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Are Dashboards Useful? - Developing and Evaluating Interactive Map-based Dashboards for Spatial Decision Making

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Are dashboards useful?

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Utveckling och utvärdering av interaktiva kart-baserade visualiseringar som beslutsstöd

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Abstract

Spatial planners, informed with relevant knowledge of trade-offs, makes better spatial planning decisions This allows decision-makers and stakeholders to benefit from state of the art research when planning for the future. However, explaining complex data to people who are not domain experts or scientists can be an extraordinary challenge. This thesis presents an investigation of the usefulness of map-based dashboards and how these can be built to support science-based spatial planning. It includes a competitive analysis of 21 dashboards in addition to an in-depth case study evaluating how users gain insights from using such a tool. The results suggest that having pre-defined clear goals and customize the dashboard to its targeted audience makes it more likely to be useful. Using the results from the evaluation, a set of guidelines are created as well as a codebase for a dashboard template. The template can be used by researchers wanting to display their own spatial data with a minimum amount of coding.

Acknowledgments

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1 Introduction

Visual representations are used within several different applications. It can be used for prototyping new houses, displaying trends, and results in economics, describing different aspects of a model, or explain advanced physical phenomenons. In either case, visual representations are means of conveying an idea to a user and support them in creating their own mental model of the task or data set. Visual representations can with this definition be seen as tools for explaining complex data to users who are not originally experts in the specific field.

Visual representations are, therefore, often used when researchers or other creators of data want to display their findings to decision-makers, or people with the task of acting on the data at hand. This thesis work will focus on representing data for decision-makers within spatial planning and how map-based dashboards can help them make better, more informed decisions. The analysis will be based on decisions related to environmental issues such as reducing coastal hazards, improving water quality, or aid pollination.

In this context, decision-makers or spatial planners can be the local government planning city expansions, company leadership wanting to know how to protect themselves from flooding, non-profit organizations with the aim of holding the authorities accountable for their actions, or just the interested public. The challenges they are facing are various and often complex [2]. Spatial planning requires various factors to be taken into account, both regarding the physiological factors around nature but also socio-economic structures [2, 24]. To this end, scientific findings about the impacts on nature as well as knowledge about local regulations and culture can be useful [37]. Since decision-makers can not be experts in all relevant areas, effective communication techniques such as visual representations and graphics are crucial to bridge the gap between science and decision-making [3, 1].

1.1 Motivation

Maps can be seen as a communication process with the aim to convey the cartographer's knowledge about the mapped phenomenon to the map-reader [32]. It is a process that transfers a known set of geographic insights from map-creator to map-reader.

For spatial planning, map-based dashboards are developed to provide decision-makers with the recent research findings and thus aim to support them in making decisions [27, 6, 16]. The interactive maps let the users explore the data in a format that, assuming that the users can read maps, are easier to understand than just viewing the raw data in itself. By then combining the maps with charts and key performance indicators (KPIs) it is possible to highlight the key messages of the data [2, 39]. These dashboards thereby helps decision-makers to generate new, previously serendipitous insights about the displayed topic.

Nonetheless, developing and maintaining these dashboards requires a lot of resources [1]. Since the researchers themselves normally are not visualization experts they have to either spend a lot of time learning new tools or outsource the development. Allocating funding for this requires that researchers can point to the benefits of having these tools. However, there is a gap in research investigating how useful these tools are when used for real problems. Visualization and cartography are highly regarded within their own research fields, but interestingly, the latest visualization research is rarely used in applied cases [2]. This results in few scientific examples researchers can show when arguing that they need more resources for visualization [39]. This thesis work will, therefore, evaluate the usefulness of interactive maps and dashboards, and hopefully serve as an entrance point for creating better visualizations in applied research.

1.2 Aim

The aim of this thesis is to investigate interactive map-based dashboards, how they are built, and how they can be of use for decision-makers. The findings can then be used for the future development of new map-based dashboards.

The work is based on four main segments, all considering different aspects of map-based dashboards.

Firstly, twenty-one dashboards are compared using a competitive analysis [28]. This investigates the features implemented in different dashboards. The aim is to analyze if there are any trends on which features are used, if there are any unmet user needs, and how this relates to the usefulness of the tools.

Secondly, how users interacting with a specific dashboard, and what insights they gain from using it, is evaluated using an insight-based methodology proposed by North [29]. This aims at contributing to the research by filling the gap about how users gain insights from visual representations [2, 17].

Thirdly, a set of guidelines for new developers is created based on the results of the two first segments, in addition to lessons learned from experts in cartography and visualization. This aims to suffice the need [36] of supporting research groups in creating their own map-based dashboards and hopes to place the research in a wider context.

Fourthly, following the guidelines, an open-source template [15] is developed as a resource for non-visualization experts. Using the template and a minimum amount of coding they can create their own map-based dashboard for displaying their spatial data.

1.3 Research questions

Throughout the four segments, this thesis work seeks to answer the following questions:

1. Are interactive map-based dashboards successful in supporting decision-makers in complex environmental reasoning leading to better, science-based, spatial planning?
2. What factors are important to consider when developing map-based dashboards to ensure that it is useful for decision-makers?
3. Given the results from (1) and (2), how can a template that facilitates the creation of new map-based dashboards be designed and implemented?

1.4 Delimitations

This thesis work will mainly focus on visual representations in terms of interactive maps and charts displayed in dashboards. Furthermore, the present work is strongly connected to real case scenarios of visualizing research data for decision-makers working with environmental issues. The research will concentrate on analyzing the representation of spatial data in dashboards. However, the guidelines presented are applicable to the development of other dashboards as well.

2 | Related Work

A literature review was done to gain an understanding of the basics of dashboards and evaluation techniques. During the reviewing process, 51 papers were reviewed. 20 of them were in the domain of dashboard design and guidelines as well as lessons learned from the field of business intelligence. The remaining 31 were targeted at *Human Computer Interaction* (HCI) and information visualization, mainly focusing on different methods for system and insight evaluation. Moreover, during the thesis work, 50 researchers, developers, cartographers, and visualization experts were interviewed to gain feedback and insights from their work.

2.1 Dashboards: definition & objectives

Dashboards are visual displays containing the most important metrics of a specific dataset needed for executives and decision-makers to achieve one or more objectives [7]. The objectives are to create awareness and facilitate actionable understanding for the sake of helping users to make well-informed decisions [37, 3, 1]. They can communicate an overview of the data, present the bigger picture of a complex situation, and thus trigger a discussion about strategy and preventative action [3, 1, 40]. For some examples of dashboards see Figure 2.1 and 2.2.

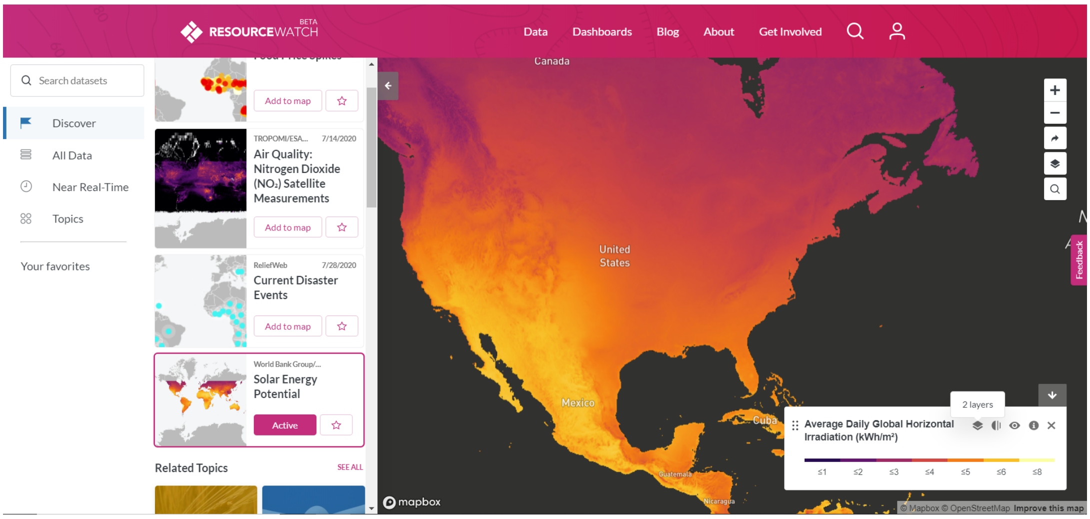

Figure 2.1: Dashboard example – Resource watch [16]. This dashboard is convened by the World Resources Institute (WRI) and features hundreds of data sets in one place to be a resource for government staff, journalists, citizens, etc. Users can display data concerning people and the planet, from climate change to poverty, water risk to state instability, air pollution to human migration, and more.

During the literature review of dashboards, most domain research belongs to the segment of design studies; how to develop dashboards in a climate-data context, what to include, and

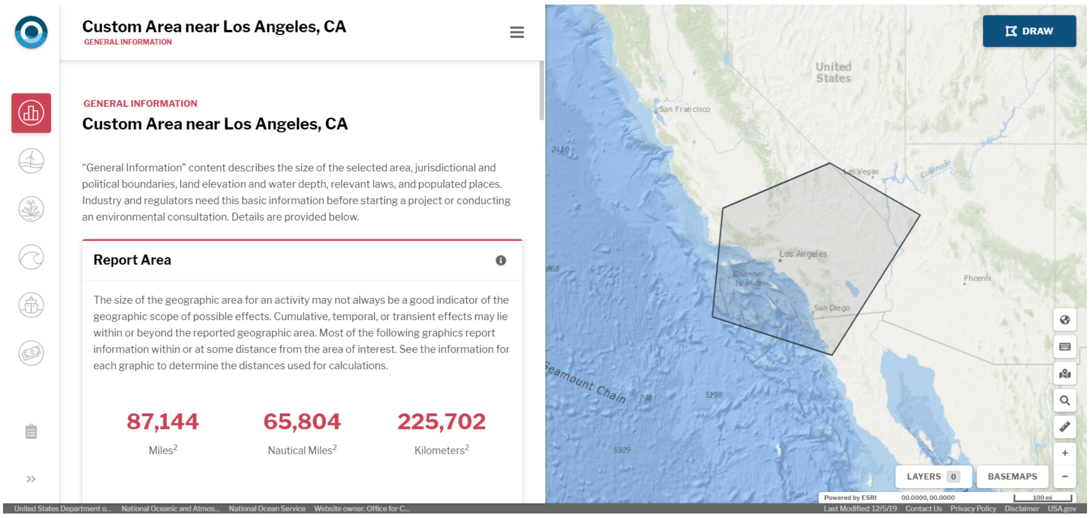

Figure 2.2: Dashboard example – Oceans report [6]. This dashboard is created by the Bureau of Ocean Energy Management and the National Oceanic and Atmospheric Administration. Users can draw a custom area of the coast in the U.S. and receive descriptive infographics and supporting data that can be used for offshore planning, permitting, environmental review, public relations, and more.

how to deploy it. An overview of this will be presented in section 2.2. However, when it comes to evaluation, most previous research is lacking relevant empirical studies where the dashboards are assessed by the targeted audience [5].

2.2 How to design a dashboard

For a dashboard to be useful, the design and implementation are critical to ensure the user is not misled nor confused. There are numerous design guidelines and principles when it comes to creating dashboards, especially when they are used in the context of business intelligence. In this chapter, common ones will be synthesized, and some challenges and lessons learned by developers and domain experts will be presented.

2.2.1 Who? – Know the audience and their knowledge level

During the preparation and design phase, it is important to define the audience and their needs [1, 36]. Different knowledge levels and overall understanding of the data will require different designs and functionality. The users' language and domain-specific knowledge must be taken into consideration when developing the dashboard. A non-technical decision-maker with a low data literacy will not be able to understand a complex graph or data representation. They will need clear legends, some context information, and a simple interface. For an audience with higher data literacy, more complex features that allow for further analysis is beneficial [1, 36].

Moreover, considerations should also be taken regarding the environment the users operate in. Decision-makers are often limited by time constraints [23], dashboards should, therefore, be simple, easy to use, and require minimal or no training [40]. To facilitate user understanding and create engaging dashboards, it is common is to start with an overview to present the big picture. For the more interested user, drill down options like zoom, filtering, or brushing can then be added to allow for a deeper analysis of a specific area [5, 36].

2.2.2 Why? – Define the insight you want the audience to gain.

Another important step during the preparation phase is defining what insights the users are targeted to gain [40]. What is the goal and main objective of the dashboard? For some dashboards the objective might help users understand a data model, for others, it might be to give suggestions for strategic development. Different objectives will call for different features and these need to be sketched out and planned in advance.

2.2.3 What? – Characterize the data needed to provide the targeted insights

The next step is to decide what parts of the data to display. The metrics and Key Performance Indicators (KPI) chosen should be aligned with the type of strategy and insights the visualization is supposed to give [1, 36, 23]. As mentioned before, it is also important to consider in what order the data should be displayed. Can the data be summarized for an overview and then divided into smaller more detailed pieces?

2.2.4 How? – Develop in iterations

Highly iterative and collaborative development has proven to help create useful tailored visualization [1, 5, 23]. By developing in cross-functional teams with both data analysts, designers, developers, and end-users, the dashboard is ensured to be understandable to its audience. It is also more likely to motivate further studies within the application area, and thus increase the chances of user action [37].

2.3 Evaluating the usefulness of map-based dashboards

In order to evaluate if the design is indeed good and adjusted to the users, some type of evaluation can be done. To evaluate how useful a visual analytic tool is, usability has to be defined. Usability is described by the International Organization for Standardization (ISO-standard) as dimensions of efficiency, effectiveness, and satisfaction [18]. Where efficiency is the how well the system achieves the targeted objectives, effectiveness is how fast and how the effective cognitive load is while using the system, and satisfaction is the user's overall experience and perceived ease of use of the system. Nonetheless, how this usability should be evaluated is not defined. In HCI, evaluation has been discussed quite extensively, however, it was not until the early 2000s that the information visualization community made a shift and started to consider the evaluation and assessing as highly important [10].

Even since this shift in research, many studies still lack an evaluation section, and the ones reported are often difficult to validate and too informal to use for cross-comparison [2, 17]. It is hard to find the right task and questions to ask, which method to use, and which variables to consider [20, 9]. Furthermore, compared to HCI, there is no standardized format for conducting these evaluations [11]. In HCI, standardized questionnaires, such as the System Usability Scale (SUS) [4] have been created for the sake of collecting usability-data in an easy and time-effective manner [11]. However, for these questionnaires to be relevant for information visualization they need to be adjusted.

2.3.1 Evaluations mostly measures tasks and algorithm performance

When considering 581 research papers, Isenberg et al. found that most focus in the evaluation research has been on task-based evaluation techniques [17]. Within this field, Algorithm Performance (AP) and Qualitative Result inspection (QRI) are the most common. AP meaning measuring, e.g memorability or the time needed to execute a specific task, and QRI; asking the reader to agree on a quality statement by inspecting a result image (e.g. *"as shown in Figure X, all data is included"*) [17]. Together, scenarios where AP or QRI were evaluated stands for 81% of the total number of coded scenarios. By definition, both AP and QRI are conducted without any actual study participants. This emphasizes that most research is done without connection to the real users.

In the context of visualizations for decision making, user feedback is key and necessary for assessing how helpful a tool is [37, 17]. The task-based methodologies conducted in controlled environments mainly targets the evaluation of a specific novel technique or a comparison between two alternative representations [20, 5]. For decision support tools that have a higher level of exploratory usage, these methods are not suitable on their own. For benchmark tasks, they need to be executed fast, there is one correct answer and finally, the answer must be fairly simple. This is not the case for tasks within a decision support tool [5, 29]. The main outcome of these tools are insights, which are not as concrete as a specific benchmark tasks [5, 29]. Further, in real use scenarios, the users do not necessarily know what they are looking for, and that is an important part of the context the tool is used within. If users knew what they were interested in, e.g. like in the scenario where they are given a task, they might prefer some other form of representation. However, in a "real-life scenario", the task is undefined and the tool must support that.

2.4 Methods for evaluating usefulness are harder to find

When evaluating tools for decision support the *basic HCI methods* evaluating the interface is not enough. Even though analyzing the interface, placement of buttons, etc, is important to create a friction-free interaction, evaluations regarding what the decision-makers actually can learn from the tool is just as important. Methods for evaluating the insights gained by the user rather than specific tasks normally require more time and resources[17]. These methods are thus harder to come by and when they are, they "are often stated matter-of-factly as opposed to explaining how certainty about these insights was achieved and invite to further investigation" [20].

The challenge increases since it is hard to compare results from two different dashboards. One user can try two dashboards, however, then the user is biased when testing the second dashboard since they already have some knowledge about the data. Two different data sets can't be used because then the gained insights about the data cannot be compared. Alternatively, two users can try one dashboard each, but since gained insights from using a tool is highly personal, the results will still be hard to compare. Further, the fact that tools for decision making are used in many different ways and are context-sensitive makes them harder to evaluate in a quantified manner [20]. Instead, qualitative approaches designed for studying the real world have to be used.

For measuring issues of a higher level such as exploration, insights, and decision-making, the scenario of evaluating Visual Data Analysis and Reasoning (VDAR) can be used [20]. Goals for methods within this evaluation scenario is to "assess a visualization tool's ability to support visual analysis and reasoning about data" [20]. Outcomes are quantifiable metrics regarding insight as well as subjective opinions about the quality and data analysis experience [20, 17].

2.5 Evaluating users' gained insights

Insight-based evaluation methodology [29] is a concrete method within the VDAR scenario and a way of leaving benchmark task-testing. Rather than instructing users on what insights they *should get* this method instead observe what insights users *gain on their own*. In this context, insight can be defined as *"an individual observation about the data by the participant, a unit of discovery"* [34]. The insight-based methodology evaluates how the user builds their mental model of the data which, in extension, is needed for them to make a better decision. Studies using this method have been done in applications of clinical data [21], health and wellbeing [22], and bioinformatics [34, 35].

2.5.1 Open-ended protocol, think aloud and insight analysis

Common for all the studies [21, 22, 34, 35] is their focus on open-ended protocol, qualitative insights analysis, and the domain knowledge relevance of the chosen participants. The protocol starts by letting the participants present some initial questions about the data, then let them explore the system and take note of the insights they gain, either by a diary or a "think aloud"-protocol. The insights recorded are then finally assessed and evaluated. Metrics to be explored can be the number of insights, clustered insight categories, the domain value of the insights, and the time it took to generate them. The insights gained by the users can also be compared to the ones aimed for by the researchers. Nevertheless, to do this kind of analysis, the concept of "insight" has to be further defined and characterized.

2.5.2 Characterizing insights

To assess and distinguish different types of insights, some insight-characteristics were presented in the original methodology [29]. These characteristics have then been refined before being used in other case studies [21, 34]. Listed below are the characteristics used in this thesis.

- **Observation/fact** – The finding or observation made by the participant. It should be connected to the existing domain knowledge and go beyond simple data statements to relevant domain impact. E.g "This area is blue" is not enough, but "This area is blue which means it is flooded" is approved as an insight.
- **Domain Value** – The value of the insight. This is defined by the complexity and depth of the finding and is context-based. The scale is coded on a five-point scale from 1, an obvious fact in the data, to 5, a deep understanding of underlying relations that integrates prior knowledge about the area or topic. Eg. "This area is blue which means it is flooded" has a low domain value while "We can see that this blue flooded area does not cover the areas that are higher up in the mountains, therefore it is safe to build our new hospital there" has a high domain value.
- **Hypothesis** – If the insight is leading the participant to identify a new hypothesis relevant to the domain or not. An example of a hypothesis could be "Since we know that this area will be flooded, maybe that means that a lot of sediments will be exported and the soil will be useless for agriculture". A Hypothesis does not have to be correct and can just be a hunch, the correctness is evaluated separately.
- **Directed vs Unexpected** – Directed insights were those expected by the researchers and developers of the tool while unexpected were those that were not considered in the design but emerged from using the tool.
- **Correctness** – Level of correctness. This is also coded on a five-point scale from 1, fuzzy not entirely correct insight, to 5, precise and correct insight. This has to be assessed by domain experts with good knowledge of the data and the domain.

2.6 Comparing dashboards

A method for comparing similar systems in the interest of usability engineering is the competitive analysis [28, 33]. It is commonly used in the prototype phase of a new product in order to examine and test already available tools [8]. Using this method, different features and assets can be compared to map out the current landscape of map-based dashboards.

Different groups of coders can be used depending on what the study aims to investigate. This thesis focuses on the features of interactive maps and how those contribute to the usefulness of the dashboard. Therefore, the following four groups of coders will be evaluated; (1) **Visual variables** – the way of symbolizing the data as described in the study by Fish and Calvert [8], (2) **Interaction operators** – how the users can interact with the map as proposed by Roth [31], (3) **Communication functionalities** – features such as tutorials or summary charts aimed to facilitate decision making and communication, and finally, (4) **Perceived Usefulness for decision making** – developed as four modified statements from the SUS questionnaire [4]. Details about the different groups are displayed in Figure 3.1

3 | Method

To understand the essence of dashboards and their usefulness, various factors have been investigated through four main segments of the thesis. (1) In the interest of *analyzing the current state* of map-based dashboards and what features they include, a competitive analysis comparing twenty-one dashboards was conducted. (2) To further examine *how* dashboards could help users gain knowledge, an insight-based evaluation of a specific tool was performed. (3) *A short paper, and a set of guidelines* for new developers wanting to create their own dashboard, was thereafter composed. (4) Finally, for the sake of further facilitating the development process for developers with little coding skills, *a dashboard template* was created.

3.1 Comparing twenty-one dashboards

Twenty-one interactive map-based dashboards were compared and evaluated during a competitive analysis [28]. This analyzed the features and cartographic techniques that are used in map-based dashboards today. In addition, interviews with developers and project managers for all dashboards were conducted to further discuss their development process, objectives, and outcomes of their tools.

3.1.1 Dashboard sample

All selected dashboards were map-based and developed for the topic of environmental data such as coastal risks, pollination, ecosystem services (how nature's ecosystem helps humans).

They were chosen to cover different scales (10 global, 7 regional, and 4 local), for various users (6 scientists, 18 policy-makers or spatial planners, and 9 interested public). Originally 27 dashboards were analyzed, however, 6 were removed since they were not finalized or developed for a particular type of advanced user.

3.1.2 Analysing features

As presented in section 2.6, four code groups were used for the competitive analysis; (1) Visual variables, (2) Interaction operators, (3) Communication functionalities, and (4) Perceived Usefulness (see details in Figure 3.1).

The first 3 code groups were analyzed by a single coder since they were only assessed based on their presence or absence. Seeing that the last code group (code group 4) subjectively assessed usability statements, three coders rated them independently and the final value was then based on the median of the ratings.

3.1.3 Semi-structured interviews with developers

For each of the selected dashboards, the developers and/or project lead were invited to participate in a 30-40 minute interview. These semi-structured [19], open-ended, interviews began with questions regarding the respective dashboard's targeted users, as well as their objectives and aimed goals. The respondents were then asked to rate the same usability statements as the experts (see Figure 3.1). This allowed a comparison between the developers and experts ratings. Finally, the interviews ended with an open discussion about what their development process looked like, did they do any evaluation, and what were their future goals.

All interviews were recorded after getting approval from the participant. The recordings were then used to extract relevant answers about goals, targeted users, and the ratings.

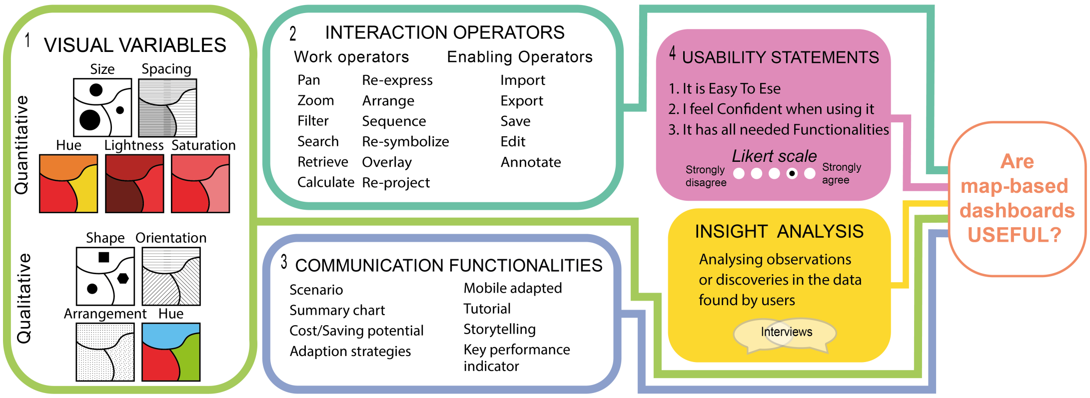

Figure 3.1: The exploratory part of the method consists of a competitive analysis based on the 4 code groups, and an insight-based evaluation of the PRO Agua viewer (see Section 3.2). Code groupings 1-3 are assessed based on presence or absence while code group 4 and the insight analysis are assessed subjectively by multiple coders.

3.2 Case study - Insight-based evaluation of the PRO Agua viewer

During the early stages of the thesis work, the PRO Agua viewer [25] was finalized to be used for a case study of a specific dashboard.

The PRO Agua (Proyecto Resiliencia y Ordenamiento Territorial del Agua translated Water Resilience and Land Management project) is a collaborative partnership by local projects in South America and the Natural Capital Project at Stanford University. The project aims to demonstrate the benefits of ecosystem services and comprehensive watershed management for the health and well-being of the growing population in the Amazon. It aspires to increase understanding of the proper use of the area and its resources to help sustainable development for a better future [14].

The aim of the PRO Agua viewer is to communicate the findings of the PRO Agua project in an easily accessible, user-friendly format. The viewer is composed of a series of interactive maps, graphs, photographs, and descriptions about the data sets (See Figure 3.2) and was developed to be support decision-makers both on a local- and national level.

The data is divided into different tabs where each tab concerns a specific topic (Watersheds, Flooding, Dengue fever, and Mining). Each topic contains two maps, one for the present situation and one for future scenarios that can be toggled using radio buttons.

The viewer was built with HTML, JavaScript, and CSS. External libraries like Leaflet and c3.js was used for the maps and charts.

3.2.1 Insight-based evaluation

The PRO Agua viewer was evaluated using the insight-based methodology presented in section 2.5. How well the users interacted with the tool and gained insights was intended to be an indication of how useful the dashboard was.

The user-evaluation was set up as remote interviews with potential end-users and project partners. Each interview was about 30 minutes long and both sound and video were

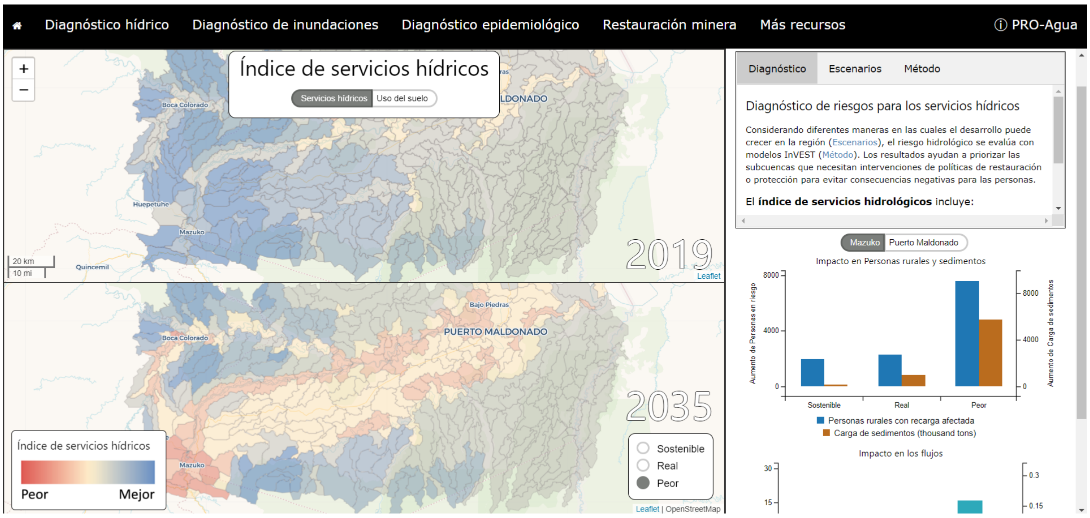

Figure 3.2: Screenshot of the Watershed tab in the PRO Agua viewer. The top map displays the current situation and the other the worst future scenario. The right panel presents information about the dataset and some summarizing charts.

recorded. The protocol started with background questions regarding the participants' occupation and previous time spent with the viewer. The participants also had to rate their own knowledge about the project and data analysis in general. The knowledge was rated on a five-point scale from 1, no knowledge, to 5, full knowledge. The rest of the interview protocol consisted of an exploratory part and an open discussion about the tool.

At the beginning of the exploratory part, the participants were given a 2-3 minute tutorial of which parts of the viewer they could use. They were then asked to use the viewer freely and act as if they were local decision-makers for 10 minutes. During these 10 minutes, the participants were encouraged to openly discuss everything they did and what conclusions and insights they could make from the data. The participants shared their screens so their interactions could be recorded. They could ask questions about specific functionality but not about the data or its origin.

After the exploratory session, the participants were asked to rate how well they understood and worked with the tool. The same usability statements as used for the competitive analysis was used. The participants were also given the chance to give other feedback and speak freely about the tool.

3.2.2 Choosing participants

An important part of the insight-based methodology is the selection of participants. They should preferably be potential end-users and have the domain knowledge needed to benefit from the data. Furthermore, the aim of this evaluation was to analyze first-time users, since that is the closest scenario to real usage. Therefore, the requirement for inclusion was that the participant had not spent more than an hour with the viewer prior to the interview.

The participants chosen were mainly located in Puerto Maldonado, Peru (which is the area displayed in the viewer), with the exception of 2 master students in Geology located in Sweden. In total sixteen participants were interviewed and twelve of them met the inclusion criteria of little or no previous usage of the viewer. No consideration was taken to age, gender, or education.

3.2.3 Analysing the interviews

When all interviews were conducted, the insights were extracted and coded using the characteristics (Observation, Domain-value, Hypothesis, Directed vs Unexpected, and Correctness) presented in section 2.5.2. The insights were coded independently by two coders. Inconsistencies for Hypothesis and Directed vs Unexpected were discussed and for the other characteristics, the average value was computed.

The insights were then analyzed and compared based on the previous knowledge of the user, how correct they were compared to their domain-relevance, and to the participant's self-rated experience. The analysis was done using *pandas* in python.

3.3 Synthesizing data to guidelines and a paper

The competitive analysis and insight-based evaluation of PRO Agua was conducted in an intertwined manner, mostly depending on waiting time for interviews and expert ratings. When they were done, work shifted to focus on analyzing the data and synthesize the findings to a comprehensive short paper (8 pages) [14]. During this process, a set of guidelines was also developed derived from the empirical data of the evaluations, literature review, and interviews with experts in the field of cartography, user research, and visualizations.

3.4 Creating a dashboard template

A simple dashboard template was developed to finalize the work and further contribute to supporting new developers in making their own map-based dashboards. The template was created to be used by researchers who are non-visualization developers but want to communicate their spatial data as map-layers on a website. Requirements were that the template, through a minimum amount of coding, could be adjusted to display shapefiles, rasters, and tilesets on maps in addition to summarising data in charts. Places to include information about the specific project, as well as descriptions and methods for creating the data sets, should also be provided.

3.4.1 Prototyping phase

During the prototyping process, the users for such a template as well as the minimum functionalities (See Table 3.1) were defined and placed in a design document. Goals regarding design objectives were also discussed and finally, a wire-frame was created in *Adobe XD*. The wire-frame was tested and adjusted before moving on to the development phase.

3.4.2 Development phase

The template was developed in React using bootstrap for styling and external libraries such as *Leaflet* and *c3.js* for the maps and charts. Functionalities for users to easily deploy their dashboard on GitHub pages were also included. The dashboard was built as several components so the users could pick and choose whichever they wanted. The code was also adjusted so the non-advanced users only had to alter a few files to make their desired changes. A comprehensive *Readme* with a step-by-step guide to how to get started and how to add data was also created.

3.4.3 Testing and evaluation

When a first version of the template, including all the required functionalities, was done it was shared with the visualization team at the Natural Capital Project (NatCap) to gain feedback and see if they would like to use it in their upcoming projects. Feedback was gained

Table 3.1: Functionalities for the dashboard template

Required functionality	
Menu	*To navigate between the dashboard page and about page*
Dashboard page	*Dashboard including all the map-layers and charts*
About page	*Placeholder for writing about the project*
Displaying map-layers on a map	*Tilesets, shapefiles and rasters*
Interactive legend to data sets	*Allowing the coder to add a legend to each map-layer*
Toggle between map-layers	*Allowing the user to choose which map-layers to display*
Display information about data	*Information button to all map-layers*
Summary bar chart	*Overviewer of the entire dashboard in a bar chart*
Download data	*Possibility to add download links to all map-layers*
Additional Functionalities	
Other types of charts	*Eg. pie charts or line charts*
Charts connected to map-layers	*Click a polygon on the map and update the chart*
Tooltips for features in shapefiles	*Add a tooltip when polygons on the map are hovered*
Icons for point map-layer	*Add possibility for custom icons for point map-layers*
Static images	*Including static images that are enlarged when clicked*

through emails but also through meetings. From this feedback, the template was altered to account for those use cases the NatCappers mostly needed a template for.

The template was finally presented at the NatCap virtual summer workshop [26]. During that event, about 350 researchers and students were introduced to the template and asked to share their results and feedback. After the workshop, some final adjustments were made based on feedback from experts at NatCap and the testers from the workshop.

4 Results

The aim of this thesis was to investigate the usefulness of map-based dashboards. The work considered both the features that are implemented in current dashboards as well as examined how users gained knowledge from working with such a tool. The results were both quantitative and qualitative and the final outcome was a dashboard template.

4.1 Comparison of twenty-one dashboards

The result of the comparison and competitive analysis served both as an overview of what features were used as well as qualitative data about the development process for the respective dashboard.

4.1.1 Most used features

The features most used are displayed in Figure 4.1. For representing data on the maps *Hue* and *Lightness* was the most used symbology. *Spacing* was never used and *Arrangement* was only found in two dashboards.These features are harder to implement according to the developers.

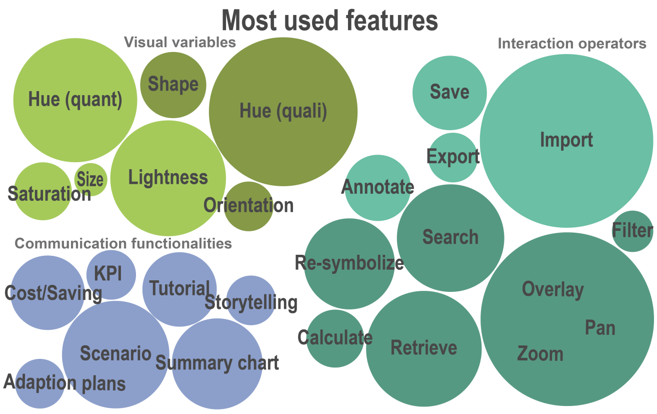

Figure 4.1: Most used Features implemented in the twenty-one dashboards that was compared during the competitive analysis. The colors correspond to the code groups visual variables (green), interaction operators (turquoise), and communication functionalities (blue). The circle size is mapped to the number of dashboards that implements the feature.

For interaction operators, *Import*, *Overlay*, *Zoom*, and *Pan* was implemented in all dashboards. Furthermore, *Retrieve*, *Search*, and *Re-symbolize* in terms of changing the opacity was commonly included. Features enabling users to share their works with others, like *Save* and *Export*, were more rarely implemented although this was often asked for by users. Moreover, features allowing users to investigate other perspectives of the data, like *re-express* or *re-project*, were sparsely implemented. Developers felt that those features would place too much of the data investigation in the hands of the decision-makers which they did not expect the decision-makers to want nor have time for.

Finally, the most common communication functionalities were presenting future *Scenarios* or including *Summary Charts*. Presenting *Adaption plans* or *Cost/Saving potential* were less common but normally asked for in dashboards created for a local topic.

4.1.2 Usability ratings

All dashboards were rated based on the 3 usability statements presented in Figure 3.1 as well as the statement: "This dashboard is useful for decision-makers". Ten dashboards were rated highly useful (usefulness rating 4.0-5.0), six were rated less useful (usefulness rating 3.5-1.7).

The medians of all usability statements were calculated and results are displayed in Table 4.1. Data from the table suggest that the dashboards, in general, are useful and rate quite high (4) on average on all usability statements. It is also suggested that developers and project leads, when self-rating their work, have a tendency to overestimate their own tools. Especially if the tools are not evaluated.

Table 4.1: Median of usability ratings made by developers and the three experts. The ratings are also divided based on E = Evaluated dashboards, and n-E = non-Evaluated dashboards.

	Usefulness			**Ease-of-use**			**Functionalities**			**Confidence**		
	All	*E*	*n-E*	*All*	*E*	*n-E*	*All*	*E*	*n-E*	*All*	*E*	*n-E*
Expert rating (Median)	4	4	4	4	4	3	4	4	4	4	4	3
Self rating (Median)	4	4	4	4	5	4	4	4	4	4	4	4

The four highest ranked dashboards based on the usability statements were (1) Resource Watch [16], (2) Ocean Reports[6], (3) Resilience and Preparedness [30], and (4) the PRO Agua viewer [25]. The features included for those dashboards are displayed in Figure 4.2

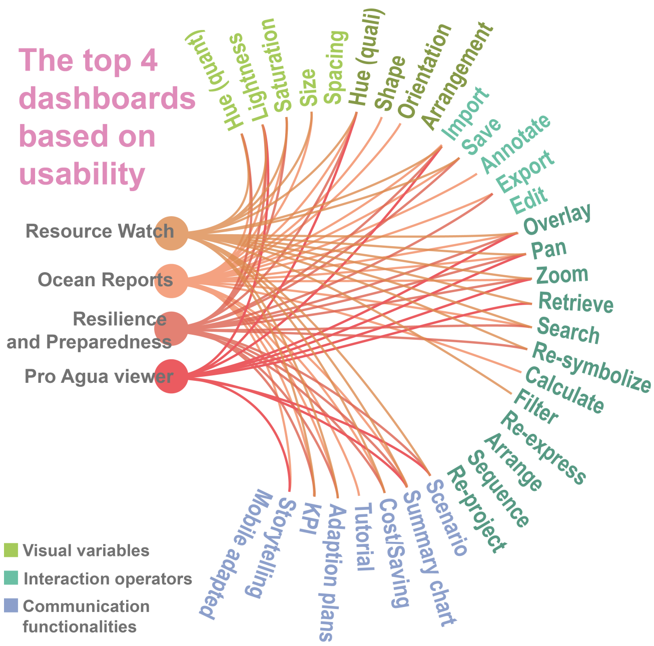

Figure 4.2: The features implemented in the four dashboards with highest usability ratings.

4.1.3 Notes on evaluation

During the interviews with developers and project leads, the question regarding evaluation was usually more extensively discussed by the respondents. From the twenty-one dashboards, only ten had been evaluated and tested at some point during the development process. The evaluation ranged from peer-reviewing by colleagues, to questionnaires and advanced user research.

The reasons described for not evaluating mostly involved lack of time, resources, and knowledge. The top four dashboards were all extensively evaluated and two of them had a dedicated user researcher connected to the project.

4.1.4 Defined goals vs usefulness

All developers were asked about the main goals and objectives of their tools. The answers ranged from clearly defined goals to more broad ones such as "let users explore our data". How well the goal was defined was then mapped to the usefulness of the tool (See figure 4.3). The data suggests, with a significant correlation of *Pearson's correlation coefficient* - r = 0.74, that dashboards with a clearly defined goal are more useful. Furthermore, customized dashboards adjusted to the targeted user group as well as the goals also are more likely to be useful.

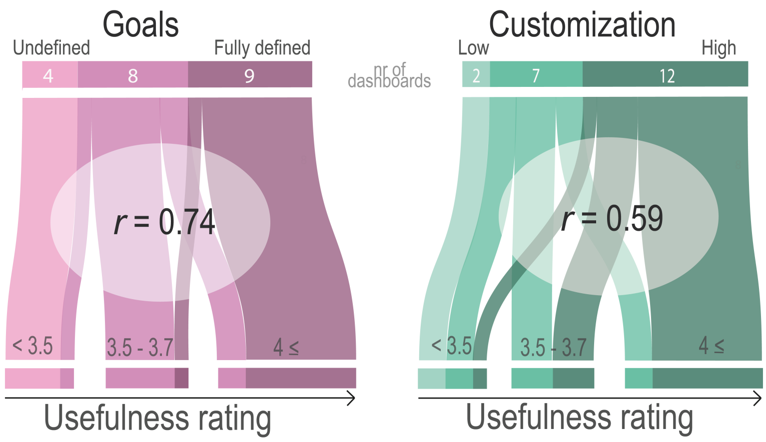

Figure 4.3: Customized dashboards with clearly defined goals are more likely to be useful. The lightness describes the level of goal definition/customization, the color clusters are then mapped to how useful those dashboards were rated.

4.1.5 Common outcomes

During the interviews, the developers were all asked about the outcomes of their tools. All of them indicated that their tools were useful and of key-value for communicating their work. However, they did have difficulties with distinguishing the outcomes solely from the tools from the outcome of their research in general.

Given the qualitative data from the interviews, the following list of dashboards' potential outcomes was synthesized. The list was also presented in the short paper [14]

- **Monitoring and creating data transparency** – Dashboards can help to monitor the status of a variety of topics such as forests, mangroves, coral reefs, etc. Reported outcomes are ranging from finding illegal logging roads in South America to being able to assess the damage of a coral reef after a ship accident. Furthermore, the dashboards can provide data transparency and were used by non-profit organizations and journalists.

- **Being a key tool for discussion** – Dashboards can be key pieces in facilitating discussion. Web-based dashboards built for non-scientist allow basically anyone to access them and inform themselves with the data provided. Examples are dashboards used in discussions regarding fishing areas vs turbines, agreeing on suitable logging areas as well as discussion about the relevance of the data itself.

- **Creating research exposure and help to secure funding** – The final group of outcomes is the exposure these dashboards give to the associated research project. Since dashboards potentially are more easily accessible than the report itself they can be a link to the interested public, other scientists, or potential funders. Dashboards, thereby, can help the scientist get feedback on their work as well as being used to allocate funding to new projects.

4.2 Insight-based evaluation of the PRO Agua viewer

The analysis of the insights gained by the participants while using the PRO Agua viewer is presented in Figure 4.4. In total 141 insights were extracted from the 12 interviews which makes for an average of $\approx$ 12 insights per interview ($\approx$ 1 insight per minute). However, the number of insights varied from 6 to 21 insights between the participants.

From all the 141 insights, 30% were hypothesis which shows that users could create their own narrative from using the tool. 72% of the insights were directed which could suggest that the users mostly followed the curated path designed by the researchers but that they also could draw some un-directed conclusions. The data further suggest that the users were able to define the insights enough to reach a quite high correctness value (median = 4 of 5). Overall the domain-value was 2.5.

The insights were also divided based on the participants' prior knowledge about data analysis and the PRO Agua project. This showed that participants with more prior knowledge could obtain more of the domain relevant insights and were also better at finding unexpected insights (insights that the researcher did not target directly). Furthermore, participants with higher knowledge were also more likely to come up with new hypothesis than those with lower prior knowledge.

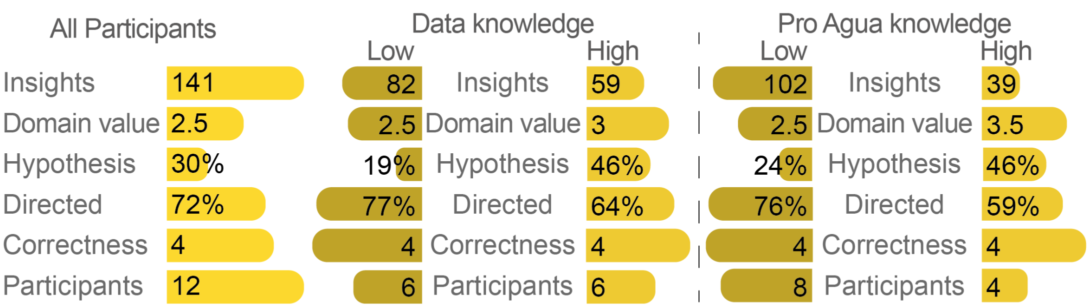

Figure 4.4: (Left) – All insights gained by users during the insight-based evaluation. (Right) – Insights divided based on the participants' previous knowledge about data and the Pro Agua project.

4.2.1 "Real" outcome compared to self-rated statements

As mentioned in the method, the participants were also asked to rate the three usability statements as well as the usefulness statement. The median ratings were between 4-5 for all statements which could indicate that there was nothing to change. However, when comparing the user ratings with how well they found insights a pattern emerged. Users tended to be "too nice" when rating the tools even if they could not gain many valuable insights (see Figure 4.5). Even participants that could not gain more than 3 high-value insights rated that the viewer was easy to use and that they felt confident while using it. This demonstrated that by just asking users to rate statements about usability, the full picture of how the users actually can use the tool will not be presented. To understand this, a qualitative user evaluation is needed (see discussion in section 2.4).

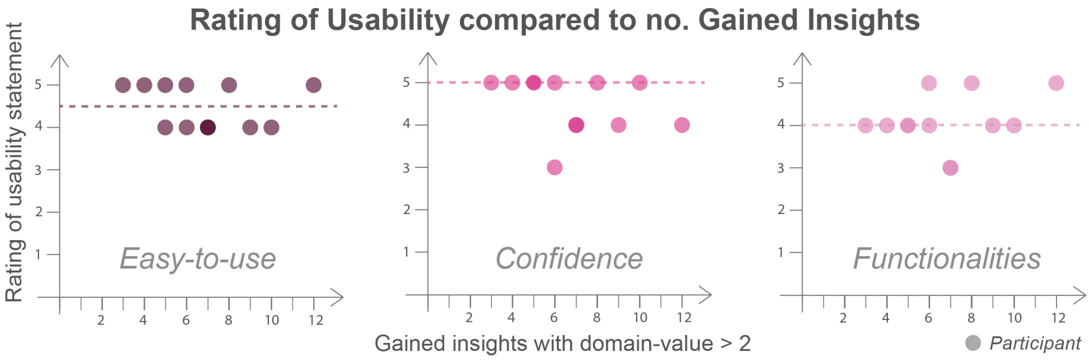

Figure 4.5: (Left) – all insights gained by users during the insight-based evaluation. (Right) – Insights divided based on the participants' previous knowledge about data and the Pro Agua project.

4.3 Guidelines

During the thesis work, several aspects of designing, implementing, and evaluating useful dashboards have been identified. These were then synthesized to a set of guidelines concerning; Time and resources, Stakeholder discussions, Prototyping, Data literacy, Guiding the users, and the Development process (see Figure 4.6).

4.3.1 Plan and prototype before coding

Just like in other cases of interface development the result from the present study as well as previous work [23, 1] emphasizes the importance of prototyping early on in the development process. This allows the developers to consider different aspects before coding, both technical but also design-wise. Drawing on paper or creating simple wire-frames is less expensive than coding and can help the developers to communicate their work and also elicit early feedback from stakeholders and end-users.

4.3.2 Guide the user through the data

The next step is to decide what parts of the data that should be displayed. By clearly defining the goal and aimed outcomes of the dashboards, this knowledge can then serve as a base when choosing which metrics to include. This can help the creation of more useful dashboards and make sure the tool fulfill the users' needs [36, 1].

In order to be able to guide the user, the user also needs to be defined in terms of what they want and what their backgrounds are (see discussion in chapter 2.2). If the dashboard e.g. is built to support concrete decisions it could be beneficial to include some strategies and cost/saving potential. Furthermore, the data can not speak for itself and needs to be properly labeled or described to make sure the users can understand it. Presenting the overall picture, e.g. with a summary chart or an image can be a good way of drawing the attention to the tool and make sure all users have the same background information. By then allowing for

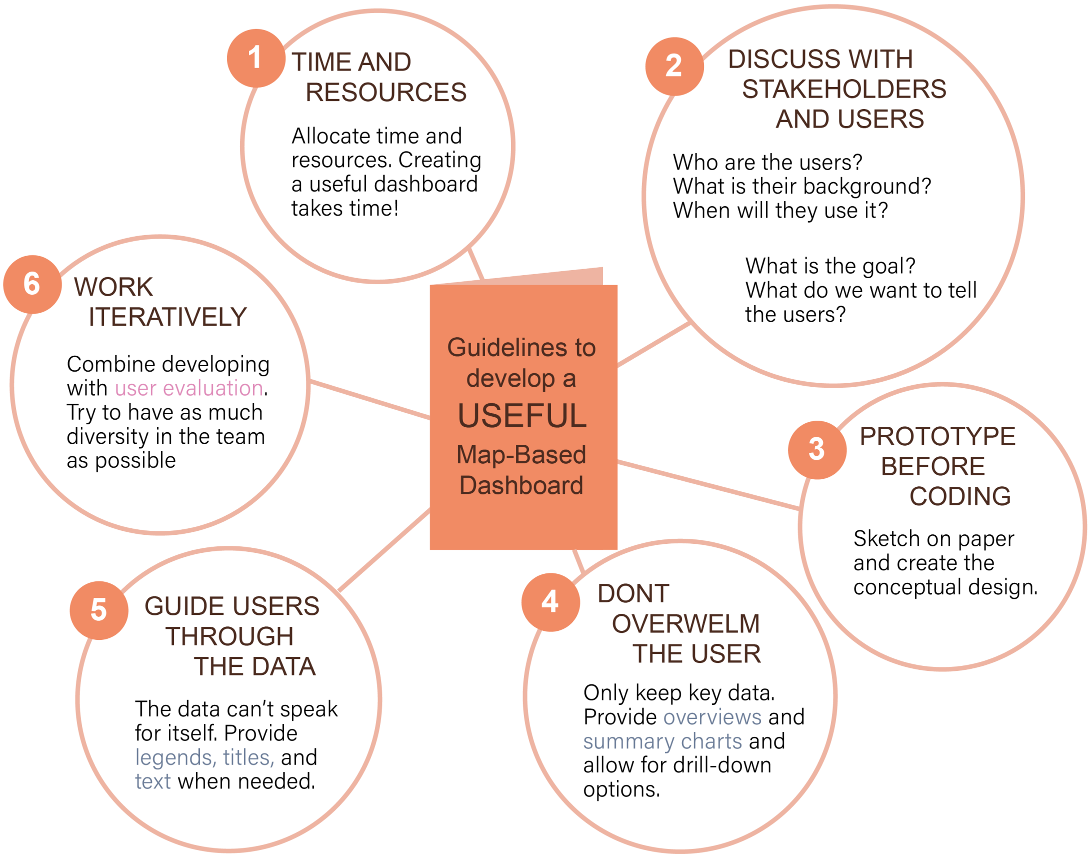

Figure 4.6: Synthesized guidelines from interviewing experts, the competitive analysis and the insight-based evaluation

exploratory options like zoom or filtering, the dashboard can be adjusted to also serve users with higher data literacy. [36, 12].

4.3.3 Conduct evaluations throughout the process

Working and analyzing the evaluation data, as well as interviewing experts, revealed the importance of conducting proper evaluation throughout the development process. This helps developers understand their users and create more useful, tailored visualization [23, 1, 12]. User evaluation and discussions with end users can also help motivate further work and increase the chances that the tool is used [37, 24]. This was the case for the dashboard template (see section 4.4.3)

4.4 Dashboard template

The dashboard template was developed in different phases and feedback from other visualization experts at NatCap was discussed and included iteratively. This section presents the results from the different phases. All functionality presented in Table 3.1 such as basic map-layers, menu, different charts, and an interactive legend was implemented.

4.4.1 Prototypes

The prototype was created in Adobe XD and was partly wired with basic buttons so testers could get a feeling of how the final product could be used. This wireframe in addition to a design document consisting of background, motivation, and desired functionalities served as the base for the first discussion with the NatCap stakeholders and potential end-users. Since the final product was supposed to be a template useful for the staff in charge of visualization at NatCap, those were the users involved in the discussions. Users (which were coders) were expended to have some basic coding skills but not necessarily be experts at web-development.

The prototype of the landing page is presented in Figure 4.7. It consists of a pop-up describing how to use the viewer. Moreover, there are two main tabs in the menu, one called *Dashboard* containing the maps and data to be displayed (see Figure 4.8) and the *About* tab (see Figure 4.9) which includes information about the project, contributors, etc. For the dashboard, the coder can decide which data-layers should be displayed by default, and can thereby guide the user through the most important data. The initial state of the dashboard is meant to provide an overview of what data is there and then allow the user to zoom in, and read more about the data sets they are interested in.

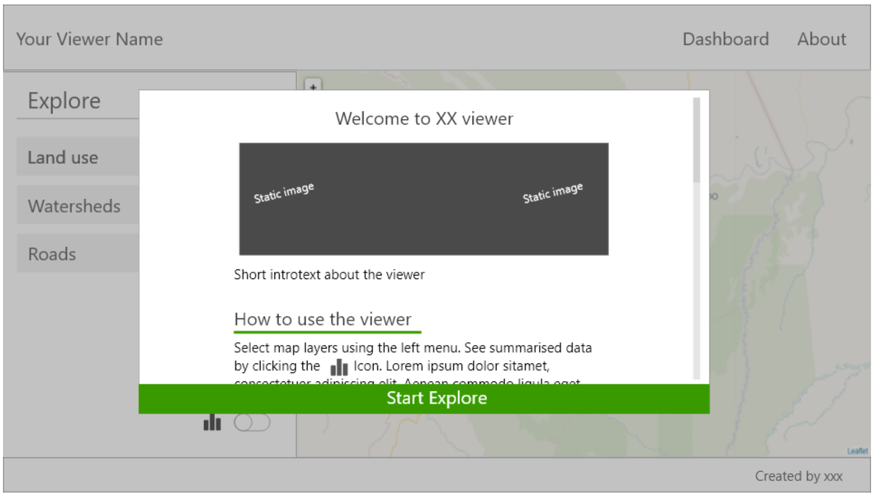

Figure 4.7: Prototype - Landing Page

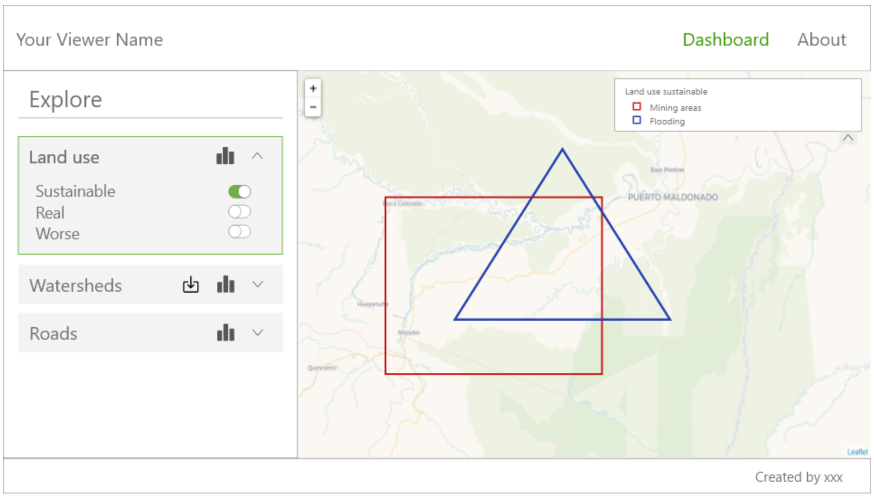

Figure 4.8: Prototype - Dashboard with selected layers. Legend in top right corner. Control panel to the left.

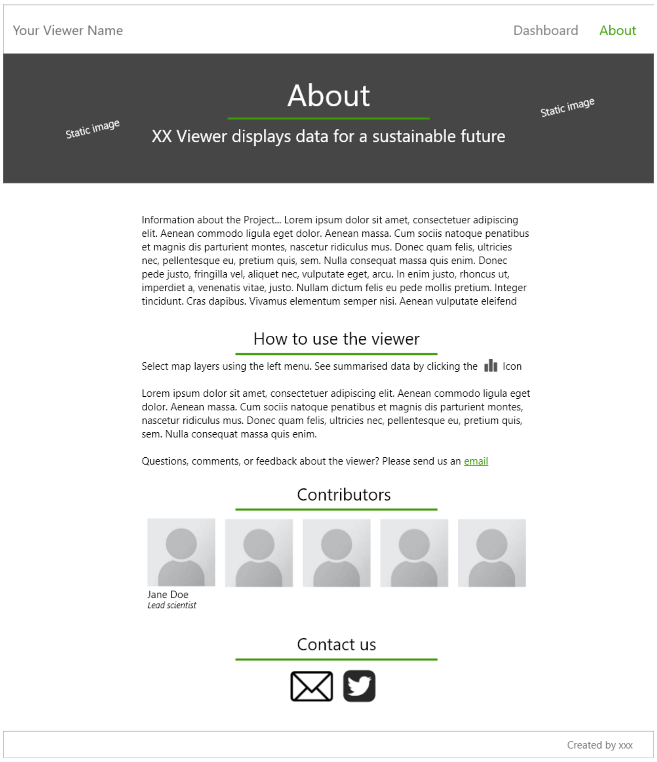

Figure 4.9: Prototype - About page

4.4.2 Final dashboard template

After the discussion with the stakeholders, some changes were made to the design before implementation. The theme was changed to a darker color pallet to make it more consistent with the rest of NatCaps' tools. Furthermore, a help button was added to the menu. When clicked, this re-launched the landing page with instructions on how to use the viewer.

Functionality wise, a major change was that instead of allowing for one chart per data section, one chart was allowed for the entire dashboard (see Figure 4.10). This made the codebase more intuitive for new coders but of course, made the template slightly less customizable. The coders could also decide if they wanted the chart to have a static dataset or if it should be linked to a map-layer and updated when the user selected points or polygons on the map. Finally, the chart was also moved from the secondary panel to be displayed directly in the left panel (see Figure 4.10 and 4.11). This change was made to make sure the users did not miss the information displayed in the chart.

Figure 4.10 is presenting a chart linked to a map-layer. The polygon corresponding to the data mapped in the chart is highlighted so the user can see what part of the map the data is coming from. If no polygon is selected the chart is emptied and replaced with a text stating "click on the map to display chart".

Images in the secondary panel (see Figure 4.11) are clickable which is highlighted with a pointer cursor when they are hovered. When the images are clicked a larger version of the image is displayed and the users also get the options of downloading it.

An example of a raster layer as well as a point map with icons is presented in Figure 4.12. When clicking on the icon a popup is displayed which the coder can adjust to display the relevant attributes of their specific data layer. Icon and polygon layers can also have tooltips.

For each data layer, a legend is displayed in the right corner. The legend is created based on images the coders have added. The legend is optional for the coder. If the coder has not

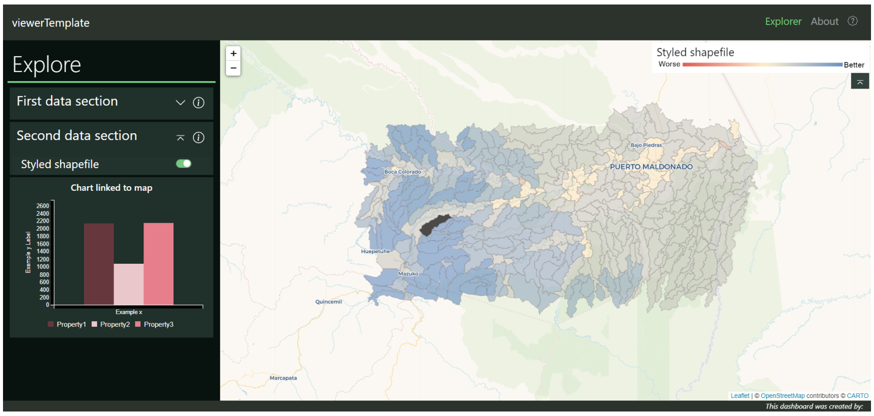

Figure 4.10: Final viewer – Chart linked to map-layer.

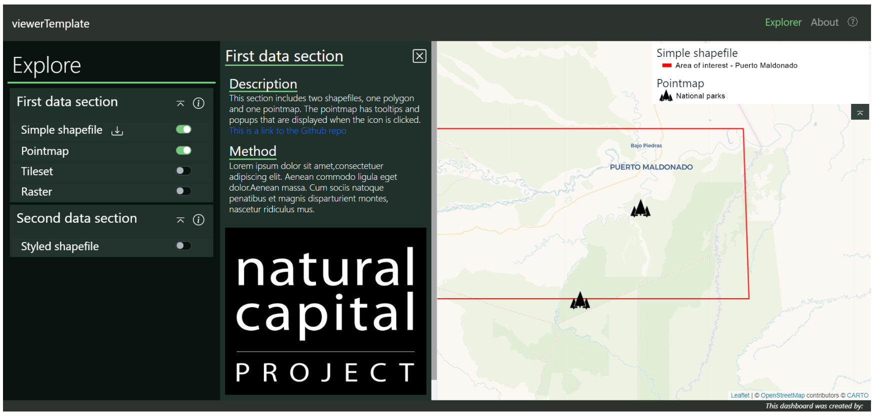

Figure 4.11: Final viewer – Secondary panel

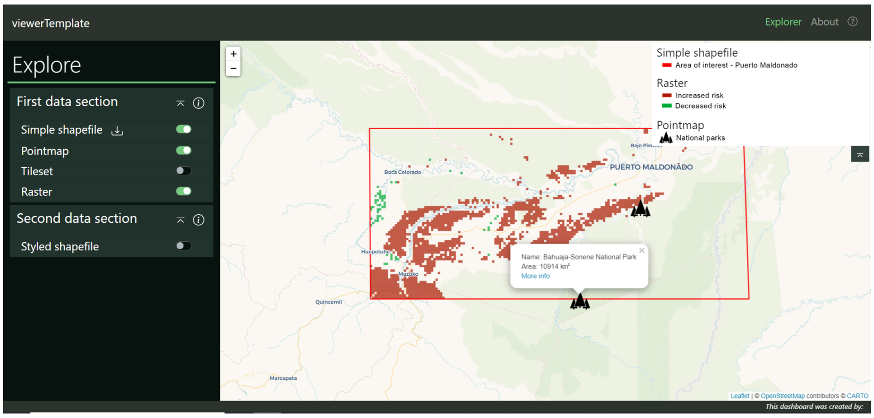

Figure 4.12: Final viewer – Example of a raster layer and a pointmap with icons

provided a legend for a data layer, the layer is still displayed on the map but does not show up in the right legend. The legend can be collapsed so the users can see more of the map.

The about page consists of a template for the coders to add their own information about their project (see Figure 4.14). A code snippet is prepared to automatically add contributors based on an array of names and images. Otherwise, that page is completely customizable.

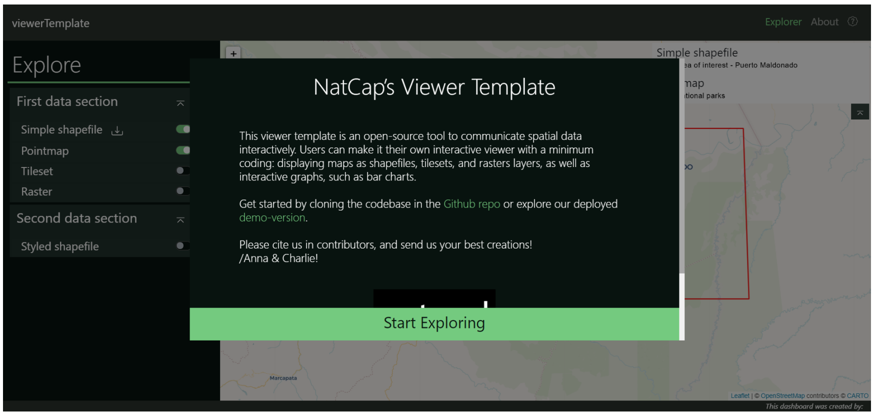

Figure 4.13: Final viewer – Landing page with a pop-up with information about the viewer

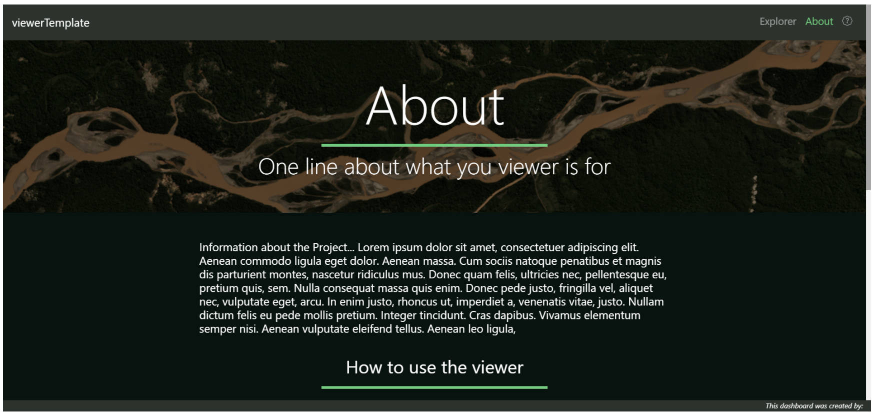

Figure 4.14: Final viewer – About page

The codebase was deployed on the official visualization page for the Natural Capital Project [15].

4.4.3 Testing and evaluation

The evaluation was strictly qualitative and based on interviews and discussions with visualization experts, software developers, and project managers at NatCap. The interviews both helped to secure feedback on the design and codebase, but also to elicit beta testers that could use the template for their own upcoming project.

5 | Discussion

The different results have highlighted a couple of aspects important for designing and developing dashboards for decision-makers. Like the related work presented in chapter 2, the results emphasize the importance of preparing and prototyping before any coding starts. Using cross-functional teams and getting feedback early on also contributes to better tools. The results also show that the insight-based methodology is an effective method to evaluate the tools and that users actually can gain relevant knowledge from using the dashboards.

5.1 More features does not imply a better dashboard

While the results of the competitive analysis present the most common features, there is no data that is implying that all of those features are needed to create a useful dashboard. Three of the top 4 dashboards (see Figure 4.2) indeed have many of the most used features included, however, among the dashboards sample there were also other dashboards with even higher complexity that all in all were less useful. The key is to find and implement features that help communicate the main research and allow the user to achieve the prescribed goals of the dashboard. In other words, the customization of features connected to the goals is important (see Figure 4.3). This finding also aligns with previous research in the field[13, 36].

The only features that are slightly correlating with the usefulness of a tool, both in the present study's result but also in previous ones, are summary charts and other communication functionalities [1]. These help create an overview of the data and thereby guides the users to the most important metrics. Nonetheless, in this thesis, the execution of these features was not assessed and future work could examine how the performance of them impacts on users gained insights. Wrongly implemented communication features might have a negative impact and mislead the users.

5.2 Unmet user needs – future features for dashboards

Data from the competitive analysis, in addition to qualitative data from interviewing the developers, revealed some features that are still rarely implemented and where developers hope to place more focus in the future. The main gap concerns the accessibility of the tools. The dashboards are rarely mobile adjusted, yet some developers stated that more than half of their users were trying to access the tool through their phone. Designing visualizations for small screens, which are normally touch-based, requires a different set of design principles [38] and new challenges arise. Eg. *hovering* is normally used to display more information and this has to be replaced by other design solutions for a touch device. Future work on how to create mobile interfaces that still allow for the same data exploration is needed to suffice for the increasing group of users working only with their phones.

Moreover, using the PRO-Agua viewer as an example, some use cases of these tools comes with the limitation of poor or no internet connection. For those cases, implementing options like export, save and editing, are features sought after by the users but as far as the results show, not that often implemented. By allowing users to export maps they have an easier way of sharing the data and also saving their created view for later usage.

5.3 Notes on the Method

From the results, it is remarkable how little resources most dashboard projects place on testing and evaluating. Apart from dashboards developed by specific companies, the projects seem to mainly conduct peer feedback sessions and maybe a short questionnaire. This despite that the benefits of evaluating are commonly accepted by both the visualization and the HCI community [23, 1].

One of the major aspects of the present study has been to find reliable methods for evaluating dashboards. To be able to investigate the usage of dashboards and how decision-makers can gain knowledge from them, common methodologies like surveys or simply asking users to perform some tasks could not be used alone. Instead, more qualitative methods had to be used. However, with those, questions about validity and replicability also has to be discussed.

5.3.1 Competitive analysis

The competitive analysis was conducted to investigate which features were normally used and their relevance to the usefulness of the tools. This indeed mapped out the landscape of the current state of dashboards but did not give too much indication on which features were the most important. Since the features only was recorded from a present vs absence perspective, there was no assessment of how well those features were implemented or if they were implemented correctly. The reason for not investigating the features more rigorously was that this would have required more than one coder since the assessment would have been highly subjective. Furthermore, evaluating the cartographic features such as visual variables would have required a more experienced cartographer.

Another noteworthy objective about the competitive analysis is the sample chosen. The sample size of the 21 dashboard can provide an overview of some dashboards but does not necessarily cover all potential dashboards. Furthermore, the sample was mainly selected based on developers and the project leads ability to participate in interviews. Projects interested in participating in such interviews might already be biased in one way or another.

5.3.2 Insight-based evaluation

From using an insight-based methodology, the insights users gained by interacting with a dashboard could be investigated. This provided feedback that could later be implemented in the final version of the specific viewer (PRO Agua viewer). It also gave an indication on how such a tool could be used to provide knowledge to decision-makers. However, the assessment of different characteristics was subjective, and different coders could potentially have presented different results. The assessments are also depending on the coders' own domain and visualization knowledge. This creates some difficulties for cross-comparison although this difficulty was reduced by using multiple coders.

For the specific case of the PRO-Agua viewer, there was also a language problem which made finding suitable users harder. As stated in chapter 2.5, the insight-based evaluation methodology emphasizes the importance of having domain-relevant participants. However, in Peru, the native language spoken is Spanish and most people do not speak English. This created a quite strict criteria for finding participants and also limited the ones that participated. Some language barriers might have made it harder for participants to understand the instructions given and also limited them from communicating more complex insights.

5.3.3 Developing the template

During the development of the template, the knowledge and lessons learned from the previous segments could be put to test. To the greatest possible extent, the guidelines were therefore followed. This revealed a few limitations; Although having a lot of input and stakeholders, in general, is imperative, it also increases the resources and time spent on synthesizing them and making sure everybody understands that all their ideas can not be implemented.

Moreover, the development process also identified the problem of a highly customized template vs something that was easy for new coders. Creating more customized dashboards requires more time and a more experienced coder. Some of the original ideas, which from an end-user perspective might have resulted in a more useful dashboard, had to be dismissed in order to make the code more intuitive.

The template was decided to be implemented as a codebase where coders had to directly edit the code. Another solution would be to create a separate GUI in which researchers could add the data layers they want to display without having to write any code at all. This would, nonetheless, require a dynamic website which means that deployment through GitHub pages would not work. This solution would also have required more resources to develop and was therefore dismissed.

5.4 The work in a wider context

Even though this thesis focused on visualizing spatial environmental data through interactive maps in dashboards, the main take away in terms of guidelines and template could also be applicable to other scenarios. Spatial data displayed in dashboards could e.g. be used in crisis management system where escape routes should be planned, in tools displaying the infrastructure of a factory, in systems allowing users to map out where to place solar panels, and more. This demonstrates that the results of this thesis are not only centered around the specific use case presented, it can also be placed in a wider context.

5.5 Future work

During the thesis work, some areas for future work have been identified. Firstly, the effects of how well/correct different features are implemented can be further analyzed. This relates to cartography and how different visual variables help present different aspects of a dataset.

Secondly, more research is needed to investigate how to develop map-based dashboards or similar tools for mobile devices. Mobile devices limit the use of interactions like hovering and because of their smaller screen sizes, the design therefore has to be adjusted.

Thirdly, how well the guidelines and evaluation techniques are adjustable to other dashboards could be further investigated. What other applications could an insight-based methodology be applied to and are there any other metrics within the insights that could provide valuable information to the developers?

Finally, this thesis work only accounts for the short term benefits of map-based dashboards and what the user can learn from just a 10 minutes session. To fully understand the use cases of these tools, the long-term effects of using them must be analyzed. This would be even more similar to real world scenarios where map-based dashboards are used by real decision-makers to support them in spatial planning.

6 Conclusion

The aim of this thesis work was to investigate interactive map-based dashboards, how they are built, and how they can be of use for decision-makers. The findings of this investigation were then to be placed in a wider context and serve as the base of the development for a set of guidelines and template for new developers.

The work was divided into four segments, the first analyzed features used in present dashboards, the second investigated how a specific tool can be used and what users can learn from it, the third synthesized the lessons learned into guidelines, and finally, the fourth developed an open source template that could be used by new developers wanting to create their own useful map-based dashboards.

6.1 Regarding the Research questions

The qualitative data from the competitive analysis and the insight-based evaluation of the PRO-Agua viewer suggest that map-based dashboards can indeed be useful for decision-makers. Using a dashboard can help decision-makers gain complex domain-relevant insights that help them create new hypothesizes about potential solutions.

Just including a specific feature does not automatically make the dashboard useful. Nonetheless, the data suggest that including overview elements such as summary charts and relevant concrete adaption strategies can guide users through the data and help them see where they can go from insight to action. An important factor for developing useful dashboards is to have a rigorous prototype process where the dashboard's end-users, as well as their objectives and goals, are clearly defined. This knowledge can then be used to properly customize the dashboard to fit the users' data literacy and needs.

Based on the lessons learned from the two experiments, a simple template could be developed. The template still requires some coding skills but the main logistics have already been implemented and the coder only has to include the different data layers and information they want to add.

Finally, this work promotes the benefits of user evaluation throughout the development process. The results suggest that evaluated dashboards are easier to use and enhance users' confidence. Furthermore, user testing provides knowledge and insights into how a dashboard can be used for solving real world problems.

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