Tailoring Base Maps: A Study on Air Quality Maps

Anpassung von Grundkarten: Eine Studie über Luftqualitätskarten

  

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Abstract

With the ease of creating maps using APIs, many thematic maps are now made by non-experts, often utilizing general-purpose base maps that are typically not well-suited for the map's intended purpose. Even though the importance of tailoring base maps to thematic content has been recognized in the literature, there is only a brief discussion of the theory and a lack of empirical testing.

The objective of this study was to create a customized base map for the topic of air quality to evaluate its effectiveness. First, existing principles for base map design were identified through a literature review, providing insights from thematic cartography and web mapping, and through an evaluation of widely used base maps. A base map was developed with a focus on appearance, interactivity, and content. For the latter, particular consideration was given to factors influencing the thematic data. This customized base map was then integrated into a thematic web map and tested through an online survey, comparing its performance to another version that used a general-purpose base map.

The results show that the custom base map is more effective than the general-purpose base map, leading to a better understanding of the thematic data and aligning with existing literature. A final refinement was done based on user feedback, creating an optimized version of the base map. This study underscores the importance of customizing base maps to enhance the effectiveness of thematic maps, but more user testing is needed in future research to draw more general conclusions.

Keywords: Base Map, Map Design, Air Quality, Thematic Map Interpretation

Kurzfassung

Aufgrund der vereinfachten Erstellung von Karten durch die Nutzung von API's, werden heutzutage viele thematische Karten von Laien erstellt, oftmals unter der Verwendung allgemeiner Grundkarten, die in der Regel nicht für den Zweck der Karte geeignet sind. Obwohl die Anpassung von Grundkarten an thematische Inhalte in der Literatur als relevant betrachtet wird, erhält die Thematik kaum Aufmerksamkeit und es fehlt an empirischen Untersuchungen.

Das Ziel dieser Studie war es, eine maßgeschneiderte Grundkarte zum Thema Luftqualität zu erstellen und ihre Effektivität zu bewerten. Zunächst wurden durch eine Literaturrecherche, mit Erkenntnissen aus der thematischen Kartografie und dem Web-Mapping, sowie durch eine Bewertung häufig genutzter Grundkarten bestehende Gestaltungsprinzipien ermittelt. Es wurde eine Grundkarte mit Schwerpunkt auf deren Gestaltung, Interaktivität und Inhalt entwickelt. Für letzteres wurden Faktoren, die Einfluss auf die thematischen Daten haben, besonders berücksichtigt. Die angepasste Grundkarte wurde dann in eine thematische Webkarte integriert und in einer Online-Umfrage auf ihre Wirksamkeit im Vergleich zu einer thematischen Karte mit einer allgemeinen Grundkarte getestet.

Die Ergebnisse zeigen, dass die angepasste Grundkarte effektiver als die allgemeine Grundkarte ist und zu einem besseren Verständnis des Kartenthemas führt, das auch von der vorhandenen Literatur unterstützt wird. Verbesserungen wurden auf Grundlage des Benutzerfeedbacks vorgenommen, was zu einer optimierten Version der Grundkarte führte. Diese Studie verdeutlicht die Bedeutung, Grundkarten anzupassen, um die Effektivität von thematischen Karten zu erhöhen, jedoch sind weitere Nutzerstudien in Zukunft erforderlich, um allgemeine Schlussfolgerungen zu ziehen.

Schlüsselwörter: Grundkarte, Kartendesign, Luftqualität, Interpretation thematischer Karten

1. Introduction

In the past 30 years, digital mapping has significantly transformed cartography, including map usage and distribution. APIs have made map creation accessible, allowing both cartographers and non-experts to easily overlay datasets onto existing base maps. However, these maps often rely on general-purpose base maps that are not tailored to specific themes, reducing their quality and understanding. This highlights the importance of choosing appropriate base maps to effectively communicate thematic information [1]. Nevertheless, this topic receives only little attention in existing thematic mapping literature [2].

This research gap reveals the need for a deeper understanding of base map design for specific themes. For this study, the design is driven by the topic of air quality and its Air Quality Index (AQI), a domain influencing various facets, including the economy, climate, and public health [3]. Its significance is further emphasized by the inclusion of air quality in the Sustainable Development Goals (SDGs) 3 and 11 formulated by the United Nations (UN) [4]. Existing web maps displaying the AQI demonstrate common issues such as cluttered designs and the usage of general-purpose base maps [5, 6, 7], underscoring the necessity for tailored base maps.

Addressing the research gap, this study contributes to the field of research concerning the utilization of a customized digital base map within the context of mapping air quality data. This study investigates the effectiveness of a tailored base map design to enhance the interpretation of thematic maps, particularly those related to air quality.

In the following chapter, design principles for a base map were identified. This was done regarding the base map's content, interactive features, and appearance. In the next step, a customized base map was developed for an air quality dataset. Then, a user test was conducted to evaluate the effectiveness of the created base map in comparison to a general-purpose base map.

2. Literature Review

Base maps are simplified versions of topographic maps but typically feature fewer details. This simplification allows base maps to serve as effective foundational layers for thematic maps by maintaining clarity and focusing only on the most relevant spatial data to understand the overall map [8, 9]. This chapter gives an overview of base map content, interactivity, and appearance.

2.1 Base Map Content

Conveying a map's message effectively relies on its content, which requires a careful selection. A base map should contain only relevant topographic information; often, less is more. As it provides the geographic context, a more minimalist approach is needed to ensure clarity and coherence [1, 2]. Topographic information typically includes hydrography, transportation networks, boundaries, cultural point features, or a form of terrain representation. Typically, web maps display the map at different scales. The level of detail (LOD) of base information should align with the map scale. To maintain legibility and ensure user orientation across all zoom levels, map features must have a consistent design and should be generalized separately for each scale [10].

In addition to incorporating general topographic elements, cartographers must ensure that the base map aligns with the theme by thoughtfully selecting base layers supporting it which is an essential part of the customization process. Since this study focuses on an air quality map, the approach involved identifying factors that directly impact air quality. The factors influencing the Air Quality Index (AQI) are summarized in Table 1 and are classified into natural, anthropogenic, and other factors [11]. The assessment of the content for the base map considers that list.

Interactivity allows users to engage dynamically with the map but can also be distracting when it is overused. Research suggests that more straightforward interactive maps lead to better decision-making. Roth's typology of interaction primitives, derived from empirical research, provides a comprehensive framework for understanding interactivity in maps [12]. As this study aims to evaluate the design of the base map, only selected interactive elements were chosen. The work operators, which is one of the interaction dimensions, are relevant for interactivity in a map. Web maps for air quality often include interactivity using zoom, pan, retrieve, filter, and search [5, 6, 7]. Zoom and pan are relevant since they directly affect the base map. The search function could be used to easily find locations on the map. Other operators refer to an engagement with the thematic overlay. Such interactivity was kept minimal to focus on the base map; only clickable data points that

Types of factors	Driving factors
Natural factors	
Meteorology	Temperature, Precipitation, Wind speed, Wind direction, Relative humidity, Atmospheric pressure, Sunshine duration, Mixing height, Diurnal temperature range, Cyclone
Topography	Orographic conditions, Altitude
Ecological infrastructure	Forest/Urban forests, Road trees, Urban park
Climate	Global warming, Climate change
Anthropogenic factors	
Population	Population size, Population density, Population urbanization
Economy	Economy development, Trade, Manufacture, Cement Industry, Steel industry
Transportation	Vehicle emissions
Urban sprawl	Urban land expansion, Urban impervious surface, Urban form
Other factors	Biomass burning and forest fires, Volcanic activity

***Tab. 1:** Driving factors of air pollution*

open information pop-up windows are included, corresponding to the retrieve operator.

2.2 Base Map Appearance

Part of the base map creation process involves selecting a suitable color scheme, which should guarantee legibility and align with the map's purpose. Generally, colors for web maps should be simple and harmonious [10]. For base maps, it is suggested to use low saturated and neutral colors, such as black, white, and gray, and a limited number of colors while ensuring a low contrast within the base map. This allows the thematic overlay to stand out and establish a figure-ground contrast [1]. Consideration should be given to users' expectations to ensure familiarity, which typically includes a preference for a light base map and a color palette similar to widely used base maps [1]. As colors are associated with feelings and experiences, which vary across cultures, the color choice must be made thoughtfully to the intended audience. Therefore, following color conventions that are widely understood across cultures is suggested for a quick recognition and understanding of map elements [9]. Unfortunately, some existing base maps are not inclusive for color vision-impaired users who struggle to distinguish certain color combinations, making it difficult to discern different map features close to each other [13].To create an accessible base map, it is recommended to utilize color combinations that can be clearly distinguished: red and blue, red and purple, orange and blue, brown and blue, brown and purple, yellow and blue, yellow and purple, yellow and gray, blue and gray [14]. When adding labels to base maps, readability is prioritized. The general cartographic labeling conventions also apply to base maps [9]. Using no more than two sans-serif fonts with increased letter spacing is recommended for web maps [1, 15].

2.3 Evaluation of existing general-purpose base maps

In addition, existing base maps for general purposes were examined, offering an overview of the current state of the art in base map design and revealing how theoretical suggestions were applied to practice. For the review, five of the most widely utilized base maps were selected [16]: Google Maps, Yandex Maps, Mapbox Streets, OpenStreetMap, Esri World Topographic Map. In addition to the commercial base maps, the Street Map of the National Geographic Institute of Spain was included as an example of an authoritative base map. This selection was made to support the creation of a customized map focused on Madrid, the capital of Spain. The base map's components and appearance were compared for scales 1:172,989 and 1:68,247, which correspond to the scales of an urban area.

Many similarities between these base maps could be identified, suggesting that a custom base map should be created considering their design. It reveals what users expect from a base map, which is important to ensure a sense of familiarity. Similar to what was stated in the literature, the color saturation is low, and the color schemes are mostly neutral in these base maps. Qualitative color conventions improve the intuitiveness of understanding features like water bodies and green spaces. The map components are common topographic elements that are very similar across the maps. They mainly differ in their visibility at different scales and levels of detail. A common problem identified is a cluttered map appearance at a larger scale due to many details and small features.

This review also showed that general-purpose base maps only use topographic content without offering context related to a particular theme. This limitation must be addressed to improve the presentation of air quality data.

3. Methodology

3.1 Base Map Creation

3.1.1 Thematic Overlay

Before starting the base map design, the thematic data was selected to which the base map was customized. For this study, the thematic layer consisted of data presenting the Air Quality Index (AQI) for an urban area, using Madrid as an example. The data was provided by the European Environment Agency (EEA), with point symbols showing the location of the monitoring stations [5]. The used color scheme corresponds to the AQI on a scale from good to poor, following that of the EEA.

3.1.2 Base Map

The base map styling was done with Mapbox Studio, which offers various customization options across multiple scales. The base map was customized between zoom levels 10 and 14, which was considered suitable for the chosen dataset. The design decisions were informed by the findings in Chapter 2.

3.1.2.1 Content

Customizing the base map content is important for a better understanding of the map theme. By considering the semantic component of map creation, the base layers also present relevant information related to the topic of air quality. Therefore, factors that influence air quality were examined to align the base map with the map theme (See Chapter 2.1). Additionally, common base map components are included to provide contextual information, which is the primary function of the base map.

While some factors influencing air quality are better suited as thematic layers, only selected factors were considered for the base map: ecological infrastructure, economy, vehicle emissions, and topography. They appeared as the following layers on the base map: landuse (wood, park, industrial area), road network (highway, primary road, secondary-tertiary road, street low), and hillshade.

Additional base layers were added, providing a geographical reference for the chosen map extent: land, landuse (national park, airport), water (waterway, water body), road labels, place labels (major settlements, minor settlements, settlement subdivision), and POI labels (historic landmarks, parks, airport).

3.1.2.2 Interactivity

The interactive features were chosen based on Chapter 2.2, where common interaction operators of air quality web maps were identified: zoom, pan, search, and retrieve. The latter refers to clicking on the data points, which opens an information pop-up window with more details about each monitoring station. Filtering was not considered since it is not related to the base map itself.

3.1.2.3 Appearance

Since the map's message should be effectively conveyed, general cartographic design rules also apply to designing an appropriate base map. This includes the five key design principles, legibility, contrast, figure-ground, visual hierarchy, and balance [17], needed to enhance readability, which is a syntactic component of map design. Moreover, the base map was designed to follow the theoretical suggestions from the literature: It has low visual contrast and balanced and neutral colors. While the thematic data used bright and highly saturated colors, the colors on the base map received a low saturation to support their distinction. The design choices were documented using a ScaleMaster diagram [18] (see Table 2). The map features are listed along the y-axis, and their color and visibility within the zoom range are shown along the x-axis. The multi-scale mapping operators [19] relate to the changes made for each feature: C+ (add content), Sz (adjust size), and L+ (insert labels).

The custom base map was integrated with the thematic overlay into an ArcGIS web mapping application using ArcGIS Online (see Figure 1).

feature	geometry type	zoom level					further details
		10	11	12	13	14	
land	polygon	C+					
roads							
highway	line	C+, Sz					increasing width (exponential), white case
primary	line	C+, Sz					increasing width (exponential), white case
secondary-tertiary	line	C+, Sz					increasing width (exponential)
street low	line			C+, Sz			appear at zoom level 12, increasing width, no case
hillshade	polygon	C+					0.06 % opacity
landuse							
wood	polygon			C+			appear at zoom level 12, opacity 0.4
park	polygon			C+			appear at zoom level 12, opacity 0.4
airport	polygon	C+					opacity 0.4
national park	polygon	C+					opacity 0.5
industry	polygon			C+			appear at zoom level 12, opacity 0.5
water							
water body	polygon	C+					
waterway	line	C+					
place labels							
major settlement	–	L+					font: Roboto Medium and white halo
minor settlement	–	L+					font: Roboto Regular and white halo
settlement subdivision	–	L+					font: Roboto Regular and white halo, uppercase
road labels	–	L+					font: Roboto Regular and white halo, low density
POI labels	–	L+					label with icon, low density

Tab. 2: ScaleMaster diagram with the design choices

3.2 User Test Set Up

To assess the base map's effectiveness in supporting the thematic map, an online survey was distributed via social media in order to reach a high number of participants. The map was designed for a general audience, with no specific target group. The effectiveness of the custom map was tested by comparing its performance to a benchmark map that used Mapbox Streets, a general-purpose base map. Therefore, two survey versions were created with the same questions, but either the custom map or the benchmark map was displayed in the first survey part. It was hypothesized that the custom map would outperform the benchmark map in conveying air quality information. The participants were unaware of

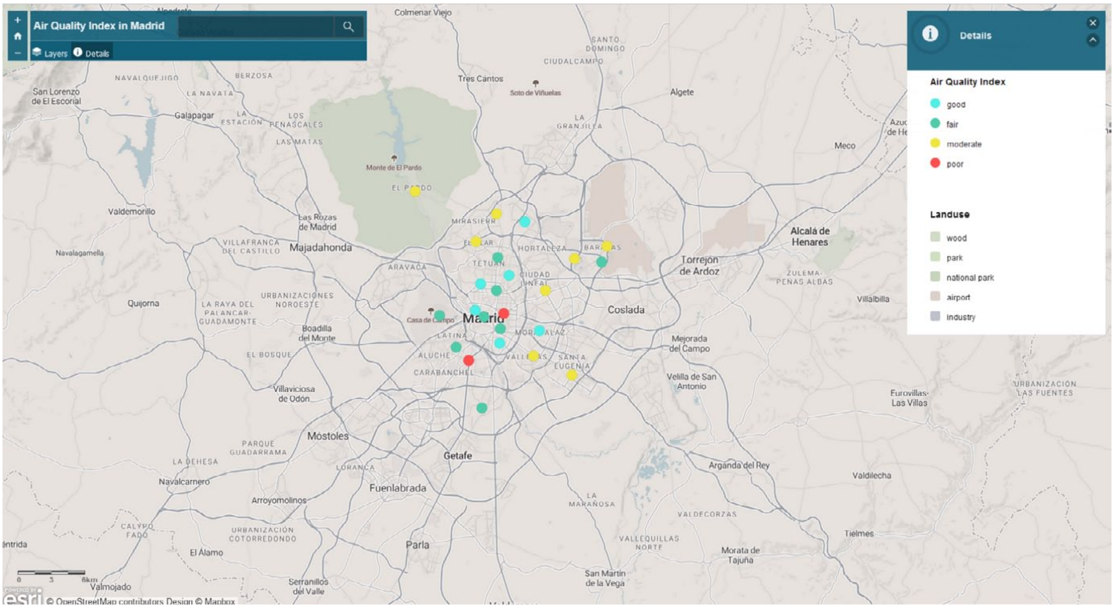

Fig. 1: Web application with the customized base map

which survey version they received. The surveys consisted of two parts:

- **Map Comprehension (Part 1):** In this section, participants answered six questions using either the custom or benchmark map, depending on their survey version. They had to combine information from the base map and thematic overlay to complete each task. The time taken for each question was recorded, and participants rated the difficulty of the tasks.
- **Feedback on the Custom Base Map Design (Part 2):** In this section, all participants viewed the custom base map, rated statements, and provided feedback on its design.

4. Results

A total of 104 responses were analyzed, with 52 participants completing each version of the survey. The demographic characteristics of both groups were similar. In both surveys, approximately half of the participants were male and half female, and around 75 % were under 30 years old. Most respondents were from Europe, comprising 85 % of users in the custom map survey and 73 % in the benchmark map survey. The vast majority of participants were familiar with interactive maps (95 % in the custom map survey, 87 % in the benchmark map survey), though most had no prior knowledge of Madrid (89 % in the custom map group, 96 % in the benchmark group). 42 % of respondents had a background in cartography or related fields, while only a few had expertise related to air quality. Approximately half of the participants had no background in either of these areas.

Out of the six questions asked in the first part of the survey, questions Q1, Q2, and Q3 involved finding specific attributes of the monitoring stations based on location descriptions. The aim was to assess the users' ability to integrate both layers of information. On the other hand, questions Q4, Q5, and Q6 focused on identifying the reasons for specific air quality at a given location. The participants had to search the surrounding area of the monitoring station to find the answer to the question. The questions were:

- Q1: Which AQI value does the monitoring station in El Pardo have?
- Q2: What air pollutant causes a moderate index level close to the airport Adolfo Suárez?
- Q3: Which index level does the monitoring station near the highway Calle 30 in the district El Pilar have?
- Q4: What could be the reason(s) for the poor air quality at the monitoring station Plaza Elíptica?
- Q5: What could be the reason(s) for the air quality at the monitoring station Ensanche de Vallecas?
- Q6: Which of the following statements are correct for the monitoring station Ramón y Cajal?

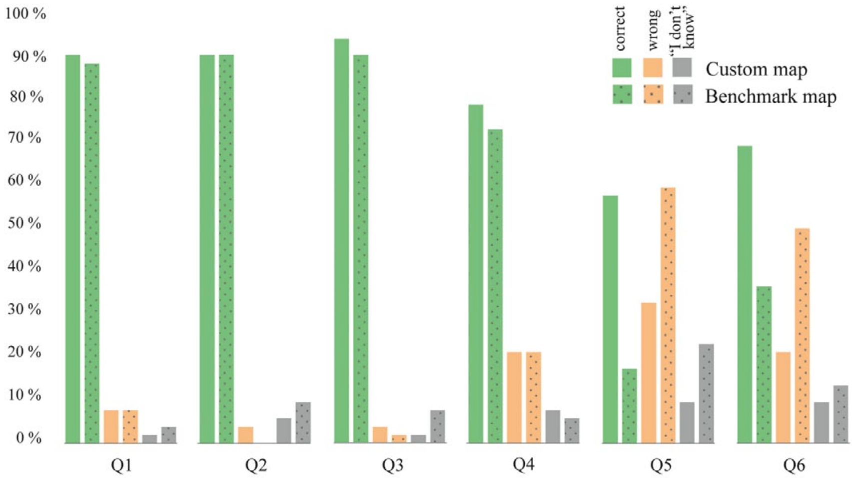

Fig. 2: *Percentage of correct answers*

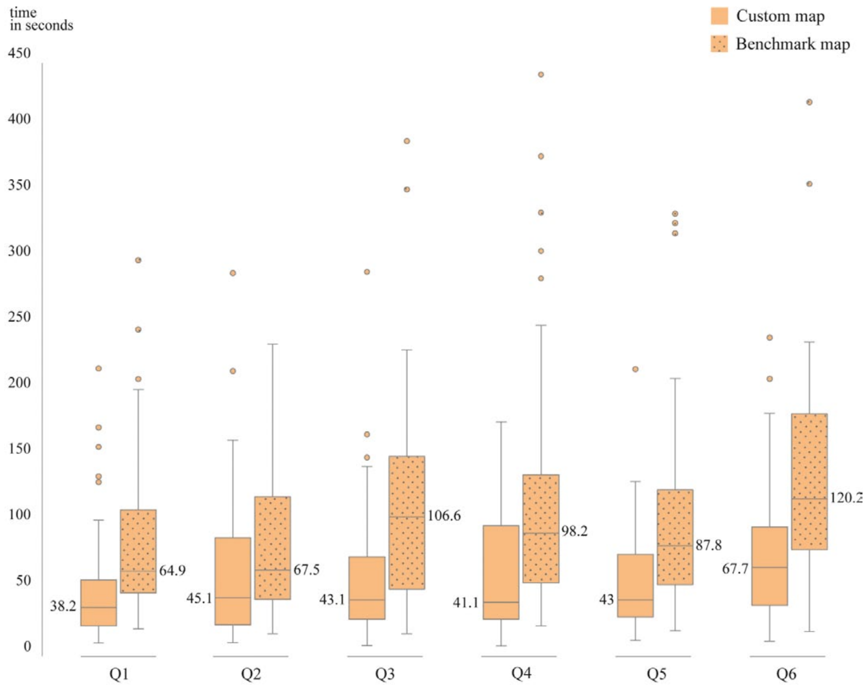

Fig. 3: *Time needed to answer the questions without outliers*

For each of the six questions, the percentage of correct answers was calculated, and the Chi-Square Test determined whether there was a significant difference in the proportion of correct answers between the two surveys. The results show that the group using the custom map had a higher percentage of correct answers across all questions compared to the group with the benchmark map, except for Q2, where both groups had the same percentage of correct answers (see Figure 2). A statistically significant difference was observed between the two groups for Q5 (p-value: 0.000) and Q6 (p-value: 0.002). Overall, the percentage of correct answers for Q1, Q2, and Q3 was around 90 % in both survey versions, while it was notably lower for Q4, Q5, and Q6.

The time taken to complete each task was also recorded, with the results summarized in Figure 3.

The boxplots reveal a clear difference in the mean time between the two survey versions. Participants who used the custom map completed the tasks more quickly for all questions than those using the benchmark map. Statistically significant differences were found in the time taken for Q1 (p-value: 0.008), Q3 (p-value: 0.005), Q4 (p-value: 0.000), and Q6 (p-value: 0.001), based on the Independent Sample T-Test.

The participants also rated the difficulty of each task on a Likert scale ranging from very easy to very difficult (see Figure 4). The results indicate that the custom map was consistently rated as easier to use across all six questions than the benchmark map. The Mann-Whitney U Test identified significant differences in perceived difficulty between the two survey versions for all questions except Q2. For Q1, Q3, Q4, Q5, and Q6, the custom map was significantly easier, with p-values of 0.000, 0.001, 0.001, 0.000, and 0.000, respectively.

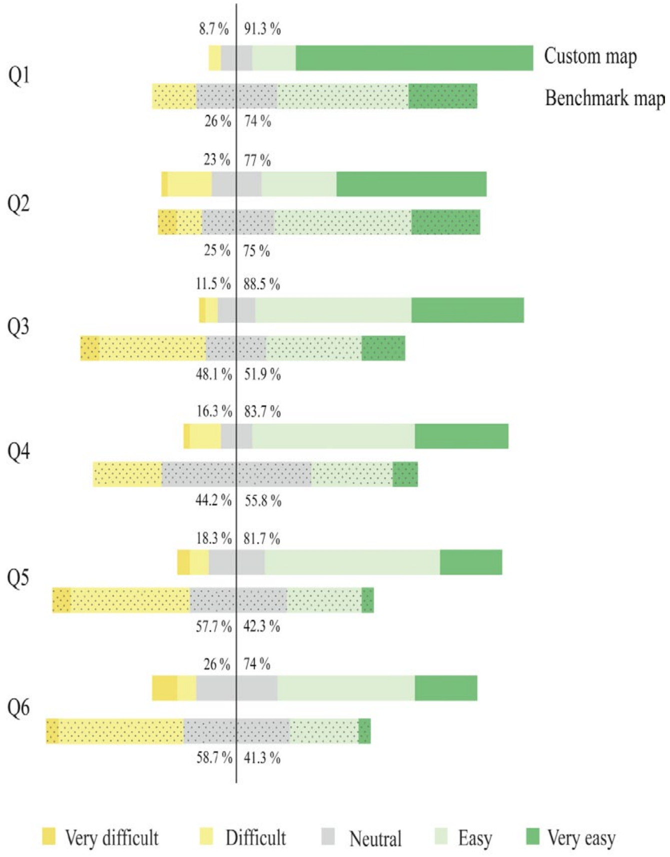

Fig. 4: Self-assessment of the question difficulty

In addition, participants were also given the opportunity to add comments explaining what they found difficult. For questions Q1, Q2, and Q3, the feedback was not related to the base map itself. Instead, users reported issues such as struggling to find locations on the map or comments indicating they misunderstood the questions. However, for questions Q4, Q5, and Q6, many users pointed out that the colors on the base map were very similar, which made it difficult to distinguish the map features. This also made completing the tasks more challenging. That issue was frequently mentioned in both survey versions despite the different styles of both base maps.

In the second part of the survey, which focused on feedback about the custom base map, participants rated four statements on a scale from strongly agree to strongly disagree. The results, shown in Figure 5, were mainly positive, although there was some criticism, particularly for Q8, Q9, and Q11. The comments of Q8 and Q9 were mainly related to the similarity of the base map colors, reflecting previous feedback. For Q11, participants mentioned that they would like the ability to zoom in further to see more details.

5. Discussion

5.1 Interpretation of the Map Comprehension Tasks

The results indicate that the custom map outperformed the benchmark map across all six questions: the percentage of correct answers was higher (except for Q2, where it was the same percentage), the participants responded more quickly, and the questions were rated as easier compared to the benchmark map, with many of the results being significant. This supports the hypothesis that the custom base map would lead to better outcomes, confirming its efficiency and effectiveness. The results also showed that the questions Q1, Q2, and Q3 performed better compared to Q4, Q5, and Q6, possibly because locating something based on a description is generally easier and less demanding than understanding more complex questions that are directly related to air quality.

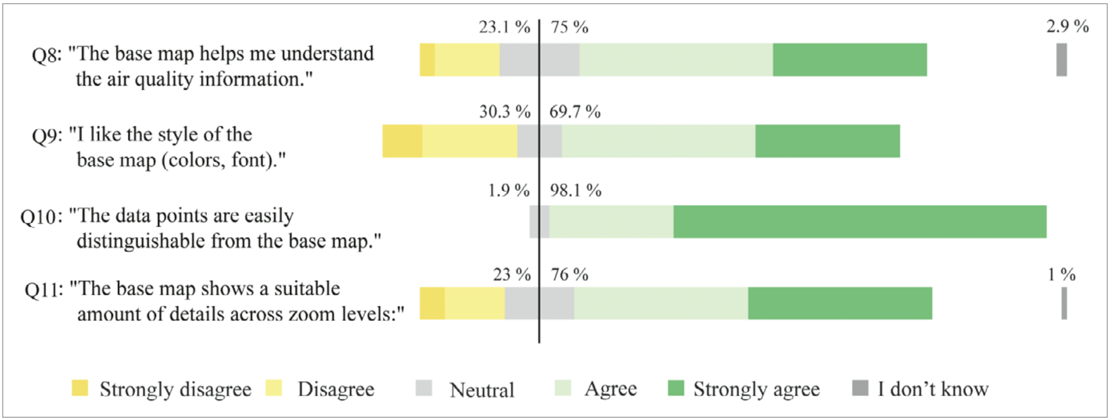

Fig. 5: Rating of statements

Consequently, customizing a base map is helpful for better understanding the thematic content, which aligns with the suggestions from the literature [20]. The custom base map likely performed better by only using landuse layers that support the thematic topic, chosen based on the factors influencing air quality. In contrast, the comparatively poor performance of the benchmark map indicates that it was more challenging to identify relevant information.

However, despite the higher effectiveness of the custom map compared to the benchmark map, the error rate was still high. This suggests that the custom map could benefit from further refinement, particularly when the map is made for a specific user group.

5.2 Interpretation of user feedback

The collected feedback on the custom base map reveals that the figure-ground contrast between the thematic layer and the base map has been achieved. However, people had difficulty distinguishing the colors on the custom base map, which made important information less noticeable. This may have contributed to incorrect answers and made the questions feel more complicated. That issue is possibly the biggest drawback, as it was repeatedly mentioned in the comments. The challenge when designing a base map is to ensure that no information stands out while providing enough contrast to make all features easily distinguishable [1]. Most participants found the level of detail across zoom levels in the custom map suitable (Q11). However, some requested the ability to zoom in further to view more details. Therefore, another challenge in base map design is to find a balance between the level of detail while keeping it as simple as possible.

Following the user feedback, the base map was refined by making minor adjustments to improve understanding of the map's theme. The contrast between map features was increased, and the zoom range was extended to zoom level 15. All green spaces were combined into one category to only include necessary base information. A video showcasing the final map is available under this link: https://kartoweb.itc.nl/msc-carto-thesis/materials/ulrike_holfeld//Appendix_F_Final_Custom_Map.mp4.

5.3 Limitations

Firstly, the web application was developed using Mapbox Studio and ArcGIS Online, which offer limited customization options. For greater flexibility, programming the application from scratch is recommended.

Moreover, conducting the survey in an uncontrolled environment generally introduces uncertainty about the accuracy of the results. Additionally, the participant profiles were similar across both survey versions, ensuring comparability, but the overall sample was mostly young and experienced with interactive maps. This raises the question of whether different user profiles might have influenced the results and how this impacts the interpretation of their significance.

6. Conclusion

This study aimed to investigate the effectiveness of a customized base map design. A base map was created with the goal of improving the interpretation and understanding of the overall map. Since base maps need to align with the theme and purpose of the map topic, a methodology for creating a custom base map was developed and can be applied in the future. The user test revealed that creating custom base maps for thematic maps is of great importance, and while this is well-known among cartographers, it might sometimes be overlooked. Since maps are no longer created by experts only, a lack of understanding about the importance of custom base maps can reduce the quality of a map. Customization can significantly enhance the effectiveness and user understanding of the map information.

The thematic map produced was only one example of tailoring a base map and testing its effectiveness. Further research is required to support these findings for different thematic overlays and map scales to draw more general conclusions. The proposed methodology can be extended by integrating eye-tracking and interviews with users and experts for more qualitative insights. Furthermore, it could be explored how to incorporate artificial intelligence into this area of research to benefit from a simplified customization process for base maps. An automated generation of base maps can advance the process, especially by saving time in their creation.

References

[1] *Muehlenhaus, I.* (2014). Web cartography: Map design for interactive and mobile devices. CRC Press.

[2] *Dent, B. D., Torguson, J. S., & Hodler, T. W.* (2009). Cartography thematic map design (6th ed.). McGraw-Hill Higher Education.

[3] United Nations Environment Programme. (2024). Why does air matter? Retrieved May 6, 2024, from http://www.unep.org/topics/air/why-does-air-matter

[4] United Nations General Assembly. (2015). Transforming our world: The 2030 Agenda for Sustainable Development, A/RES/70/1.

[5] European Environment Agency. (2024). European Air Quality Index. Retrieved May 15, 2024, from https://airindex.eea.europa.eu/AQI/index.html#

[6] The World Air Quality Index Project. (2024). World's Air Pollution: Real-time Air Quality Index. Retrieved May 17, 2024, from https://waqi.info/

[7] Umweltbundesamt. (2024). Luftqualität. Retrieved May 17, 2024, from https://www.umweltbundesamt.de/daten/luft/luftdaten/luftqualitaet/eJzrWJSSuMrIwMhE18BY19hgUUnmIkPjRXmpCxYVIyyxNDU1W5ziVgRXYGS8OCUkH1I9bhX3otzkpsU5iSWnHbwcGVfE3JBYnJOXftpBa3UEAwMDIwCSFCHI

[8] *Kraak, M.-J., & Ormeling, F.* (2020). Cartography: Visualization of Geospatial Data, Fourth Edition (4th ed.). CRC Press.

[9] *Slocum, T. A., McMaster, R. B., Kessler, F. C., & Howard, H. H.* (2022). Thematic Cartography and Geovisualization (4th ed.). CRC Press.

[10] *Nivala, A.-M., Brewster, S., & Sarjakoski, T. L.* (2008). Usability Evaluation of Web Mapping Sites. The Cartographic Journal, 45 (2), 129–138.

[11] *Liu, H., Fang, C., Zhang, X., Wang, Z., Bao, C., & Li, F.* (2017). The effect of natural and anthropogenic factors on haze pollution in Chinese cities: A spatial econometrics approach. Journal of Cleaner Production, 165, 323–333.

[12] *Roth, R. E.* (2012). An Empirically-Derived Taxonomy of Cartographic Interaction Primitives. Proceedings of GIScience 2012.

[13] *Peterson, G. N.* (2020). GIS Cartography: A Guide to Effective Map Design (3rd ed.). CRC Press.

[14] *Brewer, C. A.* (2015). Designing Better Maps: A Guide for GIS Users. Esri Press.

[15] *Jenny, B., Jenny, H., & Räber, S.* (2008). Map design for the Internet. In International Perspectives on Maps and the Internet (pp. 31–48). Springer Berlin Heidelberg.

[16] BuiltWith. (2024). Maps Usage: Statistics for websites using Maps technologies. Retrieved May 6, 2024, from https://trends.builtwith.com/mapping/maps

[17] *Robinson, A. H., Morrison, J. L., & Muehrcke, P. C.* (1995). Elements of Cartography (5th ed.). John Wiley; Sons.

[18] *Brewer, C. A., & Buttenfield, B. P.* (2007). Framing Guidelines for Multi-Scale Map Design Using Databases at Multiple Resolutions. Cartography and Geographic Information Science, 34 (1), 3–15.

[19] *Roth, R. E., Brewer, C. A., & Stryker, M. S.* (2011): A typology of operators for maintaining legible map designs at multiple scales. Cartographic Perspectives, (68), 29–64.

[20] *Arnberger, E.* (1977): Thematische Kartographie. Westermann.

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