help you give a more accurate answer. And when I have answered the three questions, combine the answers to produce the final answers to my original question.

Instructions: From the given zip file, consists of 2 shapefiles; 1. the state boundary of Portugal named "boundary", and 2. the average burned area from 2002–2022shapefile each region in Portugal.

Role: Act as a cartographer, your role is to give me a code to run in a local environment.

Task: Can you create a choropleth map of Average burned areas in each region, 2002–2022? The map should be created from Geopandas library mainly. Ask me three additional questions.

Figure 23 Cognitive verifier prompt structure

Contextual statement: From now on, whenever I tell you to do a task about adjusting the map, suggest a better version to use that incorporates information specific to map creation.

Instructions: From the given zip file, consists of 2 shapefiles; 1. the state boundary of Portugal named "boundary", and 2. the average burned area from 2002–2022shapefile each region in Portugal.

Role: Act as a cartographer, your role is to give me a code to run in a local environment.

Task: Can you create a choropleth map of Average burned areas in each region, 2002–2022? The map should be created from Geopandas library mainly. Suggest me a better version of prompt.

Figure 24 Question refinement prompt structure

4.2.1 Case Study 1: Choropleth map from advanced prompt

1. **Static map**

- **Map field**

Using Cognitive verifier pattern can provide a comprehensive output when asked to create a choropleth map. The AI provides useful questions related to specific attributes or desired color schemes which allows it to create a map properly from the specification. In this case study, the burned area attribute and warm color scheme are specified at once.

Compared to the basic prompt pattern, the AI could generate the map using a random column or colors, so it may need to be refined repeatedly and require more attempts. Besides the map field, this pattern could suggest additional map elements such as labels and legend as shown in Figure 25.

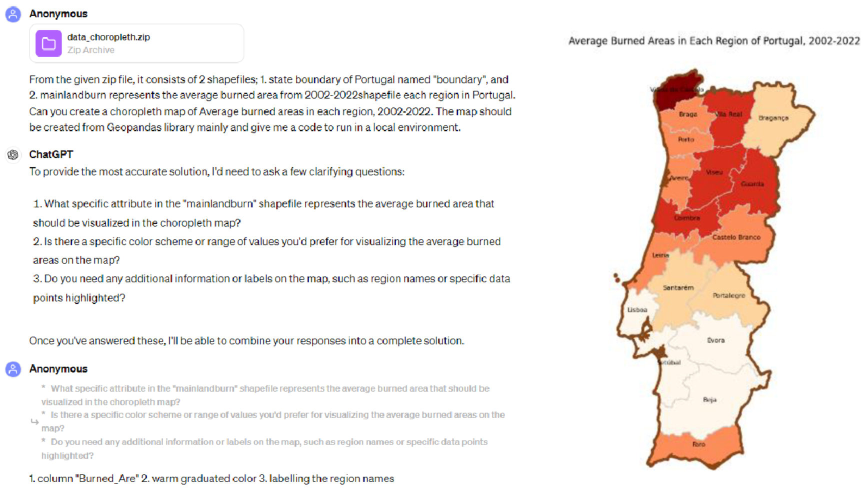


Figure 25 Additional questions and answers for creating choropleth maps

- **Legend**

The default legend labels often duplicate the lower value with the upper value of the next class. To avoid duplicating intervals of adjacent classes, the answers given to the AI can be *'edit the legend of the lower values to be unique from the upper values of the next class'*. Then the AI could subtract a value (0.01) from the upper boundary of each class, except for the last one. Additionally, Cognitive verifier can provide relevant questions about decimal numbers, legend position, legend colors and legend title within a single prompt.

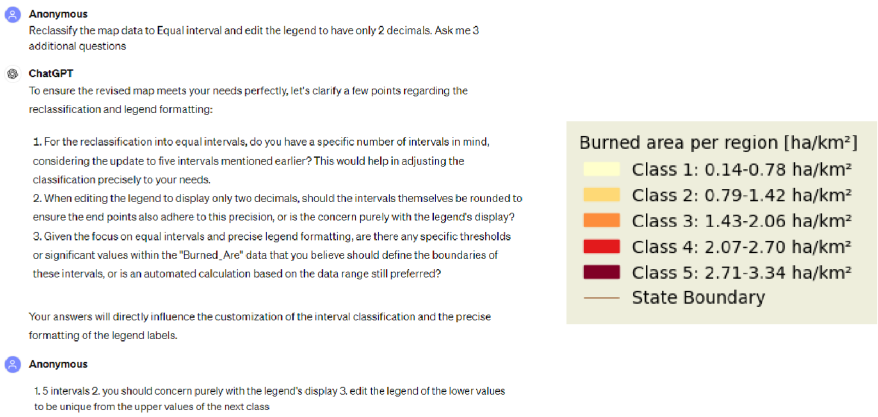


Figure 26 Cognitive verifier prompt for creating the choropleth map's legend

2. Interactive map

- **Map field**

When creating a choropleth map, AI does not only generate a map field that represents the average burned area but also offers additional map features. The AI overlays the state boundaries from the 'Boundary' shapefile and includes tooltips displaying region names and fire attribute when hovered over each region. ChatGPT-4 utilizes a warm color scheme as prompt required. Then the map represents the burned areas, which is visually intuitive showing intensity.

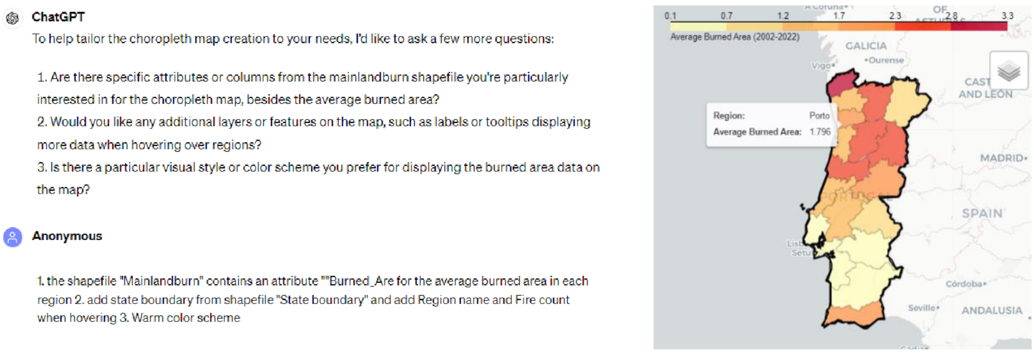
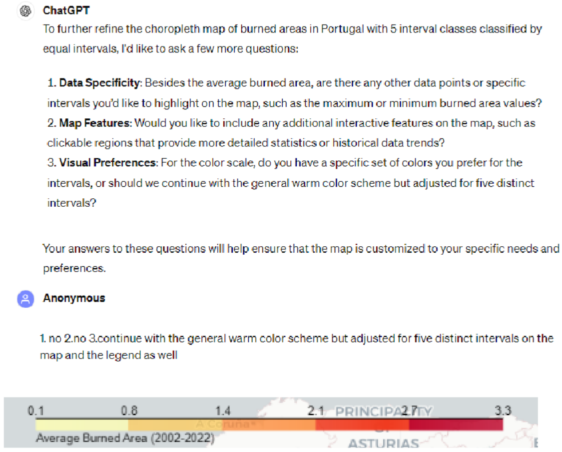


Figure 27 Cognitive verifier prompt for creating an interactive choropleth map

- **Legend**

Folium's built-in function provides legends along with maps. The legend will automatically adjust to match the map colors and classes. From the three answers given to the LLM in Figure 28, ChatGPT-4 can return the five intervals based on the map classification with a warm color scheme accurately as required.



ChatGPT
To further refine the choropleth map of burned areas in Portugal with 5 interval classes classified by equal intervals, I'd like to ask a few more questions:

1. **Data Specificity**: Besides the average burned area, are there any other data points or specific intervals you'd like to highlight on the map, such as the maximum or minimum burned area values?
2. **Map Features**: Would you like to include any additional interactive features on the map, such as clickable regions that provide more detailed statistics or historical data trends?
3. **Visual Preferences**: For the color scale, do you have a specific set of colors you prefer for the intervals, or should we continue with the general warm color scheme but adjusted for five distinct intervals?

Your answers to these questions will help ensure that the map is customized to your specific needs and preferences.

Anonymous

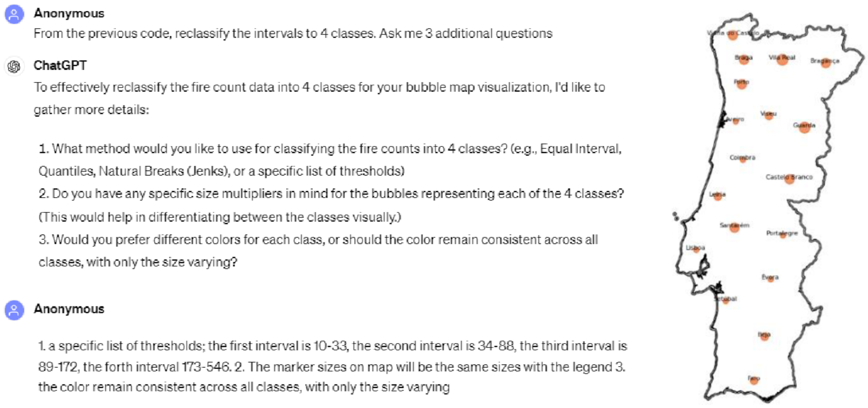
1. no 2.no 3.continue with the general warm color scheme but adjusted for five distinct intervals on the map and the legend as well

Figure 28 Cognitive verifier prompt and proper discrete legend result

4.2.2 Case Study 1: Graduated symbols map from advanced prompt

1. **Static map**
   - **Map field**

When generating the graduated symbols map by the Cognitive verifier pattern, the answers need to be clear and detailed in both classification method and circle sizes. Common issues with this thematic map method are undistinguishable symbol sizes and incorrect data classification. The answers in this case indicate the specific sizes and thresholds for each interval. However, this advanced prompt pattern could give the symbols that the magnitudes are difficult to differentiate across the area. Then, Question refinement can be used to refine and adapt the original prompt to achieve the desired outputs.



Anonymous
From the previous code, reclassify the intervals to 4 classes. Ask me 3 additional questions

ChatGPT
To effectively reclassify the fire count data into 4 classes for your bubble map visualization, I'd like to gather more details:

1. What method would you like to use for classifying the fire counts into 4 classes? (e.g., Equal Interval, Quantiles, Natural Breaks (Jenks), or a specific list of thresholds)
2. Do you have any specific size multipliers in mind for the bubbles representing each of the 4 classes? (This would help in differentiating between the classes visually.)
3. Would you prefer different colors for each class, or should the color remain consistent across all classes, with only the size varying?

Anonymous

1. a specific list of thresholds; the first interval is 10-33, the second interval is 34-88, the third interval is 89-172, the forth interval 173-546. 2. The marker sizes on map will be the same sizes with the legend 3. the color remain consistent across all classes, with only the size varying

Figure 29 Cognitive verifier prompt and undistinguishable symbol sizes

- **Legend**

For customizing the legend to accurately reflect the map symbols, all aspects need to be specified to the answers such as threshold, sizes, legend labels, placement and color. Even though the legend size is generated consistently with the map symbol, it is possible that several aspects still need to be adjusted. In Figure 30, the legend color is more opaque than the map symbols and the label spaces need to be increased to avoid overlapping. Therefore, sub-questions from the advanced prompt in this thematic method do not often generate the completed results according to the requirements at the first attempt.

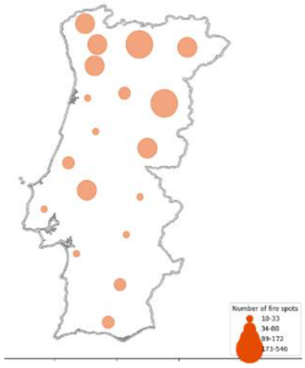


Figure 30 Inappropriate legend color and placement

2. Interactive map

- **Map field**

The graduated symbols map required several refined prompts because the AI often misunderstands this thematic map method as mentioned in the Graduated symbols map from the basic prompt. In several cases, the AI simulates a small dataset for demonstration instead of using the given data. To solve the issue, it is necessary to determine the symbol sizes and use the existing data. In the experiment, the common sub-questions ask about specific radius values for each circle size, color and classification details which allow a user to provide the expected result to the AI.

For example, the specific range for the first interval is 10–33, the second interval is 34–88, the third interval is 89–172, and the fourth is interval 173–546. Additionally, pixel radius should correspond to previous intervals, which are 6000, 12000, 18000, and 30000 respectively. Additionally, when the AI asks about the symbol sizes, answers can be mentioned in mathematical methods such as linear and logarithmic scaling methods.

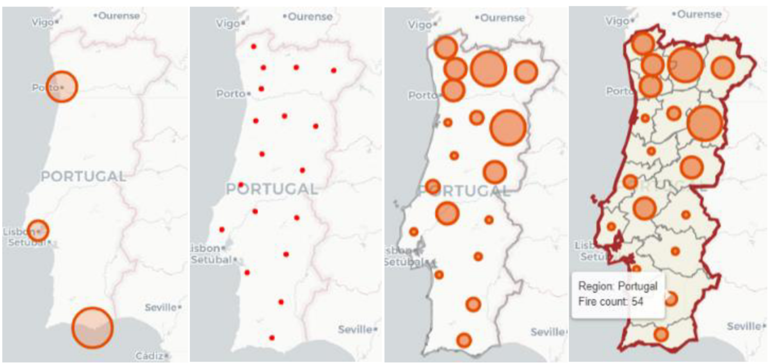


Figure 31 The development of graduated symbol maps refined by advanced prompts

- **Legend**

Legend elements such as legend labels and circle objects in the interactive version are customized by HTML independently. For some attempts, CgatGPT-4 cannot achieve all requirements by using only Cognitive verifier pattern, so Question refinement pattern is applied to customize map details. For example, the Question refinement can suggest a better prompt when the legend labels do not appear. In Figure 32, the suggested a version emphasizes the predefined intervals that need to be added to the legend box and ensures the clarity of the texts. Then the modified HTML template included the text elements positioned alongside the circles.

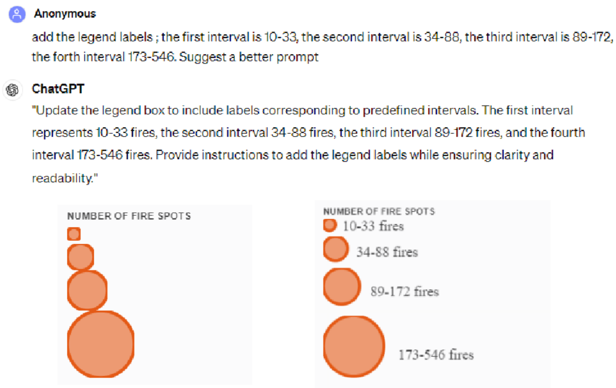


Figure 32 Question refinement prompt and the legend outputs

4.2.3 Case Study 1: Dot density map from advanced prompt

1. **Static map**

- **Map field**

The dot density map normally does not use prompts as many as the other maps. Generally, Cognitive verifier prompt offers additional map layers such as state boundary and labels in one response, this reduces the time consumed in producing the map. In Figure 33, red dots, state boundary and labels are added on the map as indicated in the answers, but the AI could not fill the main land color in this attempt. Therefore, this feature will be processed in one more attempt.

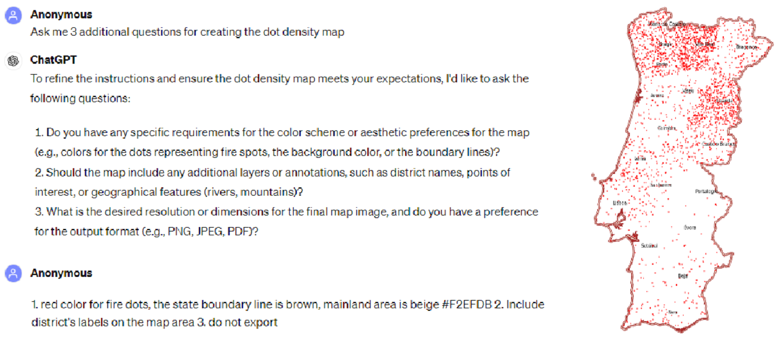


Figure 33 Cognitive verifier prompt and dot density map output

- **Legend**

Generally, the dot size in the legend does not correspond to the map. In this case, Question refinement clarifies the context and requirements for the AI. The original prompt requires only matching the legend and map symbol size, the suggested version potentially asks the AI to provide additional guidance and recommend an approach for better matching the marker size.

2. Interactive map

- **Map field**

Creating the interactive maps mainly uses the same prompts as the static version. However, additional questions given by the Cognitive verifier pattern sometimes did not generate a question about symbol color, leading to a misleading result. In Figure 34, the dot colors are varied instead of using a unique color throughout the map because this fire spot data represent only one phenomenon.

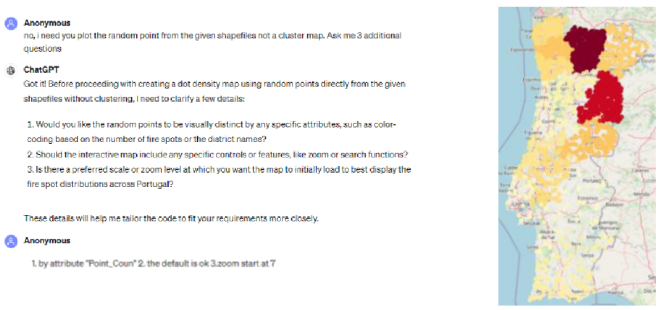


Figure 34 Cognitive verifier prompt and the result of inappropriate color

- **Legend**

As explained in the interactive graduated symbols map, the legend size might not be successfully created by the Cognitive verifier, then the Question refinement will be applied for a specific detail in the visual presentation. For example (Figure 35), the black outline was added to the legend from the Cognitive verifier pattern, then it was customized to red to match the map symbol using the Question refinement pattern. The refined prompt addresses the code adjustment directly that SVG color will be customized in HTML.

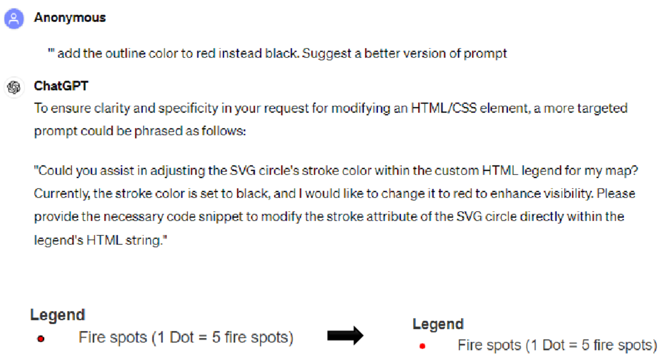


Figure 35 Question refinement prompt and the refined legend output

4.3 Map compositions

Besides a legend and map field, other map compositions are also generated along with the maps by similar prompts in both basic and advanced prompt patterns.

1. **Title and subtitle**

The default titles given by the AI do not indicate thematic content of where and when a phenomenon happened. The AI usually duplicates the text from a prompt directly or generates a title based on the file's name, so it is not suitable. To solve the issue, a prompt can assign the text title explicitly. The main title is styled in black bold font to stand out as the primary focus. A subtitle is added below the main title, with a smaller font size ensuring it is less dominant.

However, the subtitle always overlaps with the main title in a static version. An exact spacing parameter must be specified between a title and subtitle to prevent overlapping. For an interactive map, there are no overlapping issues between the title and subtitle because Folium typically adds them through a custom HTML script with style attributes for positioning.

Figure 36 Title and subtitle of a static map (left) and an interactive map (right)

2. **Scale bar**

Creating a scale bar for a static map needs to consider the following aspects;

- **Scale Bar Placement:** the scale bar could be placed in an inappropriate location that overlaps with the other elements. Common options are the lower right corner, lower left corner, and upper left that does not obscure important map details.
- **Scale Bar Unit of Measurement:** the scale bar utilizes 'Matplotlib-scalebar' which provides metric unit options (e.g., kilometers, miles, etc.). The prompt also includes the 'Scale Bar Length' which calculates the length of the scale bar in pixels to represent the unit in km accurately.
- **Scale Bar Style:** to make the scale bar less dominant than the map field, the prompt can customize the scale bar color for both numeric text and bar.

The scale bar for the interactive map can be added to the map using the built-in 'Scale control' in Folium. This control automatically adds a scale bar to the map, showing distances in both kilometers and miles, which is dynamically adjusted according to zoom levels.

Figure 37 scale bar of a static map (left) and an interactive map (right)

3. Labels

Anonymous
Add district labels on the map using the column "indicators".

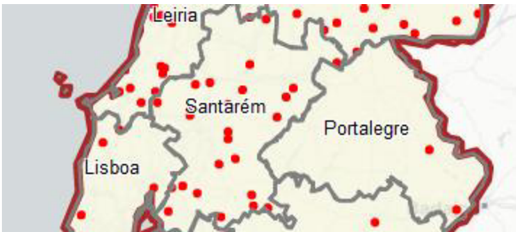


Figure 38 Labels of region's name

To add labels with a thin white stroke, 'folium.Marker' function places labels at the centroids of each region. Then, the text stroke is customized by HTML script. This technique might produce a thick stroke that obscures the text, so prompt refinement is required for further improvements.

For a static map, 'PathEffects' function from Matplotlib is applied halo effects on the labels. The prompt includes the column of the region names. Then the script iterates over each row and extracts the centroid coordinates of each geometry.

4. Credits

Author: Parinda Pannoon
Date: 17/03/2024
Spatial Reference: EPSG:3857
Data source: FIRMS NASA, Global Wildfire Information System (GWIS)

Author: Parinda Pannoon
Date: 04/04/2024
Spatial Reference: EPSG:3857
Data source: FIRMS NASA and Global Wildfire Information System (GWIS)

Figure 39 Credits of a static map (left) and an interactive map (right)

To add a proper credit that includes data source, author's name, and date when the map was created, the information is assigned directly in a prompt to generate a text string. The prompt also indicates that the credits should not overlap other elements and ensure it is less dominant in size and color. In general, the credits maintain small font and spaces between lines properly.

For an interactive version, the prompt identifies the hyperlinks of the data sources and embeds them in the credits. The links allow users to interact and explore for more information of GWIS and FIRMS NASA. Moreover, Cognitive verifier prompt pattern potentially offers additional details about the credits such as tooltips, hover effects, text alignment, and font size.

5. Basemaps

The AI provides several basemap providers, the common sources include OpenStreetMap, Stamen Terrain, CartoDB and Esri imagery. However, the AI is not able to visualize some base maps because of provider limitations. In this research, CartoDB visualizes as a map background (Figure 40) because the low saturation color allows the map content to be effectively emphasized.

Using Cognitive verifier prompt could reduce the number of errors since it provides additional questions to ensure map projection handling. Basemaps typically use the Web Mercator projection (EPSG:3857), the data are reprojected to align with the tiles effectively. For a static map, 'contextily' library adds tiles as the basemap background. Built-in Folium supports custom tilesets that can be added to the map with the parameter 'tiles'.

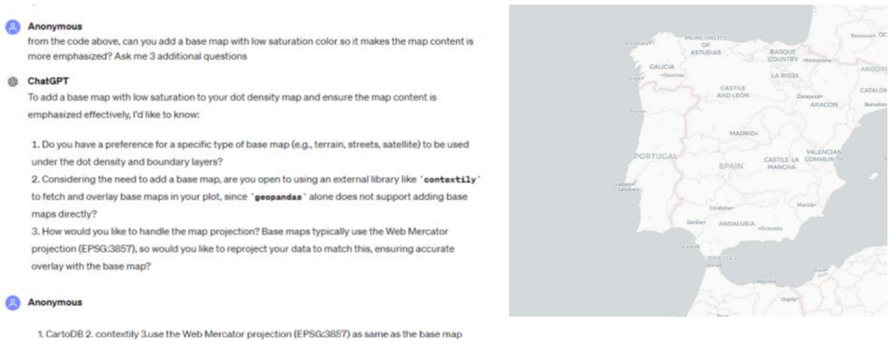


Figure 40 Cognitive verifier prompt for creating CartoDB base map

6. Data visualization

There are three types of data visualizations in this study which are bar chart, stacked bar chart and bar-line chart. This aims to evaluate the AI's capability in creating data visualization in a map layout. The charts are generated based on the prepared dataset in CSV format. The static version is created by Matplotlib and Plotly library for an interactive version. The prompt specifies requirements of dimension, axis labels, title and color preferences that intend to improve understanding for readers and enhance the visual appeal.

For a static map, the charts given by AI often overlap with other map compositions and obscure a map field. The chart layout can be adjusted by 'Gridspec' settings of a subplot which requires exact dimensions in a prompt. This leads to charts being unsuccessfully generated by the AI in some sessions.

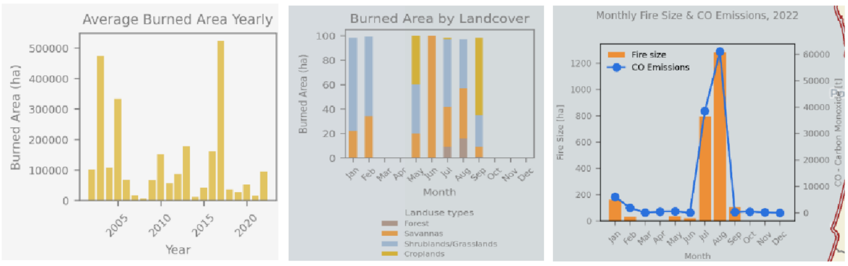


Figure 41 Data visualizations on choropleth (left), graduated symbols (middle), and dot density maps (right) respectively

The interactive charts are created using Plotly and converted to HTML. Custom HTML elements are embedded into 'IFrame' and added to the map's root HTML. The interactive charts provide attractive widgets such as popups, zoom and capture buttons. The common issue is that a chart usually does not appear on a map because of a wrong plotting method in the code. A basic prompt can be useful when it is concise and does not contain complicated requirements in one attempt so the chart can be updated step by step. An advanced prompt can be used for customizing several small details at once such as color, title, position, width, height, and background transparency.

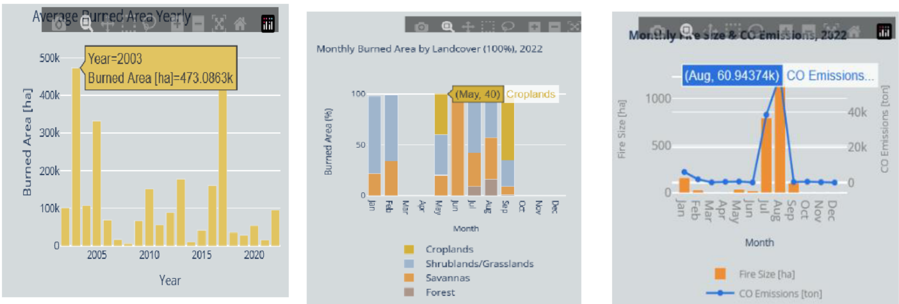


Figure 42 Data visualizations on interactive choropleth (left), graduated symbols (middle), and dot density maps (right) respectively

7. Tooltips and Layer Control

Tooltips and Layer control are additional map elements for the interactive version. The 'folium.GeoJsonTooltip' function displays more informative details, combining region names with fire information (Figure 27). Additionally, map effects can be added along with the tooltips when the mouse hovers over each region.

State boundary and Mainland area are added in the layer control widget, which uses Folium's 'LayerControl' function. This involves creating GeoJson objects as the layer's name and adding a layer control for toggling these layers on and off. These interactive widgets do not require complex requirements in a prompt. Among five iterations, ChatGPT-4 often returns desired results with few attempts.

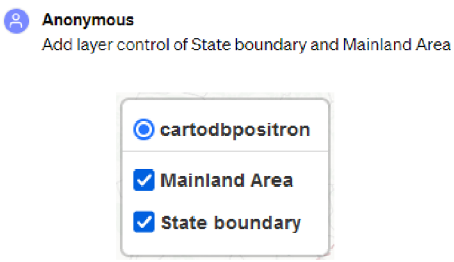


Figure 43 A prompt for creating Layer control

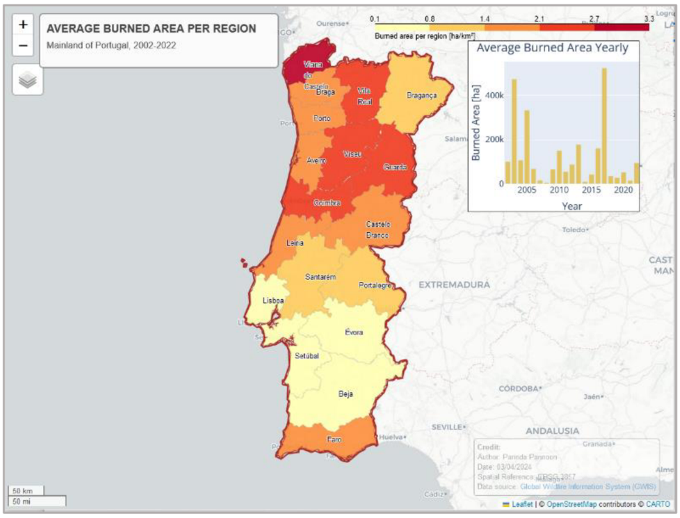


Figure 44 Interactive choropleth map

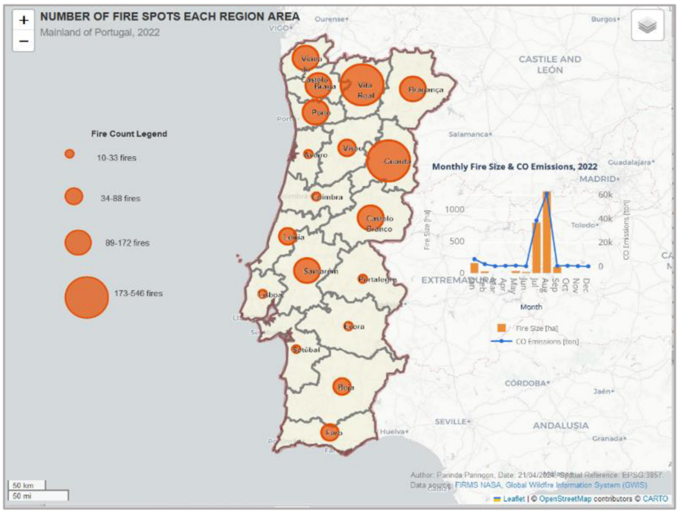


Figure 45 Interactive graduated symbols map

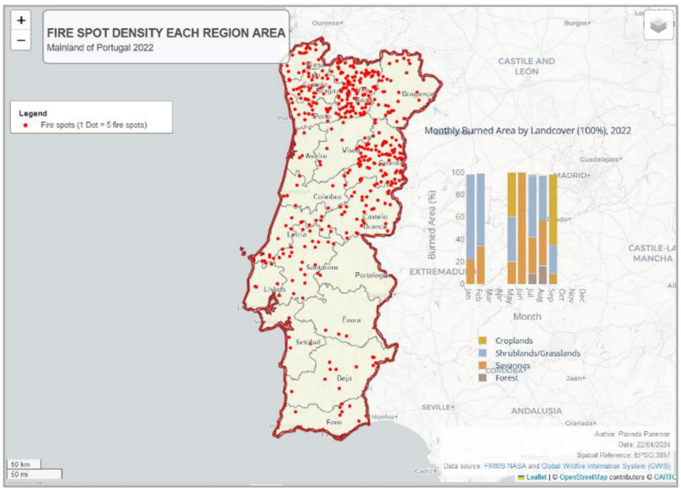


Figure 46 Interactive dot density map

5 MAP QUALITY ASSESSMENT

This chapter aims to answer the research question of how well the quality of AI-generated maps when compared to human-generated maps. Since the AI-generated map has several limitations, this evaluation can measure whether the ability of ChatGPT-4 achieves correct cartographic principles as the traditional method. The human-generated maps are conducted by using ArcGIS Pro software. To assess the map quality, this stage considers two main factors. The first one is setting map references based on principles of cartography. The second factor is considering the map readability which consists of size, color, lettering, and interpretation.

According to Vansteenvoort and Maeyer (n.d.), a predefined set of cartographic principles that apply to a particular map is called a map specification. Setting map references from predefined specifications guarantees map quality. Each map composition in both AI-generated and human-generated maps is created based on the same specifications according cartographic rules. Such a method helps identify the strengths and weaknesses of a map. The more map composition complies with cartographic rules, the better quality and communication efficiency will be.

Map readability focuses on the ease of reading and interpreting a map. The first issue of the AI-generated map is a placement, the AI does not concern the overlapping with the other map elements, leading to illegible and less aesthetic appeal. Moreover, some outputs cannot be completed properly in terms of symbol sizes, color and typography. In the typographical hierarchy, a subtitle was generated with the same characteristics as the main title which is not supposed to attract so much attention, so a prompt needed to be customized to meet the specification.

Additionally, legend sizes also do not correspond with map symbols, leading to misleading interpretations. The map quality is divided into three levels of suitability which are the most suitable, intermediate, and least suitable based on how much the maps meet cartographic and readability criteria. The map criteria have been set according to cartographic designs and rules in the publication of Field (2018).

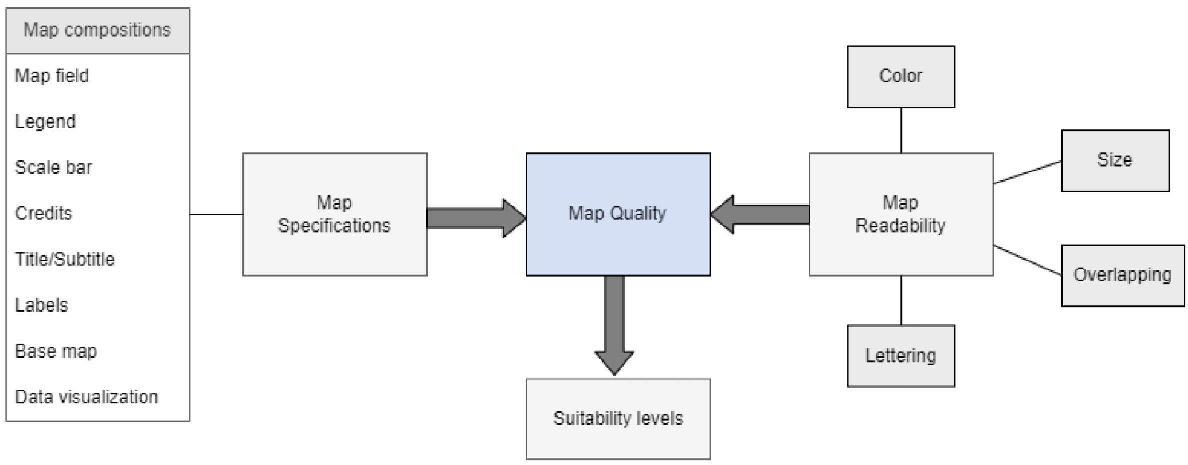


Figure 47 Factors for assessing map quality

5.1. Choropleth map

Evaluating a choropleth map for cartographic suitability involves several key considerations. The suitability levels were set according to the thematic method, data classification, sequential colors with a clear presentation from low to high, legend colors and description.

The most important characteristic of the choropleth map is that the burned area data is normalized and organized into discrete classes with a sequential color scheme. Creating a legend in ChatGPT-4 requires users to specify a legend color and description that corresponds to the map because ChatGPT-4 is likely to give results inconsistently. For example, the legend represents a continuous legend, or legend labels describe the severity of the burned areas instead of showing the numeric data. The following table shows three suitability criteria for the choropleth map.

Table 1 Suitability criteria for evaluating choropleth map

Map compositions	**Suitability levels**		
	Least suitable	Intermediate	Most suitable
1. legend	- Not representing burned area values in each class. -Use a legend as a continuous bar. -Colors do not correspond on the map.	-Represent ranges of the value in each class. -Discrete legend from high to low, with graduated colors. -Colors do not correspond on the map, the tones are slightly different but still be able to understand the data. - Upper and lower values of each class are duplicated.	-Represent ranges of the value in each class. -Colors correspond with the color on the map. -The number of classes is the same as the map -The data intervals are classified properly according to statistical methods.
2. map field	-Not using a sequential scheme on areas. -Not using a warm color scheme. -Data is organized into more than 7 or less than 4 classes. -Colors do not associate with the actual data. -The colors on the map do not correspond to the legend.	-Use a sequential scheme on areas. -Single data value is represented by each area as a ratio. -Use a warm color scheme -Data is organized into more than 7 or less than 4 classes. But -The colors on the map are slightly different from the legend.	-Use graduated-color: sequential scheme on areas. -The data value is ratios(normalized) represented by each area. -Use a warm color scheme -The color symbols support the reader in making comparisons between high and low. -Data is organized into more than 7 or less than 4 classes. -The colors on the map correspond to the legend.

5.2 Graduated Symbols map

For a graduated symbols map, the most suitable characteristics are the symbols representing graduated sizes from small to big and the proportional data values. The data use absolute values of the number of fire spots and allows users to determine magnitudes across the map intuitively. For a legend, both color and size on the map must be consistent with the legend and the legend must clearly explain the scaling. The following table shows three suitability criteria for the graduated symbols map.

Table 2 Suitability criteria for evaluation of graduated symbols map

Map compositions	**Suitability levels**		
	Least suitable	Intermediate	Most suitable
1. legend	-Not representing values in each class, and labeled as “min”, “medium”, “max” instead of numeric values. -Show other symbols in which different from the map symbol. -Color or size does not correspond to the map -The values in each class cannot be shown as actual data on the map.	-Represent ranges of the value in each class. -Ranging values from high to low or bigger size to smaller class with the same color. -The number of classes is the same as the map. - Each class of the legend should have the same size as the symbol on the map BUT -The color, opacity or size is a bit different from the map. - Upper and lower values of each class are duplicated.	-Represented each class interval enabling readers to understand the different magnitudes. -Color corresponds with the map. - Each legend class should have the same size as the map symbols. -The number of classes is the same as the map. -The data intervals are classified properly according to statistical methods. -Ranging values from high to low or bigger size to smaller class with the same color.
2. map field	-Use various color schemes in the symbol. -Represent other thematic methods (e.g. proportional map) -Data is organized into more than 7 or less than 4 classes.	-Use graduated symbols placed in each area. - Each area represents an absolute data value. -Data is organized between 4–7 classes. But -Most of the symbols overlap with others. -Symbols are difficult to distinguish the magnitudes. -The color or size on the map is slightly different from the legend.	-Use graduated symbols placed on each area. - Each area represents an absolute data value. -Symbol sizes designed for the magnitudes that are easily distinguished. -The relative difference allows users to determine a pattern across the map. -The minimum class is not too small and the maximum class is not too large. -The color or size on the map corresponds to the legend.

5.3 Dot Density map

The suitability of this thematic map method considers the distribution pattern. The map is necessary to show the dot clusters well, not too sparse which allows users to easily discern spatial patterns. When the dot is too clustered, the AI should be able to represent multiple dots in one dot. The dot size and color correspond with the real size in the legend. The following table shows three suitability criteria for the dot density map.

Table 3 Suitability criteria for evaluating dot density map

Map compositions	**Suitability levels**		
	Least suitable	Intermediate	Most suitable
1. legend	-Not representing values of dot per unit. -Representing other symbols in which different from the map symbols. -Color/size do not correspond to the map	- Represent values per dot unit. BUT -The color, opacity or size is a bit different from the map.	-Represent values per dot unit -Dot size or color correspond with the map.
2. map field	-Use various color schemes in the dot symbol. -Represent other thematic methods (e.g. heatmap, aggregated symbol) -Use various sizes of the dots	-Quantitative value is represented per dot unit -Can be able to gauge the relative difference between area densities across the map -The dot size is legible but slightly large and covers most of the areas.	-Symbols represent the number of points per 1 dot. -Can be able to gauge the relative difference between area densities across the map. -The dot is legible, not too small or sparse, showing the dot clusters well that it is easy to discern spatial patterns in the data. -The dot size or color corresponds with the real size in the legend.

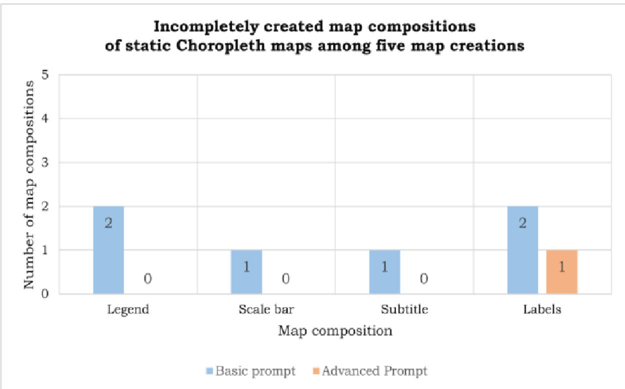
The rest of the map compositions can be found in Attachment 1. Additionally, other aspects involved in map production such as time consumption, basic knowledge, creative style, software subscription and technical limitations will be discussed in Chapter 7.

6 RESULTS

This section summarizes the results of the two stages and answers all the research questions. In the first part, as performed in Chapter 4, the functional capability, learning ability and prompt patterns are assessed from the AI-generated outputs. The map suitability levels as set in Chapter 5, are also evaluated to compare the traditional method. All the code snippets and maps can be accessed through Attachments 5 and 6 respectively.

6.1 Completeness of AI-generated maps

The map compositions created in Chapter 4 will be evaluated to see how many map elements were created successfully. The results aim to answer the research question of how well AI-generated maps can achieve cartographic aspects by formulating prompts.



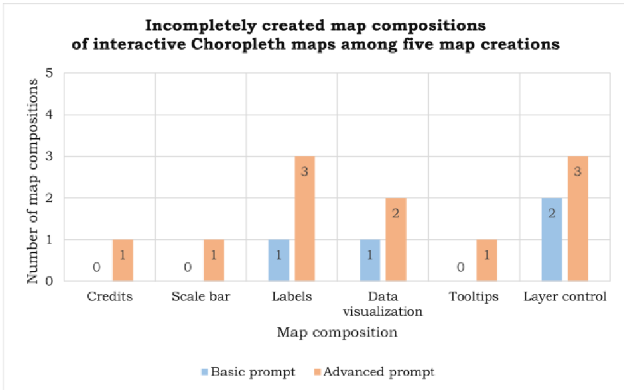


Figure 48 The number of map compositions of static (left) and interactive (right) choropleth maps that were unsuccessfully created among five iterations.

The map fields of choropleth maps are created successfully in both static and interactive versions. There are two legends of the static maps that are not consistent with the map colors. Scale bar, subtitle and labels of the static maps are also unsuccessfully created by the AI. Comparing the number of static map compositions that cannot be achieved to the interactive version, six elements failed for interactive maps which are credits, scale bar, labels, data visualization, tooltips and layer control. Most of them are from advanced prompts.

Using the advanced prompt patterns for creating static choropleth maps can achieve more elements than interactive maps. The common issue is map labels, there are three of five map labels that cannot be completed by using advanced prompts on the interactive maps. The static version has only one label that is unsuccessfully achieved. Conversely, using the basic prompt for creating static maps gives more incomplete outputs than the advanced prompt.

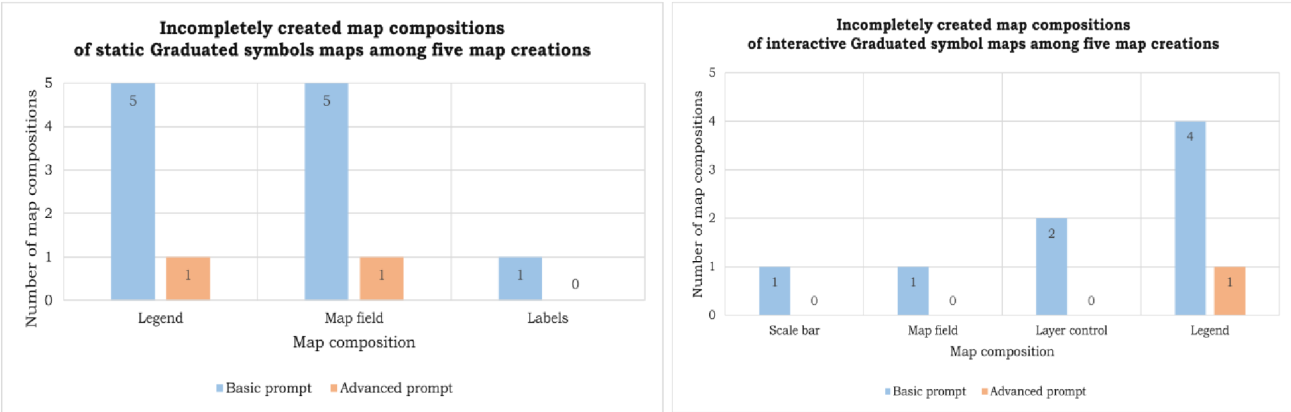


Figure 49 The number of map compositions of static (left) and interactive (right) graduated symbol maps that were unsuccessfully created among five iterations.

The main issues of the graduated symbols map are legend and map field, the basic prompt cannot be able to create a correct legend and map field for all five static maps. On the contrary, advanced prompts can create most of the map fields and legends successfully, only one legend and one map field are not completed in static maps. Likewise, the basic prompt returns four out of five incomplete legends in interactive maps, while the advanced prompt has only one incorrect legend. Overall, Cognitive verifier and Question refinement prompts can be useful to create this thematic method successfully.

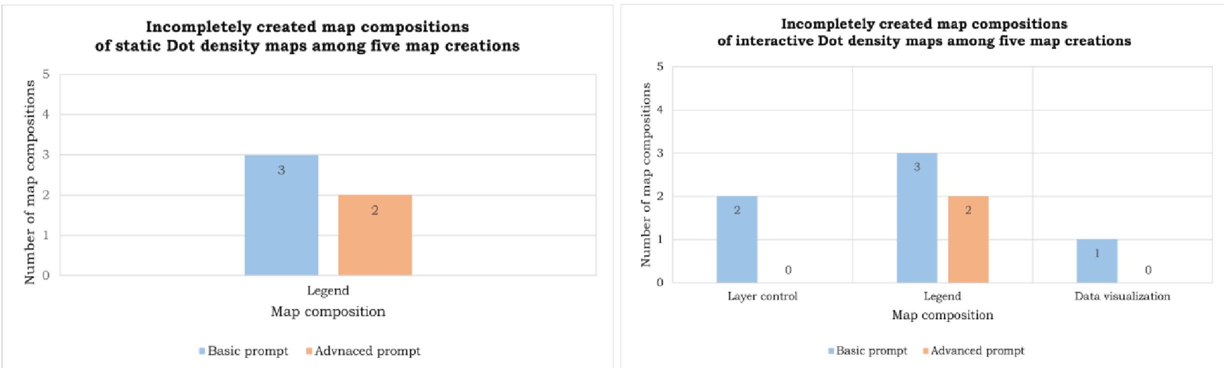


Figure 50 The number of map compositions of static (left) and interactive (right) dot density maps that were unsuccessfully created among five iterations.

The fundamental element that cannot be achieved mostly is legend. In both map versions, ChatGPT-4 similarly failed to generate three legends using basic prompts and two legends from advanced prompts. However, incomplete layer control is also commonly found in all three thematic methods. Generally, the layer control cannot organize or add the map layers to be toggled effectively according to prompt commands. This leads to unsuccessful interactive outputs which can be solved by utilizing the advanced prompts. To summarize, the number of incomplete map compositions of the dot density maps is still lower than the other thematic methods either basic or advanced prompt.

6.2 Influence of Prompt Patterns

This section aims to answer the research question of whether different prompt structures influence AI-generated maps significantly. To understand how they affect the output, this study focuses on identifying the number of attempts, error analyzing, and incorrect results on each pattern. By analyzing these factors allows users to identify best practices leading to successful map creation and understand the limitations of AI that lead to cartographic improvements.

6.2.1 Number of attempts

An attempt indicates the number of prompts used during the map creation until it achieves a final map or desired output. Creating thematic maps requires several attempts because ChatGPT-4 can give hallucinated or incorrect results. Moreover, map elements can be degraded and disappear during the process, then those elements need to be regenerated again and use more refined prompts.

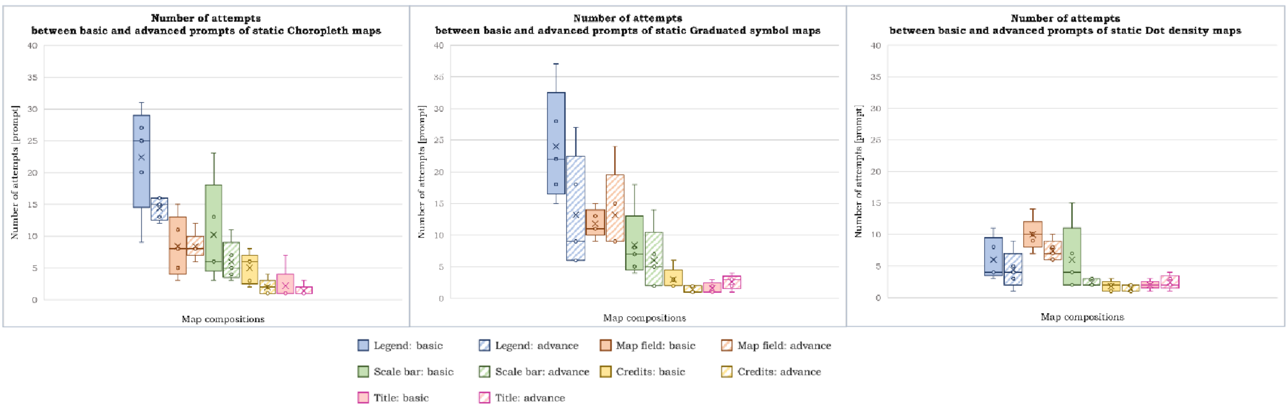


Figure 51 Comparison of the number of attempts between basic and advanced prompts used to create the choropleth (left), graduated symbols (middle)and dot density maps (right).

Figure 51 indicates that the basic prompt pattern in the choropleth maps uses more attempts of all five iterations which is 362 attempts. On the other hand, the advanced prompt requires fewer attempts which is 261. All the map compositions in the basic prompt have a wider range of attempts indicating a high variability of attempts. However, the total number of basic prompts to create map fields in five sessions is the same as the advanced prompts.

For creating a map field of the graduated symbols map, the total number of attempts required between basic and advanced prompts is similar, which is 66 for advanced and 59 for basic prompts. In the advanced prompt, the number of attempts for each map is wide and varied, most elements require more attempts than the basic prompt. A graduated symbol map has several complex elements to concern either proper graduated circle sizes or classification. Therefore, using complex instructions may not satisfy all requirements at a time. Creating a legend is complicated, the basic prompts varied from 15 to 37 prompts which is significantly larger than the advanced prompts required from 6 to 27.

The advanced prompt gives fewer attempts than the basic prompt in total. Most of the map elements of dot density maps do not vary among the five sessions, indicating more consistency in the number of attempts. More advanced and refined prompts lead to fewer attempts as users become more precise in their instructions. When using the advanced prompt, the number of attempts is decreased, which means the advanced prompt facilitates creating a dot density map and reduces the number of iterations to achieve desired outputs.

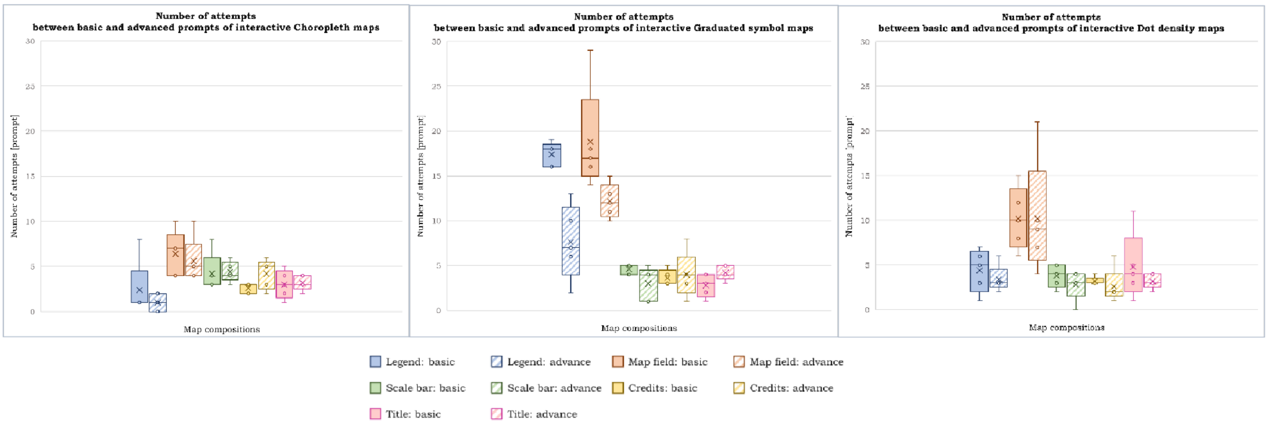


Figure 52 Comparison of the number of attempts between basic and advanced prompts used to create the choropleth, graduated symbols and dot density maps.

Advanced prompts generally result in fewer attempts across all map types, but the distributions are more varied and not consistent as the static maps. For the interactive choropleth map, the map field of the basic prompt has a similar range to the advanced pattern, with a slightly higher distribution. The number of attempts used in the advanced prompt for the legends shows a small range from zero to two attempts, which means some legends in the interactive map are automatically created by the predefined functionality of Folium library.

The range of attempts for creating the interactive graduated symbols maps is larger than the choropleth and dot density maps. The map field and legend in advanced prompts have lower attempts than the basic prompt at every iteration. The dot density has a similar range of number of attempts between the basic and advanced prompts. The mean of the two prompt patterns is the same with 51 attempts in the map field and some sessions even use more advanced prompts than the basic one.

For the credits and title, a complex pattern can lead to more attempts since the map library does not have a predefined text box for adding text elements, so it requires more attempts to create HTML elements overlaid on the layout. To create the choropleth and dot density maps, both basic and advanced patterns do not have a large difference in the average number of attempts. However, the advanced prompts facilitate the creation of the graduated symbols maps with fewer attempts.

6.2.2 Number of incorrect results

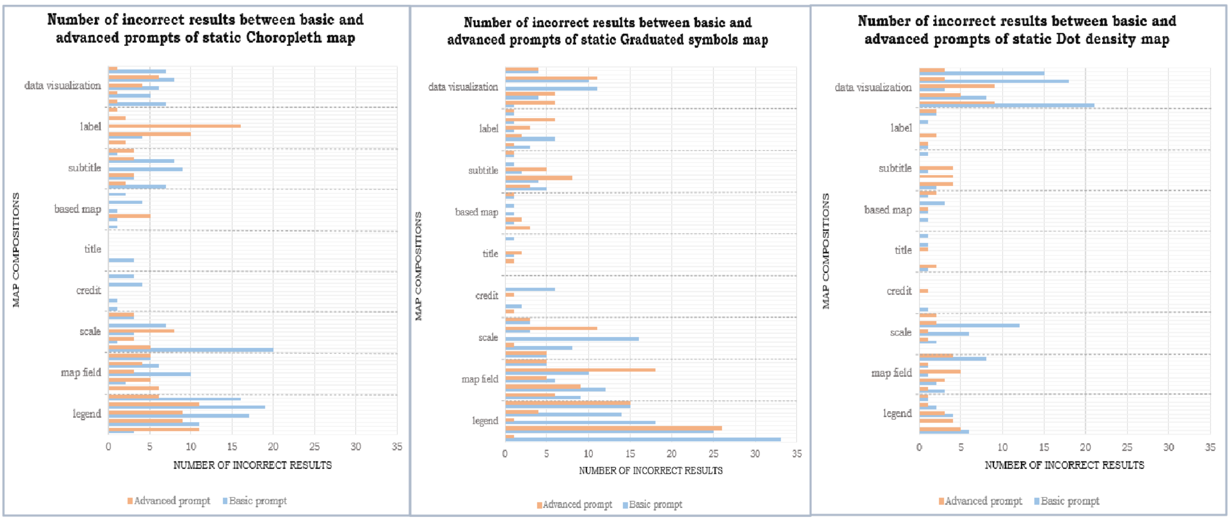


Figure 53 Comparison of the number of incorrect results between basic and advanced prompts used to create the static choropleth, graduated symbols and dot density maps.

The charts reveal patterns in how the two types of prompts return incorrect results caused by the AI. ChatGPT-4 can cause hallucinations in the code results which means generating facts with reasoning errors (OpenAI et al., 2024). Such results indicate that the model's learning ability has limited cartographic knowledge leading to the failure in outputs.

The incorrect results vary highly across map elements of legend, map field, scale bar and data visualization, with some elements showing a significant reduction in errors when using advanced prompts. The advanced prompt pattern gives the total number of incorrect results fewer than the basic one. However, all five iterations of the choropleth map's fields have the same total errors in two types of prompts. Legends are made more accurate with the advanced prompts and have fewer mistakes than the basic prompt.

Similarly, the graduated symbols legend produces fewer errors from the advanced prompts than the basic prompt significantly. Considering the map field of the graduated symbols map, it has about the same number of code errors between the two types of prompts. Therefore, this thematic map requires the same number of attempts to create the map field.

For the dot density map, both prompt types have a similar number of incorrect results, with the basic prompts having slightly more. The advanced prompts generally return fewer incorrect results compared to the basic prompt, especially noticeable in data visualization and scale bar. Certain components like labels, title, and credit do not show significant differences between the two prompt types, indicating that the AI's learning ability performs similarly for both prompt types in creating this thematic method.

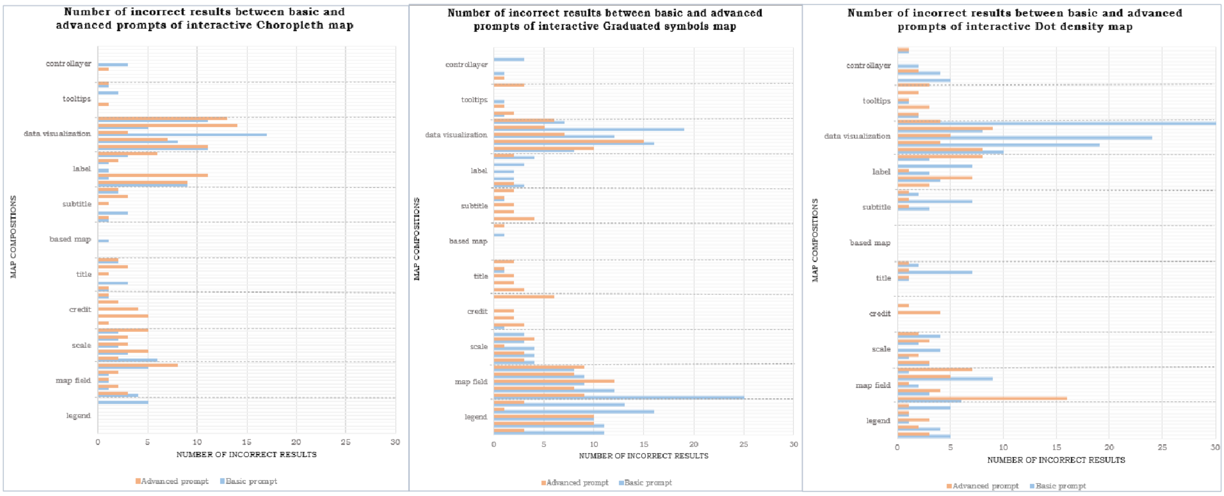


Figure 54 Comparison of the number of incorrect results between basic and advanced prompts used to create the interactive choropleth, graduated symbols and dot density maps.

Figure 54 shows the high number of incorrect results in the data visualization and map field across the three thematic maps. For the interactive maps, both prompt patterns do not show noticeable differences. This is because the interactive version produces similar mistakes and some components cannot be improved by using the advanced prompts.

Advanced prompts lead to more incorrect results in the choropleth maps for all five iterations. The map field, generated by both prompt types shows minimal differences and even slightly high in the advanced prompts. Conversely, the advanced prompts of the graduated symbols maps produce fewer incorrect results in map field and legend but using the basic prompts to create text elements such as title, subtitle and credit in this interactive map hardly gives incorrect results. For the interactive dot density map, the distribution of the incorrect results is similar to the static version but the errors of map fields are not reduced by the advanced prompt. However, the advanced prompt can highly reduce the number of code errors when embedding a chart or data visualization. As a result, the number of attempts will also be reduced.

In conclusion, ChatGPT-4 produces more errors or hallucinated results in complex components like map field, legend and data visualization, both static and interactive maps have similar distribution across three thematic maps. The use of advanced prompts consistently leads to fewer incorrect results some map elements, particularly in data visualization and legend. However, when considering the map fields of the choropleth and dot density maps, there are small differences between advanced and basic prompts but mostly the advanced prompt returns more incorrect results for interactive maps and the same number of incorrect results for static maps. On the other hand, the graduated symbols maps have fewer attempts and errors from the advanced prompt but slightly more incorrect results occurred in the static version.

6.2.3 Number of error messages

Error messages can occur during code generations in ChatGPT, the cause can be from several factors. The main error that usually happens in the experiments is the 'Error Analyzing' issue. The error is potentially caused by the model bias in training data, complex datasets and data handling capability. As shown in Figure 55, the error analyzing interrupts the code generation because ChatGPT-4 cannot process and read the shapefile datasets properly. This can happen with certain types of spatial data and issues on processing plotting geometries. Assessing the technical issue helps to understand the limitations of ChatGPT-4 model in processing spatial data and its performance in creating maps.

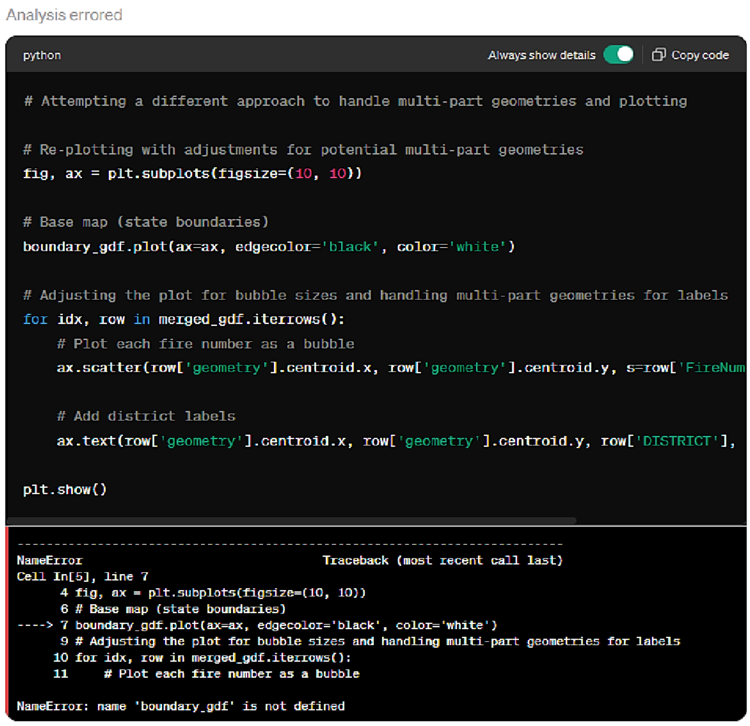


Figure 55 Error Analyzing in ChatGPT-4

Error Analyzing issue consistently occurs when creating map fields and data visualizations, these map elements are created from shapefiles and CSV attached along with the prompts. The shapefiles are processed for plotting maps and the CSV file is for generating charts or data visualization inside a map layout. ChatGPT-4 processes the given data by unzipping and preparing them to a data frame, the issue could happen when the AI cannot process, plot or load the given files.

Most of the map compositions from advanced prompts have a low number of errors. However, choropleth and graduated symbols maps have a lot of errors occurring in the interactive maps using the advanced prompts. This indicates the complexity of processing interactive elements.

When comparing the map fields to data visualizations, errors are more prominent in data visualization across both static and interactive maps. The advanced prompts generally reduce error results but not uniformly, because there are more errors in the data visualization of the interactive choropleth map and static dot density maps.

Table 4 The number of error messages occurred during code generations for static maps

Error messages occurred during code generations for static maps						
Map compositions	Choropleth map		Graduated symbols map		Dot density map	
	Basic prompt	Advanced prompt	Basic prompt	Advanced prompt	Basic prompt	Advanced prompt
Legend	1	0	0	1	2	0
Map field	12	0	3	5	8	0
Scale bar	4	0	0	0	0	0
Base map	0	0	0	1	0	0
Data visualization	3	3	3	0	19	4

Table 5 The number of error messages occurred during code generations for interactive maps

Error messages occurred during code generations for interactive maps						
Map compositions	Choropleth map		Graduated symbols map		Dot density map	
	Basic prompt	Advanced prompt	Basic prompt	Advanced prompt	Basic prompt	Advanced prompt
Map field	3	6	3	4	7	5
Scale bar	1	0	0	0	0	0
Credits	1	0	0	0	0	0
Data visualization	8	15	35	13	12	9

6.3 Map quality between ChatGPT-4 and traditional method

This section aims to evaluate how well the quality of AI-generated maps compared to human-generated maps. Implementing of AI to create maps is still new in Cartography and GIS domain. The maps created by human or traditional method can be customized and flexible. GIS software such as ArcGIS Pro has various pre-defined functions available to create accurate thematic maps. Therefore, evaluating the quality of AI compared to human-made maps It can point out how far the AI's abilities are from the traditional method.

6.3.1 Choropleth map

According to the suitability criteria in Chapter 5, the AI-generated map quality based on how many map elements fall in the most suitable specifications. Results of both basic and advanced prompts are combined and compared with human-generated maps as shown in the following figures.

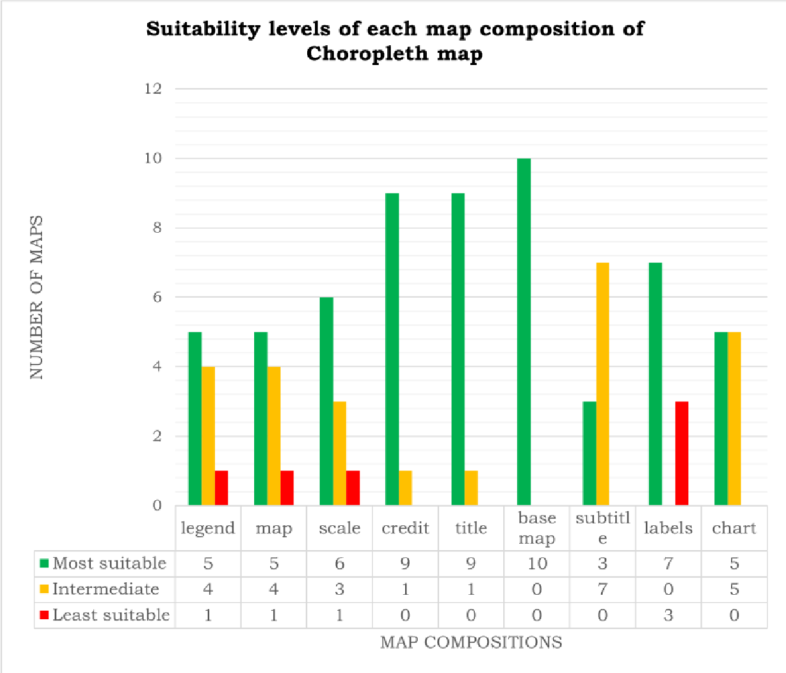


Figure 56 Suitability levels of each map composition of the Choropleth map

ChatGPT-4 performs well in generating maps but occasionally produces intermediate or unsuitable results. Among ten maps of two prompt patterns, the choropleth map has almost the same number of the most suitable and intermediate maps. Especially legends, maps, and charts. Also, some maps have the least appropriate levels such as scales, labels, legends, and map fields. The issue with inappropriate maps is that the codes cannot be visualized or successfully generated. For example, the legend color is slightly different from the map causing it to be assessed as intermediate level. For the map field, the map itself is incorrectly classified into specific ranges, and the map cannot be classified into certain colors or ranges.

There were five out of ten maps that are rated as the most suitable as well as the legend. However, the AI-generated map lacks flexibility in placement. Most of the subtitles are in intermediate quality because of the overlapping issues with the main title.

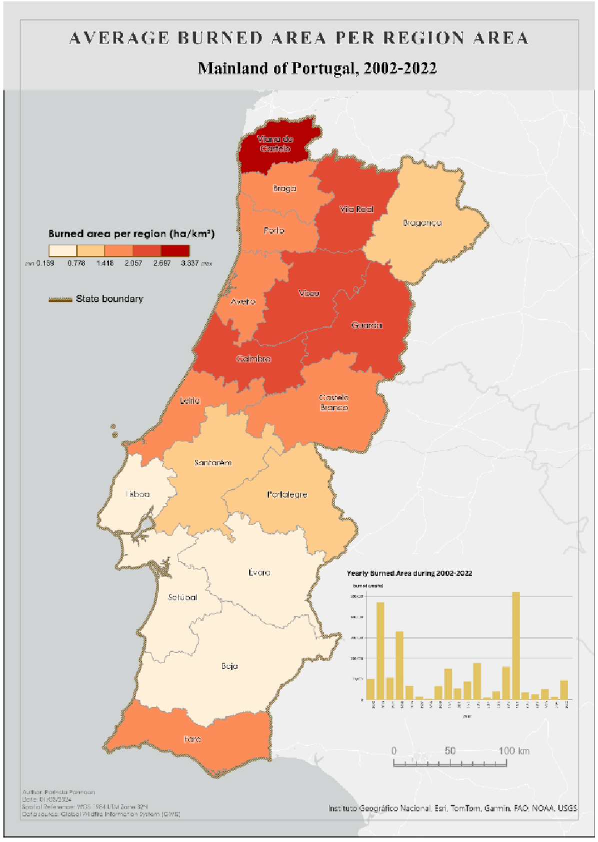


Figure 57 A Choropleth map created by ArcGIS Pro

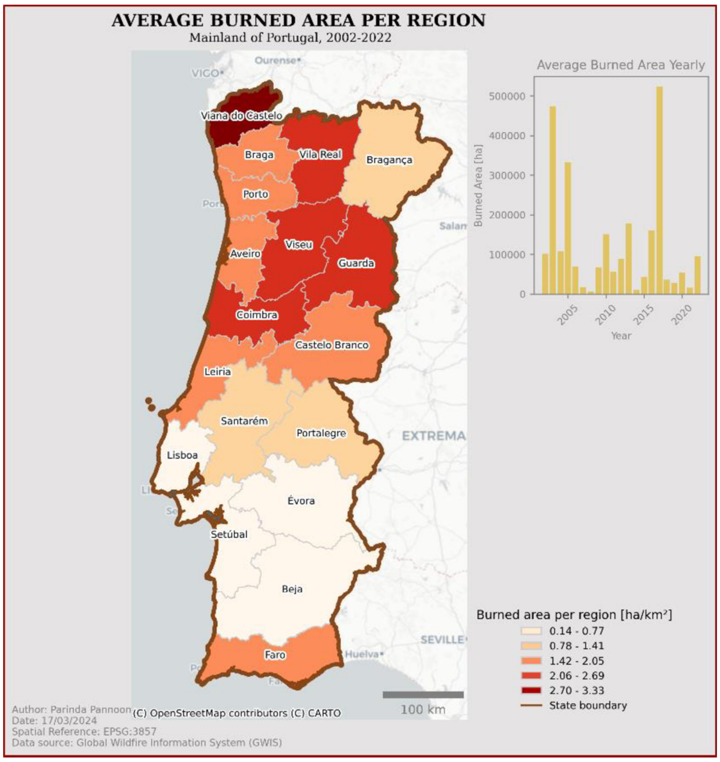


Figure 58 A Choropleth map created by ChatGPT-4

6.3.2 Graduated symbols map

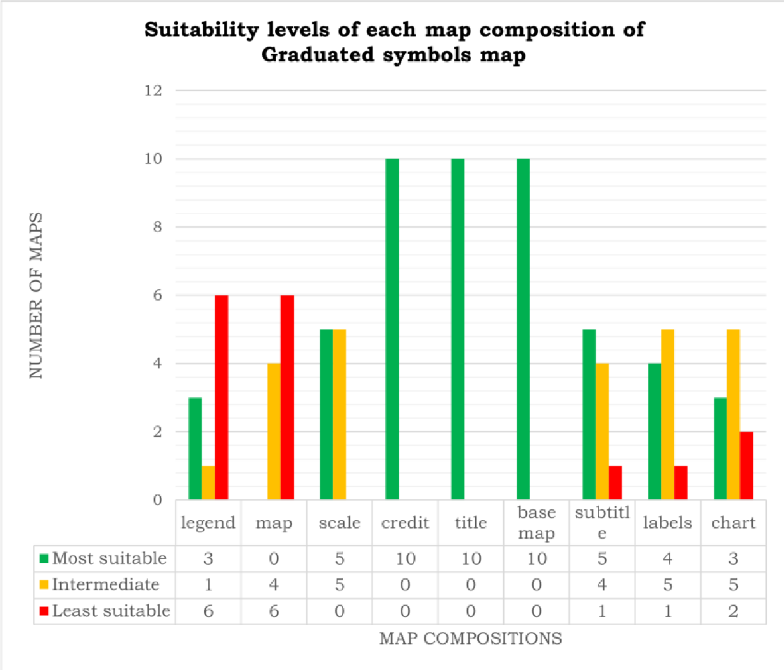


Figure 59 Suitability levels of each map composition of the Graduated symbols map

From Figure 59, the experiment reveals map quality is mixed across all three levels, especially legends and map fields that are mostly evaluated as least suitable. This is because the initial results from the AI often return a choropleth map or proportional map. Moreover, the legends hardly corresponded with the symbols on the map. From the results of the completeness section, there are five out of a total of ten maps that the AI cannot successfully generate according to specifications. The low quality of this thematic map points out the limitations of training data in ChatGPT-4's model.

The following level of the map fields is intermediate quality, there are four out of ten maps. Moreover, the intermediate and least suitable levels also appear on subtitles, labels and data visualization. Therefore, generating a graduated symbols map from ChatGPT-4 seems to be the weakness of the model, the map outputs generally are most unacceptable based on cartographic rules.

Creating a graduated symbols map in ArcGIS Pro can be performed straightforwardly, the predefined functionality of symbology and classification is ready to use, making legend and symbols have the same quantitative difference. Conversely, the issue of ChatGPT-4 is that it constructs a map symbol and a legend separately, the legend rarely simulates the same characteristics as the map, and it has several incorrect results that cause prompt refinements.

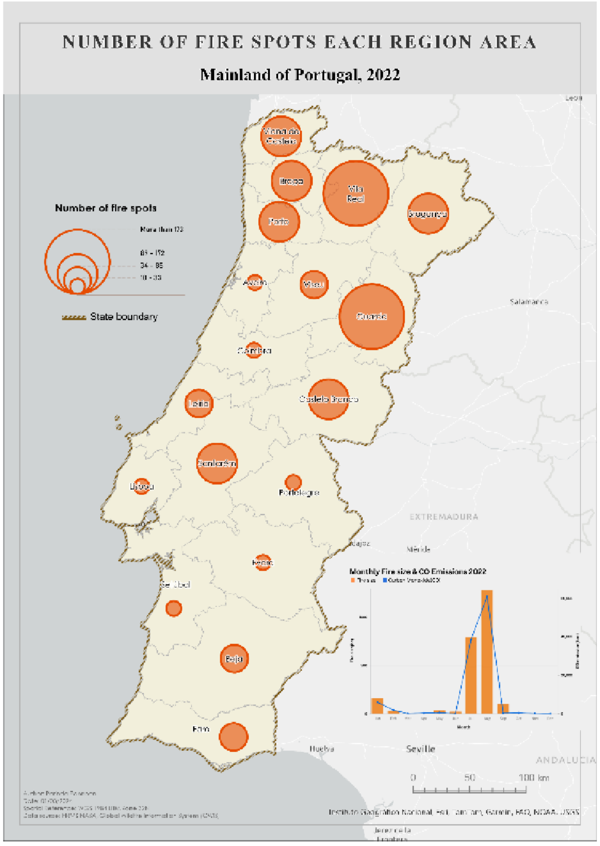


Figure 60 A Graduated symbols map created by ArcGIS Pro

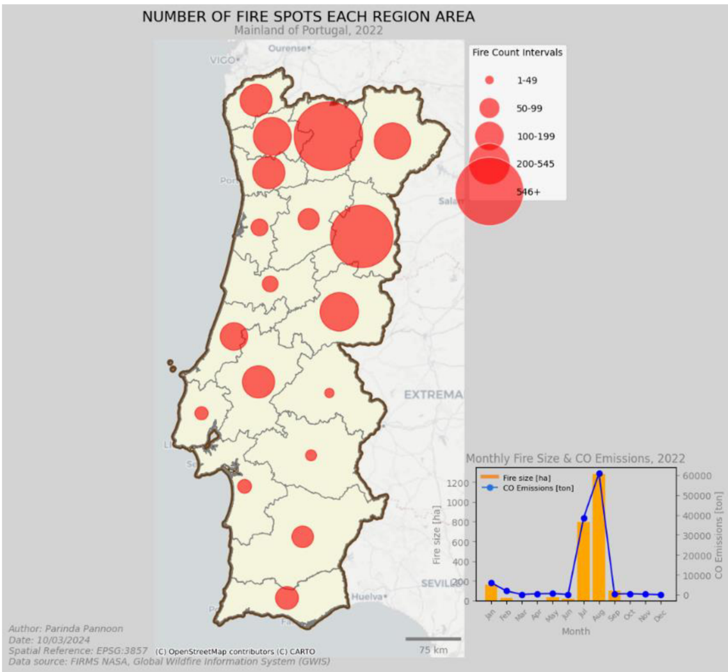


Figure 61 A Graduated symbols map created by ChatGPT-4

6.3.3 Dot density map

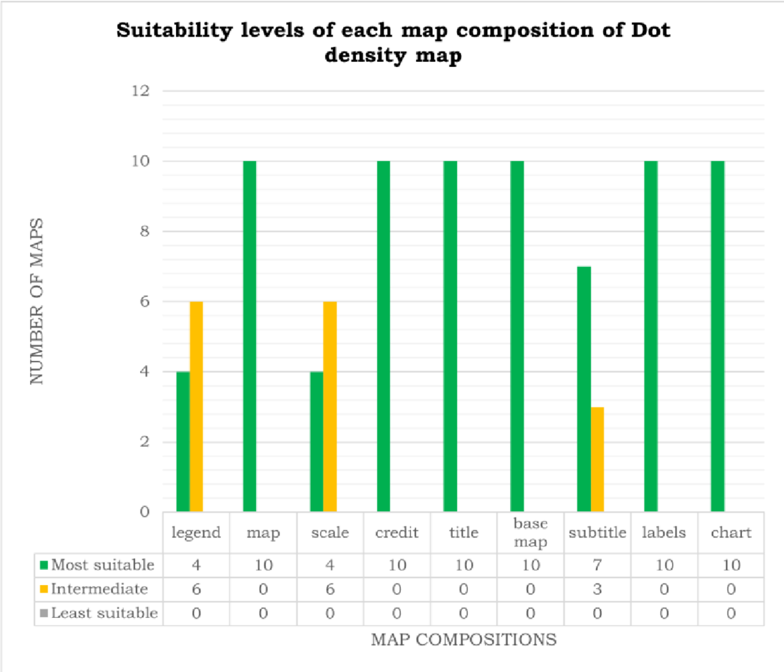


Figure 62 Suitability levels of each map composition of the Graduated symbols map

For dot density map, ChatGPT-4 performs well in creating map elements, the map fields are successfully generated having the most suitable level of all 10 maps for both basic and advanced prompts. However, there are some elements that are in intermediate level which are legend, scale bar and subtitle. The legend of dot density map is not as complicated to create as other maps. However, the problem is that most of them are evaluated in the intermediate level because the dots on Legend have inconsistent sizes, colors, and opacity with the map symbol. The AI code customizes the point size according to pixel size both width and height.

Generally, even if the prompt is specified to create a size to be the same as the map symbol, the AI still cannot simulate the size as it should be. The default result of this map usually plots the actual number of dots in a column, making it is difficult to distinguish the fire distributions across the area. However, the AI can solve the issue of representing one dot for certain values.

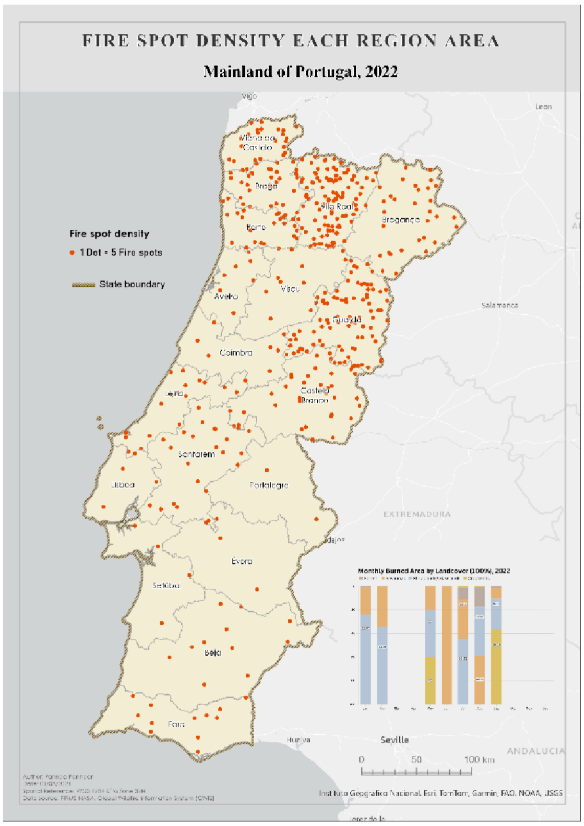


Figure 63 A Dot density map created by ArcGIS Pro

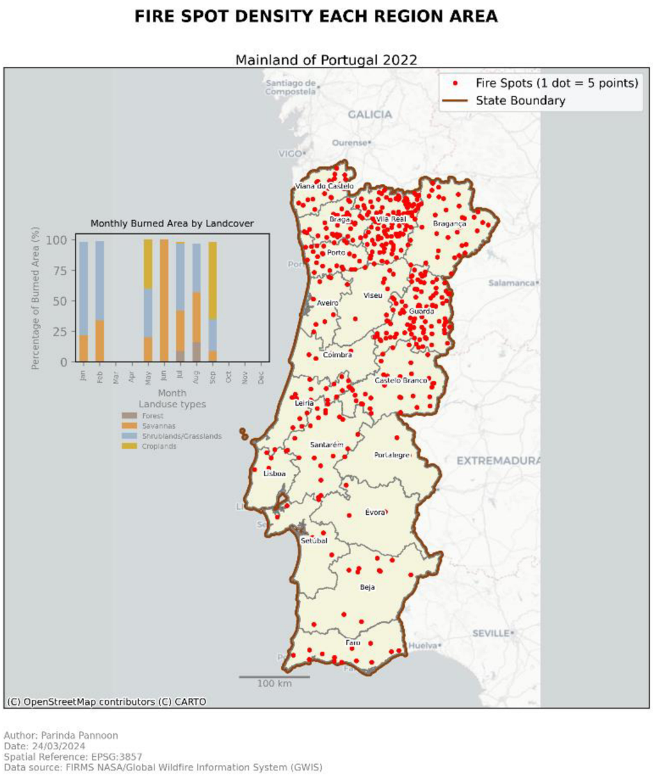


Figure 64 A Dot density map created by ChatGPT-4

7 DISCUSSION

In evaluating the performance and capabilities of AI, in addition to using the indicators explained in Chapter 6, related aspects can also be considered, such as time consumption, technical limitations, advantages, subscription, and design. Nowadays, AI technology has developed several approaches that can be leveraged in the Geoinformatics domain, this study will discuss the text-to-text approach from code generations.

Advantages of ChatGPT-4 in GIS and Cartography

The main advantage is its ability to interpret and analyze large data sets and support shapefile format. Large data can be processed much faster than humans, the AI provides and analyzes in-depth information within a short time. This is useful for users who need to see spatial patterns from a map at a glance.

ChatGPT-4 creates a basic map that does not contain complex elements much faster than humans can. It also helps in constructing code for further development. ChatGPT-4 significantly reduces hallucinations or made-up facts. The accuracy of factual evaluation in the coding ability is higher than in previous versions (OpenAI et al., 2024).

This advantage facilitates users who want to create maps from the code without starting from scratch. Additionally, creating a web map can be complicated but ChatGPT-4 can automatically generate web maps in HTML format along with exporting files within the interface that allows users to display in a web browser immediately. Moreover, the AI is capable of plotting data visualization as a subplot inside a map field without using an external tool. While creating a well-designed chart or table in GIS software is necessary to create them from external tools independently.

Technical Limitations of ChatGPT-4

For some specific domains, LLMs can be improved by fine-tuning, adding more labeled data and customizing parameters for particular tasks. However, fine-tuning requires extra resources in both compute units and processing time. Recently, the trend of optimizing Small Language Models (SLMs) has been increasing for specific use cases because the SLMs are trained on specialized and proprietary knowledge. Therefore, the parameters are not as many as LLMs and the risk of bias is naturally reduced compared to LLMs (Raza, 2024). AI in the Cartography and GIS domains can be challenging when the data is trained on SLMs in further development.

The research reveals that a prompt often needs to specify more details to ChatGPT-4 because the model misunderstands mapping methods. According to OpenAI et al (2024), GPT-4 model outperforms in academic knowledge especially, biology, mathematics and writing but there is still no improvement in some domain. Therefore, it is necessary to take into account that creating a thematic map by the AI can give unexpected map outputs.

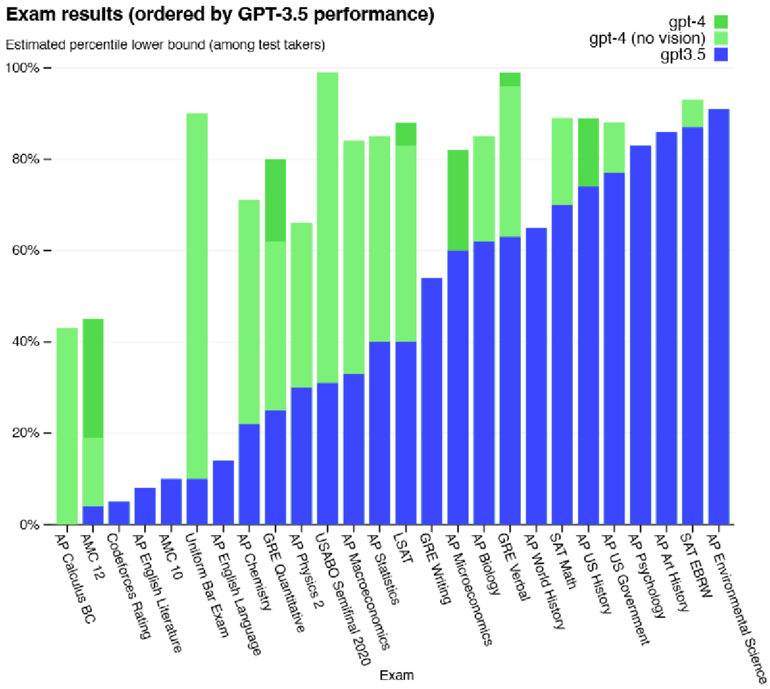


Figure 65 GPT performance on academic and professional exams. (OpenAI et al., 2024)

ChatGPT-4 occasionally raises unexpected errors caused by the server side. The interface can be interrupted by error messages that require a user to contact OpenAI. Such a problem will stop a window session and users will not be able to prompt. The recommendation is to clear caches, VPN, or change the web browser. Moreover, the GPT-4 model limits 40 messages per three hours, once it reaches the limits, it can be continued until the next hour. In this case, using advanced prompts may not be efficient due to the number of prompts. The advanced prompt like Cognitive verifier requires three additional answers to finish a task. As a result, the number of prompts continues to increase.

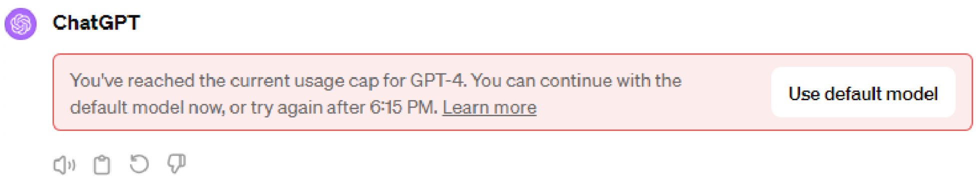


Figure 66 Message limits on ChatGPT-4

ChatGPT4 is capable of taking a context length of 8,192 tokens without any loss but if the token exceeds, the output will not completely return all of the previous information. The recommendation is that when correct outputs are generated, the code should be saved separately and appended to the next outputs. Creating a thematic map requires several fundamental elements such as a scale bar, map field, title and credits, the AI is not able to create the completed map with all elements, some of them disappear during the process because of token limitation. This leads to an increase in the number of prompts and errors.

In addition, there are issues with library and package availability, ChatGPT interface does not support some library packages. Those libraries can be executed only on Google Colab or IDE environments such as Visual Studio code, Pycharm. As mentioned in the work of Tao and Xu (2023), they avoid the inconsistency of ChatGPT by using external IDE since some packages or libraries are not available within ChatGPT environments.

A constraint associated with using ChatGPT-4 for creating code, is the necessity for users to understand parameters to fix and optimize the code. Even though the model can generate code snippets for various GIS tasks, ChatGPT-4 may lack the contextual understanding that users are required to identify the errors. The improper map outputs can be fixed through clear and precise prompts that specify the correct parameter values. For example, plotting a scalebar from Matplotlib requires 'dx' parameter which is the size of one pixel in a specified unit, also 'units' that can either be km, m, or cm, etc. Results from ChatGPT-4 are generated randomly from training data, so color, style, or map symbol can be varied in each window session which a user must control by prompts to achieve the desired results.

Thematic mapping limitations of ChatGPT-4

To use ChatGPT, it is necessary to understand the data structure. It occasionally encounters an error in zip file extraction. This can be due to an incorrect file name or path specified in the code. Defining a specific column name can avoid such issues. ChatGPT-4 usually takes a couple of hours to give correct codes for creating maps, if there is an error, it can spend more time debugging it. Therefore, users need to understand how the programming libraries work. Then, it can take fewer errors in the next turn.

When creating a graduated symbol map that usually creates a choropleth map instead, the training data of Geopandas for this map may not be sufficient. A refined prompt can be specified with the term *'bubble map'*. The legend does not represent the exact value ranges and even generates improper circle sizes that are difficult to differentiate. Also, colors usually do not correspond with the map symbols. Overall, there are many incorrect results in the legend of a graduated symbols map, using a traditional method is potentially more efficient.

The dot density method is easily generated by ChatGPT-4, compared to the other maps. However, the default legend shows only a dot that does not indicate any unit, but it does not require many prompts to refine it. For the choropleth map, the average number of attempts across five map creations are the same between the two types of prompts. This is because the AI usually returns the choropleth maps without normalization or the color scheme does not correspond to a legend. It cannot classify the data according to the defined method efficiently. For example, when reclassifying data using Equal intervals, but Quantile method may appear instead.

Considering the placement of the map elements, changing the position is quite difficult because it works on pixel values. The generated codes do not adjust to the proper position initially, resulting in overlapping issues, and inappropriate alignment, these need to be prompted specifically to adjust them.

Tao and Xu (2023), discussed the limitations of ChatGPT's capability in using programming libraries. Even ChatGPT understands the prompts, map outputs may not be produced properly because ChatGPT still lacks knowledge about those libraries. Generally, ChatGPT does not return correct results on the first attempt. Because of this, it takes more attempts to eliminate the mistake. Even though the prompt has been adjusted, it may not yet return the desired results as requested. The final solution is to adjust errors directly in the script. As with this study, the problem of inconsistent legend and map symbols is solved by assigning a parameter value in a prompt to adjust color or size.

Aesthetics

Traditional map-making involves a deep understanding or interpretation of phenomena so the map detail and design convey more than just geographic information but AI-generated maps sometimes lack proper context and style. The use of AI in map creation offers significant advantages in terms of the ability to handle geospatial datasets. This leads to maps that may be accurate but less appropriate in layout, color scheme, and creativity, leading to underrepresented in text-to-text models. The common error found in the AI-generated maps is the overlapping issue, most of the map elements usually do not consider placement. For example, a subtitle overlaps or covers a main title. In this case, the text-to-image model of DALL·E could be an alternative approach for creating a map focusing on only aesthetics but not accuracy.

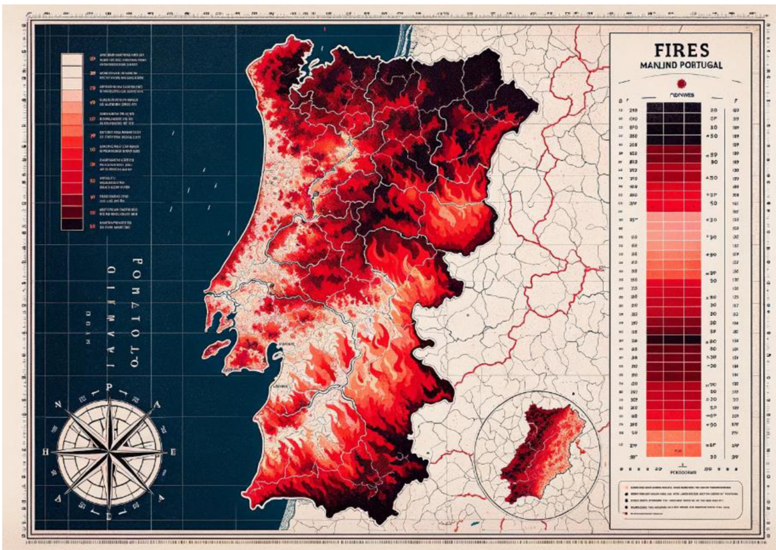


Figure 67 Map of Wildfire in Portugal generated by DALLE

Initial Setup and Costs

Executing the code from ChatGPT-4, requires a proper IDE and well-configured environment. In this study, Geopandas, Folium library and additional packages are installed within Google Colab and Visual Studio code. Ensuring all necessary tools and libraries are readily available, can be a complicated task for people who are not familiar with programming languages. Conversely, A comprehensive GIS platform like ArcGIS Pro which all built-in functionalities are already set along with a user-friendly interface. Therefore, users can perform complex GIS tasks without writing any code.

Regarding costs, ArcGIS Pro is commercial software with licensing costs that available tools depend on the level of licenses. However, using Quantum GIS (QGIS), an open-source software can be an alternative to the traditional method. ChatGPT-4 subscription price is 20 dollars per month, it provides an advanced model for complex tasks. On 13. 5. 2024, OpenAI launched a new GPT-4o model available in both free and paid subscription. The new model is more efficient with faster text generation, working across audio, vision, and text in real-time (OpenAI, 2024). This advanced capability can be challenging in GeoAI industry for automating geospatial and mapping tasks.

Time consumption

Time efficiency is one of the key factors in producing maps. Creating accurate maps within a short time can enhance decision-making on projects, especially, rapid mapping for emergency responses. The study results reveal a map created by ChatGPT-4 generally takes up to 4–6 hours to get the final result. This indicates that using the AI tool is not an efficient approach for creating a thematic map with comprehensive elements. On the other hand, ArcGIS Pro is generally more time-efficient for creating maps that are quick and easy to use because of comprehensive functionality and map view on the interface. While a map from the AI's code needs to be executed in external tools to visualize the result.

To summarize, ChatGPT-4 is suitable for a quick overview of a map, it has the capability of plotting a map field and manipulating data within a short time. The weakness is that it cannot generate a complex map correctly with all fundamental map elements as quickly as humans. Creating a map with GIS software can be costly and requires a subscription and a map quality depends on the user's expertise and GIS knowledge. However, in terms of functionality, ArcGIS Pro offers a variety of built-in tools for data pre-processing, analyzing and professional geovisualization.

8 CONCLUSION

The aims of this thesis are to evaluate the capability and learning ability of ChatGPT-4 in producing maps, in both static and interactive maps, to evaluate different prompt patterns that influence map outputs and to assess the map quality between maps generated by the AI and those produced through a traditional method. Making a map with GIS software can be complicated for nonexperts, and the software could be costly, leading to the exploration of alternative approaches. The growth of AI has been implemented in the field of cartography, but the accuracy remains to be evaluated and developed. This leads to the assessment of the capability and accuracy of AI in creating maps as well as the map quality. This study utilizes ChatGPT-4 to create thematic maps in the case study of Wildfire events in Portugal, the AI model generates a choropleth, graduated symbols and dot density.

A prompt is the main tool to communicate with ChatGPT-4, then the maps are visualized from AI-generated codes. Regarding map completeness, the study reveals ChatGPT-4 can achieve all the map composition according to cartographic rules. The advanced prompt creates most of the map compositions successfully more than basic prompts, particularly in complex elements like legends, map fields and data visualizations. However, both prompt types still face challenges in maintaining consistency and achieving complete map compositions across all the thematic map.

The number of attempts is a factor to evaluate how map results are affected by different types of prompts. The advanced prompts generally reduce the number of attempts in most of the elements, their effectiveness is more pronounced in complex scenarios such as creating interactive graduated symbols maps. However, when considering only the map fields of the choropleth and dot density map, both basic and advanced patterns do not have a large difference in the average number of attempts.

AI-generated maps using ChatGPT-4 can produce hallucination or incorrect outputs due to the limitation of cartographic knowledge. The advanced prompt reduces the number of incorrect results for certain map elements, but the prompt does not consistently improve all elements. Considering map fields from five iterations, the advanced prompt returns more inaccurate results for interactive maps. For static maps, there are no significant differences in static versions.

Another factor in evaluating the capability of ChatGPT-4 is 'Error Analyzing' issue, highlight the limitations of the AI in processing spatial data since the error often shows when manipulating the given shapefiles and CSV. The error issue significantly affects two elements which are a map field and data visualization. For static maps, the advanced prompt generally reduces the number of errors, but this pattern does not eliminate the error in interactive maps which means more prompt refinement is required to solve the data processing issues.

The last stage of the thesis aims to evaluate the map quality between the AI and traditional methods. The AI-generated maps are assessed based on the suitability criteria categorized into most suitable, intermediate, and least suitable. ChatGPT-4 shows potential in map generation but still requires more improvements to match the quality and flexibility of traditional methods like ArcGIS Pro. Results from the case study indicate that ChatGPT-4 needs more development in thematic maps and visual representations to achieve cartographic standards. The choropleth and dot density maps are the most suitable and the graduated symbols map is the least suitable compared to the reference criteria.

ChatGPT-4 produces maps with inconstant quality in complex map elements like legends, map fields, and data visualization. Therefore, the capability of ChatGPT-4 at the period of this study requires more improvement of cartographical knowledge, the traditional mapping method by ArcGIS still outperforms, being more accurate and consistent. This is due to predefined functionalities and better handling of symbology and visualization.

In conclusion, this study reveals the potential of ChatGPT-4 in the field of cartography and GIS but also highlights several limitations. ChatGPT-4 is useful for a basic map without containing so many elements such as plotting an overview visualization of the data. The results can be improved based on the prompts used in this thesis. The thesis can be a guideline for further studies related to ChatGPT-4's functionality in map creation. Also, the results show the insights of the strengths and weaknesses of AI in cartography. In addition, the map outputs based on Geopandas and Folium pave the way for more visual and mapping improvement in the future development of the libraries.

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ATTACHMENTS

LIST OF ATTACHMENTS

Bound attachments

Free attachment

Attachment 1

Suitability criteria for evaluating the map quality

Map compositions		Suitability levels		
		Least suitable	Intermediate	Most suitable
Choropleth map	1. legend	- Not representing burned area values in each class. -Use a legend as a continuous bar. -Colors do not correspond on the map.	-Represent ranges of the value in each class. -Discrete legend from high to low, with graduated colors. -Colors do not correspond on the map, the tones are slightly different but still be able to understand the data. - Upper and lower values of each class are duplicated.	-Represent ranges of the value in each class. -Colors correspond with the color on the map. -The number of classes is the same as the map -The data intervals are classified properly according to statistical methods.
	2. map field	-Not using a sequential scheme on areas. -Not using a warm color scheme. -Data is organized into more than 7 or less than 4 classes. -Colors do not associate with the actual data. -The colors on the map do not correspond to the legend.	-Use a sequential scheme on areas. -Single data value is represented by each area as a ratio. -Use a warm color scheme -Data is organized into more than 7 or less than 4 classes. But -The colors on the map are slightly different from the legend.	-Use graduated-color: sequential scheme on areas. -The data value is ratios(normalized) represented by each area. -Use a warm color scheme -The color symbols support the reader in making comparisons between high and low. -Data is organized into more than 7 or less than 4 classes. -The colors on the map correspond to the legend.
Graduated symbols map	1. legend	-Not representing values in each class, and labeled as "min", "medium", "max" instead of numeric values. -Show other symbols in which different from the map symbol.	-Represent ranges of the value in each class. -Ranging values from high to low or bigger size to smaller class with the same color. -The number of classes is the same as the map.	-Represented each class interval enabling readers to understand the different magnitudes. -Color corresponds with the map. - Each legend class should have the

		-Color or size does not correspond to the map -The values in each class cannot be shown as actual data on the map.	- Each class of the legend should have the same size as the symbol on the map BUT -The color, opacity or size is a bit different from the map. - Upper and lower values of each class are duplicated.	same size as the map symbols. -The number of classes is the same as the map. -The data intervals are classified properly according to statistical methods. -Ranging values from high to low or bigger size to smaller class with the same color.
	2. map field	-Use various color schemes in the symbol. -Represent other thematic methods (e.g. proportional map) -Data is organized into more than 7 or less than 4 classes.	-Use graduated symbols placed in each area. - Each area represents an absolute data value. -Data is organized between 4–7 classes. But -Most of the symbols overlap with others. -Symbols are difficult to distinguish the magnitudes among the classes. -The color or size on the map is slightly different from the legend.	-Use graduated symbols placed on each area. - Each area represents an absolute data value. -Symbol sizes designed for the magnitudes that are easily distinguished. -The relative difference allows users to determine a pattern across the map. -The minimum class is not too small and the maximum class is not too large. -The color or size on the map corresponds to the legend.
Dot density map	1. legend	-Not representing values of dot per unit. -Representing other symbols in which different from the map symbols. -Color/size do not correspond to the map	- Represent values per dot unit. BUT -The color, opacity or size is a bit different from the map.	-Represent values per dot unit -Dot size or color correspond with the map.
	2. map field	-Use various color schemes in the dot symbol. -Represent other thematic methods (e.g. heatmap, aggregated symbol)	-Quantitative value is represented per dot unit -Can be able to gauge the relative difference between area densities across the map	-Symbols represent the number of points per 1 dot. -Can be able to gauge the relative difference between area densities across the map.

		-Use various sizes of the dots	-The dot size is legible but slightly large and covers most of the areas.	-The dot is legible, not too small or sparse, showing the dot clusters well that it is easy to discern spatial patterns in the data. -The dot size or color corresponds with the real size in the legend.
	3.scale	-A unit of distance is not proportional to the map scale. -Have a wrong distance unit such as dm, Gm.	-A unit of distance is not proportional to the map scale. - It can combine a graphic and numeral scale. But -The size of the scale bar is too large or too short.	-A unit distance on a map corresponds the distance on the ground. - The scale bar should be subtle and should not attract the attention of the map readers.
	4.credit	- Not specifying the data source, WHO (the author name), WHERE (place) and WHEN (year) the map was created.	-Contain the data source, WHO (the author name), WHERE (place), and WHEN (year) the map was created. -Placed below the map. BUT -Overlap or cover other elements.	-Contain the data source, WHO (the author name), WHERE (place), and WHEN (year) the map was created. -Placed below the map properly by not overlapping other elements. -Less dominant in size and color.
	5. title and subtitle	-A title is based on the input data, or prompt that does not rewrite the title from the context properly. -Not showing the subtitle. -the title shows the word “Map”.	-Describe the thematic content of the map. -The subtitle shows the phenomenon location and year of data correctly. But -A subtitle does not placed properly below the main title. -A subtitle is not less dominant than the main title.	-Describe the thematic content of the map, focusing on the phenomenon. -A subtitle shows the phenomenon location and year of data correctly. -Main title has large bold characteristics. -A subtitle is placed properly below the main title. -A subtitle is less dominant than the main title.

6. base map	-Cannot visualize any base maps. Or -High saturation or high details on the base map(e.g. Imagery with labels, Navigation map, Street map night).	-Visualize a base map with medium saturation is still acceptable (e.g. Topographic map, Oceans).	-Visualize a base map with low saturation to make the map content more emphasized (e.g. Light gray canvas map, CartoDB).
8. labels	-Most of the district labels are illegible. -Labels overlap one another.	-Labels are legible. BUT -Some of them overlap each other.	-Labels are legible easily. -Halo effect in the texts. -Font family and color support to read.
9. data visualizati on	-A chart does not appear on the map. OR -There are no x and y axes. OR -A chart is illegible and has a wrong representation of the data.	-A chart appears on the map successfully. BUT -x and y axes are too large or too small. -A Chart is too large or dominant to attract the user's attention. -A chart's legends indicate the information correctly but the colors are slightly different from the chart.	-The chart appears on the map successfully. -x and y axes support reading and understanding the data. or -A chart is not too dominant to attract the user's attention -All chart's labels appear.

Attachment 2

Archive chats of ChatGPT-4

1. Static Maps

1.1 Choropleth Map: Basic Prompt pattern

- https://chat.openai.com/share/1763437f-2964-4fba-8e16-8cbf1b0f4d78 &
- https://chat.openai.com/share/a054ab0b-49fa-4e66-b0cd-207691a0a583
- https://chat.openai.com/share/b5dc860d-4103-4afe-9be4-fb9db2184991
- https://chat.openai.com/share/ec5fa524-7e81-4244-8d5f-00651ca1aced
- https://chat.openai.com/share/703279b3-c8ab-463c-b5ce-ec31a3d013f8
- https://chat.openai.com/share/7971c36d-c642-4508-905c-001b87db6f54

1.2 Dot Density Map: Basic Prompt pattern

- https://chat.openai.com/share/a5358f9f-4af9-45e6-94f0-ea61fbb4aca5
- https://chat.openai.com/share/8d73509c-10f2-4f59-91a4-78b55a4b24ab
- https://chat.openai.com/share/66ad03b8-1696-4eb2-8236-5626027aab71
- https://chat.openai.com/share/c0f38c00-822e-47f5-bf88-96f291991258 & https://chat.openai.com/share/fe34c1a5-5479-4241-b189-bf114217573e
- https://chat.openai.com/share/9c9ebab4-df45-4ead-95e2-aaa2a19de353

1.3 Graduated Symbols Map: Basic Prompt pattern

- https://chat.openai.com/share/ba5efea6-0656-4492-8950-40dee83bcd12
- https://chat.openai.com/share/87916755-4822-4361-90ad-fd71b98bfe70
- https://chat.openai.com/c/4c594667-da27-4083-a7c5-edc20738c0eb
- https://chat.openai.com/share/e233d875-2391-4178-9b2a-63b5aa0e8fc9
- https://chat.openai.com/share/d41bf4bb-2b85-4ec7-9963-3307ea463b04

1.4 Choropleth Map: Advanced Prompt pattern

- https://chat.openai.com/share/559838e2-a63d-4389-be7a-10b97786c0c9
- https://chat.openai.com/share/c3b86d41-b9ab-4fdf-945c-152f6de6fc10
- https://chat.openai.com/share/139fcdd1-eb5e-4128-a7c1-fc320bf19662
- https://chat.openai.com/share/a6dc8f0f-dbde-4100-b8f0-daa6989db616
- https://chat.openai.com/share/5ef52675-f0bd-4efe-ac36-b55b504a65fc

1.5 Dot Density Map: Advanced Prompt pattern

- https://chat.openai.com/share/9dc482ee-f141-45be-aba3-e4ff1c3f8933
- https://chat.openai.com/share/b663499d-83e4-4050-8c84-855f298ad92c
- https://chat.openai.com/share/d8751068-bf4a-4a00-b82a-ed4aeb01e2cd
- https://chat.openai.com/share/d3166bf0-e32a-4418-abd7-8643bd94f6bc
- https://chat.openai.com/share/92e62dc0-22be-4397-a3c3-697053b4ae53

1.6 Graduated Symbols Map: Advanced Prompt pattern

- https://chat.openai.com/share/2e9c69c7-d4d5-4515-9b6d-100cbfca3061
- https://chat.openai.com/share/ecd45521-38e2-44f6-90ee-acc1a3b6371b
- https://chat.openai.com/share/9c99b1d4-b3bc-4353-956a-e316f0306fd3
- https://chat.openai.com/share/d02855f0-7162-4a5d-9ae7-21f3b3621941

- https://chat.openai.com/share/91f1e10a-b4fb-4d87-b6ee-3bec6c5dc2cf

2. Interactive Maps

2.1 Choropleth Map: Basic Prompt pattern

- https://chat.openai.com/share/7504daf8-2683-40ff-8a88-20b58c800bab
- https://chat.openai.com/share/1d0d0d73-d3ca-4e1a-b2b1-ada8a990f06f
- https://chat.openai.com/share/1b9e97da-3936-44f5-bc9b-860fccedb114
- https://chat.openai.com/share/32478f5e-47ca-4c51-b35b-214d3ba79090
- https://chat.openai.com/share/f67d0a17-e253-440b-a430-1daf94c29f72

2.2 Dot Density Map: Basic Prompt pattern

- https://chat.openai.com/share/ce004d91-11ec-4484-b5e3-e9c7cb89923c
- https://chat.openai.com/share/ea7f0835-d592-4c8f-afc2-bf48b2eb25d5
- https://chat.openai.com/share/56286d2d-7d8a-4a46-b433-57f06e116a06
- https://chat.openai.com/share/0007afdf-8ac8-4614-a614-d7917a72e878
- https://chat.openai.com/share/a3bb385c-f8fe-40bb-a794-fd13c13c45ad

2.3 Graduated Symbols Map: Basic Prompt pattern

- https://chat.openai.com/share/51f4cc6b-bd2e-4cf0-8c98-491226c9471f
- https://chat.openai.com/share/4b0b5bd9-1f49-45a4-954a-652114b695fd
- https://chat.openai.com/share/a495853c-fa3f-4803-9732-458558de43b7
- https://chat.openai.com/share/9bc50784-a4f8-4850-8ee3-6fc5df6a7c73
- https://chat.openai.com/share/9805c994-04cb-4e8b-9e88-55579edd82b6

2.4 Choropleth Map: Advanced Prompt pattern

- https://chat.openai.com/share/12607c2e-5bb4-4dc0-acc0-a5fa3a3e02e4
- https://chat.openai.com/share/40ce52d0-250b-43f4-bd6f-8c1e51c924ab
- https://chat.openai.com/share/e867706a-5658-4d72-842f-a6d6616e23de
- https://chat.openai.com/share/bfa7e0df-a05a-4bfa-b034-223a222a2907
- https://chat.openai.com/share/061694a8-0084-4e65-93b2-e360eafa340f

2.5 Dot Density Map: Advanced Prompt pattern

- https://chat.openai.com/share/3ddd204f-1bac-4679-b4d5-8342777087cb
- https://chat.openai.com/share/ef2ef147-2727-4a1d-af48-95bd66873bbc
- https://chat.openai.com/share/b4ca78fd-7d91-402b-b423-8d3af21980d5
- https://chat.openai.com/share/6b4a9dd1-fc62-499b-bf2f-517a860eeff9 &
- https://chat.openai.com/share/1344bbec-8ea4-4c92-bffb-0f31703918d2
- https://chat.openai.com/share/5d7d5a3d-1204-4c86-972d-6c935d2eb6ec

2.6 Graduated Symbols Map: Advanced Prompt pattern

- https://chat.openai.com/share/ecd65a6a-c148-456a-ab72-42c710b1928e
- https://chat.openai.com/share/a8f71824-1806-4a4c-9997-ff26187d3754
- https://chat.openai.com/share/81f87e21-ec59-4836-a5d0-921e14b0c40b
- https://chat.openai.com/share/7dfe6704-c871-469c-aad5-144982639813
- https://chat.openai.com/share/3b661a65-bf00-451f-b38f-f51fe3f0cf98