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HUMAN-DATA INTERACTION IN GEOPROCESSING APPLICATIONS: DESIGN RECOMMENDATIONS FROM INSPECTIONS, USER EVALUATIONS AND EXPERT EXPERIENCES

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Master's Thesis submitted to the Federal University of Lavras, as part of the requirements for the Graduate Program in Computer Science, specializing in Software Engineering and Information Systems, in fulfillment of the requirements for the degree of Master.

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INTERAÇÃO HUMANO-DADOS EM APLICAÇÕES DE GEOPROCESSAMENTO: RECOMENDAÇÕES DE DESIGN DE INSPEÇÕES, AVALIAÇÃO COM USUÁRIOS E EXPERIÊNCIAS DE ESPECIALISTAS

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I dedicate this work to my family - even from afar, we are always together. I am so lucky to have you all. Thank you for always being by my side.

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"It is only with the heart that one can see rightly; what is essential is invisible to the eye." — Antoine de Saint-Exupéry, The Little Prince

ABSTRACT

Interactive applications to explore data are increasing daily as numerous data sources are used across various contexts. Consequently, it becomes imperative to consider the quality of user interaction and interpretation when dealing with data. In recent years, another noteworthy aspect gaining prominence is the utilization of geoprocessing to depict distances on maps, determine routes, and perform other related functions in the environmental area. Analyzing data within geoprocessing systems demands appropriate procedures to enhance the interactive technologies employed in such systems. This issue entails adopting user-centered approaches and strategies to mitigate the inherent complexity. While numerous heuristics are available for human-computer interaction studies, and some heuristics for human-data interaction have been developed recently, the availability of heuristics specifically catering to interaction and interpretation of data in maps remains limited. This study aimed to propose design recommendations specifically for human-data interaction within the geoprocessing domain. The development of these recommendations involved a series of studies conducted to identify the most significant issues pertaining to the interactions and development processes. The method included interviews with geoprocessing experts, usability inspections and tests with users. The first step involved interviews with 15 specialists in geoprocessing applications to understand the primary challenges associated with the development of this technology. The second step involved performing heuristic evaluations with three specialists in human-computer interaction, utilizing existing heuristics. The final step involved conducting user tests to ascertain users' difficulties when interacting with data displayed on maps. For this investigation, four geoprocessing applications from the market were evaluated: "SNISB" (18 users), and "SIOUT SC", , "P3M", and "Observatório da Agropecuária" (27 users, 9 on each system). These applications, developed by the Brazilian Government, aim to provide information to diverse user groups. Following an analysis of the obtained results, the thematic analysis of the interviews yielded two themes: 1) Characteristics of Geoprocessing Systems in Environmental Contexts and Implications for Design and 2) Development of Applications for Geo Data Interaction in Environmental Contexts, divided into three subthemes each. The usability inspections of the four applications yielded 211 problems. Usability evaluations with users yielded 186 unique problems. The problems from both evaluations yielded seven categories. From the analysis of the expert interviews, inspections with usability specialists, and user evaluations, the study drew ten recommendations for the design of geoprocessing interactive applications, which were divided into product and process recommendations. The proposed recommendations aim to improve the development of interactive data-intensive geoprocessing and improvements in the usability of such applications.

Keywords: Human-data interaction; Geoprocessing; Usability; Heuristics

RESUMO

Aplicações interativas para explorar dados estão aumentando diariamente, visto que inúmeras fontes de dados são usadas em vários contextos. Consequentemente, torna-se imperativo considerar a qualidade da interação e interpretação do usuário ao lidar com dados. Nos últimos anos, outro aspecto notável que vem ganhando destaque é a utilização do geoprocessamento para representar elementos em mapas, determinar rotas e executar outras funções relacionadas na área ambiental. Analisar dados em sistemas de geoprocessamento exige procedimentos apropriados para aprimorar as tecnologias interativas empregadas em tais sistemas. Essa questão envolve a adoção de abordagens e estratégias centradas no ser humano, a fim de mitigar a complexidade inerente. Embora inúmeras heurísticas estejam disponíveis para estudos de interação humano-computador, e algumas heurísticas para interação humano-dados tenham sido desenvolvidas recentemente, a disponibilidade de heurísticas que atendam especificamente à interação e interpretação de dados em mapas permanece limitada. Este estudo teve como objetivo propor recomendações de design especificamente para interação humano-dados dentro do domínio do geoprocessamento. O desenvolvimento dessas recomendações envolveu uma série de estudos conduzidos para identificar as questões mais significativas relativas às interações e processos de desenvolvimento. O método incluiu entrevistas com especialistas em geoprocessamento, inspeções de usabilidade e testes com usuários. A primeira etapa envolveu entrevistas com 15 especialistas em aplicações de geoprocessamento para entender os principais desafios associados ao desenvolvimento desta tecnologia. A segunda etapa envolveu a realização de avaliações heurísticas com três especialistas em interação humano-computador, utilizando heurísticas existentes. A etapa final envolveu a realização de testes de usuários para verificar as dificuldades dos usuários ao interagir com dados exibidos em mapas. Para esta investigação, quatro aplicações de geoprocessamento do mercado foram avaliadas: "SNISB" (18 usuários), e "SIOUT SC", "P3M" e "Observatório da Agropecuária" (27 usuários, 9 em cada sistema). Essas aplicações, desenvolvidas pelo Governo Brasileiro, visam fornecer informações a diversos grupos de usuários. Após uma análise dos resultados obtidos, a análise temática das entrevistas produziu dois temas: 1) Características dos Sistemas de Geoprocessamento em Contextos Ambientais e Implicações para o Design, e, 2) Desenvolvimento de Aplicações para Interação de Dados Geográficos em Contextos Ambientais, divididos em três subtemas cada. As inspeções de usabilidade das quatro aplicações produziram 211 problemas. As avaliações de usabilidade com usuários produziram 186 problemas únicos. Os problemas de ambas as avaliações produziram sete categorias. A partir da análise de entrevistas com especialistas, inspeções com especialistas em usabilidade e avaliações de usuários, o estudo extraiu dez recomendações para o design de aplicativos interativos de geoprocessamento, que foram divididas em recomendações de produto e processo. As recomendações propostas visam melhorar o desenvolvimento de geoprocessamento interativo intensivo em dados e melhorias na usabilidade de tais aplicativos.

Palavras-chave: Interação humano-dados; Geoprocessamento; Usabilidade; Heurísticas

IMPACTOS SOCIAIS, TECNOLÓGICOS, ECONÔMICOS E CULTURAIS

O trabalho apresentado nesta dissertação tem como objetivo identificar quais são as maiores dificuldades e gargalos no processo de utilização e criação de elementos no contexto de tecnologias envolvendo geoprocessamento, com o intuito de propor recomendações de design para melhorar o processo de produção e de interação com ferramentas de geoprocessamento. Com o aumento do volume de dados diariamente e, considerando o aumento do uso de plataformas de geoprocessamento, é necessário que a qualidade das interações seja avaliada. Considerando o aumento da utilização de elementos de geoprocessamento pelo Governo Brasileiro para representar dados ambientais, envolvendo informações relevantes no que diz respeito à segurança pública, é de extrema importância garantir que os usuários, dos mais variados perfis que acessem as plataformas de geoprocessamento públicas e disponibilizadas pelo governo, consigam compreender as informações ali apresentadas. O estudo em questão realizou investigações levando em consideração os mais variados perfis envolvidos no geoprocessamento: entrevistas com especialistas que produzem materiais e tecnologias de geoprocessamento diariamente, bem como testes de usabilidade com aplicações governamentais envolvendo usuários sem conhecimento específico em geoprocessamento. Além das duas abordagens realizadas, avaliações heurísticas por profissionais da área de interação humano-computador foram realizadas. Após a análise dos resultados, a análise temática das entrevistas revelou dois temas principais: 1) Características dos Sistemas de Geoprocessamento em Contextos Ambientais e Implicações para o Design, e 2) Desenvolvimento de Aplicações para Interação de Dados Geográficos em Contextos Ambientais, cada um dividido em três subtemas. As inspeções de usabilidade das quatro aplicações identificaram 211 problemas, enquanto as avaliações de usabilidade com usuários revelaram 186 problemas únicos. Esses problemas foram classificados em sete categorias. Com base na análise de entrevistas com especialistas, inspeções de usabilidade e avaliações de usuários, o estudo formulou dez recomendações para o design de aplicativos interativos de geoprocessamento, divididas em recomendações de produto e processo. As propostas visam aprimorar o desenvolvimento de sistemas de geoprocessamento interativo intensivo em dados e melhorar a usabilidade desses aplicativos. Tendo em vista um aprimoramento das plataformas de geoprocessamento e uma maior facilidade na interpretação dos dados apresentados pelo público, é possível gerar campanhas públicas de prevenção de desastres ambientais, e melhoria nos processos de tomada de decisão.

SOCIAL, TECHNOLOGICAL, ECONOMIC AND CULTURAL IMPACTS

The work presented in this dissertation aims to identify the major challenges and bottlenecks in the process of using and creating elements within the context of geoprocessing technologies, with the objective of proposing design recommendations to improve both the production process and the interaction with geoprocessing tools. Given the daily increase in data volume and the growing use of geoprocessing platforms, it is essential to assess the quality of these interactions. Considering the increasing use of geoprocessing elements by the Brazilian Government to represent environmental data, which includes crucial information related to public safety, it is of utmost importance to ensure that users of diverse profiles who access publicly available government geoprocessing platforms can comprehend the presented information. This study conducted investigations involving various profiles engaged in geoprocessing: interviews with experts who daily produce geoprocessing materials and technologies, as well as usability tests with governmental applications involving users without specific geoprocessing knowledge. In addition to these two approaches, heuristic evaluations by professionals in the field of human-computer interaction were performed. Following the analysis of the results, the thematic analysis of the interviews revealed two main themes: 1) Characteristics of Geographic Information Systems in Environmental Contexts and Implications for Design, and 2) Development of Applications for Interaction with Geographic Data in Environmental Contexts, each subdivided into three subthemes. Usability inspections of the four applications identified 211 issues, while user usability evaluations uncovered 186 unique issues. These issues were categorized into seven groups. Based on the analysis of interviews with experts, usability inspections, and user evaluations, the study formulated ten recommendations for the design of interactive geoprocessing applications, divided into product and process recommendations. The proposed recommendations aim to enhance the development of data-intensive interactive geoprocessing systems and improve the usability of such applications. With an improvement in geoprocessing platforms and an easier interpretation of the presented data by the public, it is possible to generate public campaigns for environmental disaster prevention and improve decision-making processes.

CONTENTS

1 INTRODUCTION

The prevalence of interaction with data is steadily increasing across diverse contexts, thereby underscoring the critical importance of assessing the quality of user interactions and interpretations when engaging with data. Furthermore, geoprocessing has experienced a surge in prominence in recent years due to its capacity for representing distances on maps, facilitating route finding, and enabling other related functionalities. Effective data analysis within geoprocessing systems requires the implementation of appropriate processes to enhance the interactive technologies employed. This need calls for carefully considering user-centered approaches and strategies to mitigate the inherent complexities. Despite the existence of numerous heuristics centered on human-computer interaction and data interaction, the availability of heuristics and guidelines dedicated explicitly to the interaction and interpretation of data through maps remains limited. Consequently, the primary objective of this study is to develop a set of guidelines that specifically address the intricacies of human-data interaction within the geoprocessing context.

According to the research conducted by Ziegler and Chasins (2023), geospatial data is assuming a progressively crucial role in the endeavors of Earth and climate scientists, social scientists, and data journalists who seek to analyze spatiotemporal changes in our environment and societies. The authors further argue that geoprocessing technologies present significant challenges, as they are difficult to use and require substantial learning effort.

Rodrigues et al. (2021) mentions that users have specific inquiries they seek to address when engaging with data, shaping their interpretation process. Additionally, Victorelli and Reis (2020) has contributed to the field by developing a comprehensive set of heuristics that specifically target human-data interaction in various application domains. However, it is worth noting that despite the existence of perspectives on heuristics for human-data interaction, they have yet to be specifically tailored to the geoprocessing context. In the study performed by Popelka et al. (2019), the authors highlighted the increasing challenge cartographers face in dealing with big data, mainly due to the localization of a significant portion of this data. Their research focused on evaluating three map-based visual analytics techniques using eye-tracking technology. The study's objective was to assess user accessibility, identify potential issues and limitations, and subsequently propose recommendations for map creators. The study outlined in (MARQUEZ; MEIRELLES; SILVA, 2021) introduces a framework designed to streamline the creation and assessment of interactive web maps, addressing a notable gap in evaluating user engagement with such maps. The aim is to define domain-specific usability principles.

This study aims to understand the major limitations in the production and interaction with environmental geoprocessing platforms, with the goal of addressing the following question: **"What are the design guidelines that can facilitate product design and optimize the development and the interaction related to geoprocessing applications for the context of environmental management?"**.

To identify the gaps and acquire the necessary material for developing design recommendations and guidelines, the methodology outlined by Quiñones, Rusu and Rusu (2018) served as the foundation, involving the following sequential steps: 1) Exploratory Stage, 2) Experimental Stage, 3) Descriptive Stage, 4) Correlational Stage, 5) Selection Stage, 6) Specification Stage, 7) Validation Stage, and 8) Refinement Stage. Due to time constraints, the validation and refinement stages were not conducted within the scope of this study but will be evaluated in future research endeavors.

To fulfill the research objective, a comprehensive series of usability evaluations were undertaken to identify the most significant issues related to human-data interactions. Multiple perspectives on human-data interaction were considered to gather the necessary data for analysis. The first approach involved conducting interviews with 15 specialists in geoprocessing to gain insights into the primary challenges encountered during the development of such technologies. By collating the issues raised by these specialists, distinct categories of guidelines tailored to their specific needs could be established.

The second approach encompassed conducting heuristic evaluations with three experts in human-computer interaction, employing existing heuristics. This approach served a dual purpose: identifying navigation-related problems and demonstrating the absence of guidelines designed explicitly for geoprocessing applications.

Lastly, user testing were conducted to examine the difficulties associated with interacting with data presented on maps. This investigation utilized four geoprocessing applications from the Brazilian Government — "SIOUT SC", "SNISB", "P3M", and "Observatório da Agropecuária". These applications cater to diverse user groups and aim to provide information on various topics.

By following this methodology and utilizing the selected geoprocessing applications, the research aims to bridge the identified gaps and obtain the necessary insights to develop design recommendations and guidelines focused on human-data interaction within the geoprocessing context.

These applications serve many users and aim to deliver information on diverse subjects. After a comprehensive analysis of the acquired results, the ultimate goal is to offer design recommendations rooted in guidelines prioritizing human-data interaction within the geoprocessing context. These recommendations will significantly support the development of novel platforms that leverage geoprocessing technology. Ultimately, the primary objective of this research endeavor was to enhance the usability of geoprocessing applications by suggesting design guidelines to assist in addressing these issues.

2 THEORETICAL BACKGROUND

This study aimed to comprehend the principal concerns that arise during the usability evaluation of geographic information systems. The forthcoming chapter will demonstrate that no heuristic guidelines have been developed for assessing user interaction with data within the geoprocessing framework, thereby underscoring the rationale for undertaking this study.

The first search of references was initiated on October 3, 2022, and updated on May 1, 2023, before the qualification of this master's thesis. The search using the search string TITLE-ABS-KEY ((("human-data" OR visualization OR visualisation) AND (geographic OR gis OR geospatial) AND (usability OR "user experience") AND (user AND (test OR evaluation OR assessment OR testing)))) resulted in 127 outcomes, of which 28 were utilized. To bring updated information for this work, a new search was conducted on March 30, 2024, resulting in 138 works. Among the works found in the recent search, the same 28 papers remained as references. Additionally, published works related to the development of guidelines for maps and interviews with geoprocessing experts were appended to the obtained results.

2.1 Human-data interaction

Recently, the definition of the concept of human-data interaction has been revised. In the past, when databases were not widely used and new tools for manipulating data had yet to emerge, the concept of human-data interaction was limited to the data itself without considering the user who interacted with it. However, with the advent of new data manipulation tools and their evolution, the study of human-data interaction has shifted its focus towards user interaction and interpretation. This shift has resulted in a departure from the notion that data is the sole central element of the interaction (WERMAN, 2021).

As stated by Knaflic (KNAFLIC, 2015), in the realm of human-data interaction, it is crucial to establish the intended audience for a presentation of data. This principle is the foundation for creating a context for presenting the data. Furthermore, it is imperative to clearly explain the data being presented while avoiding overloading information to ensure user clarity. This information is of great significance in the context of evaluated data since users will typically access it without assistance or supervision.

Throughout history, human beings have communicated information and shared experiences through the medium of storytelling. This trend is attributed to the fact that a well-crafted narrative enables the listener to better assimilate the presented information instead of a mere list of data (GERSHON; PAGE, 2001). Furthermore, according to the authors above, storytelling can be even more effective than images, which may be subject to interpretation and often require accompanying text to provide clarification in some instances.

The interaction between humans and data enables the acquisition of knowledge on various topics through specialized tools that support the complete lifecycle of data, allowing for user access and comprehension (VICTORELLI et al., 2020).

A fundamental incentive for individuals to engage with data pertains to questions that necessitate answers, thereby leading to the discovery of new insights and facilitating the learning process (RODRIGUES et al., 2021).

In their article, Mortier et al. (2014) discuss three primary dimensions of human-data interaction: readability, action, and negotiability. The first dimension, readability, is related to presenting data transparently and comprehensibly for readers. The second dimension, action, concerns users' actions based on the information gleaned from the data. The third and final dimension, negotiability, entails visualizing how individuals and society may change over time due to the interpretation of data.

According to Matteson et al. (2018), recent technological advancements in data collection and distribution have increased the size and complexity of data. In their study, they explore a tool called ATLAS, which is designed for the discoverable visualization of multi-dimensional geospatial data.

2.2 Usability evaluation

According to the International Organization for Standardization (ISO) standard 9241-11 (ISO - International Organization for Standardization, 2018), *usability* may be defined as: "The extent to which a system, product, or service can be used by specific users to achieve specific goals with effectiveness, efficiency, and satisfaction in a specific context of use". International Organization for Standardization (ISO) standard 9241-210 (ISO - International Organization for Standardization, 2010) defines *human-centred design* as an "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques". The ISO standard still mentions that the users who will interact with it and the stakeholders must be involved in creating a product.

As stated by Rogers (ROGERS; SHARP; PREECE, 2013), a usability evaluation involves scrutinizing usability aspects to assess if a product has room for improvement in task efficiency, learnability, and error rate.

In order to achieve this, a variety of evaluation methods, such as tests and inspections, may be employed to examine aspects of the interaction and address different questions. Tests may be conducted in controlled or uncontrolled environments, with or without user involvement (ROGERS; SHARP; PREECE, 2013).

Rogers, Sharp and Preece (2013), complemented the concept of usability, which is defined by the authors as: “[...] ensuring that interactive products are easy to learn to use, effective and pleasant - from the user’s perspective”.

One possible way to conduct a usability inspection is utilizing heuristic evaluation, a concept introduced by Nielsen and Molich (1990). This inspection is guided by a set of usability principles designed for evaluation. In this approach, experts inspect the application, observing aspects of the interface and linking them to the heuristics.

Besides user testing, expert inspections can be carried out to anticipate common issues users encounter. Multiple methods, such as heuristic evaluations, can be applied in this context. The heuristics proposed by Nielsen and Molich (1990) regarding user interaction with an application are among the most frequently used in industry and research, providing design knowledge.

Therefore, regarding human-data interaction, assessing the usability of data presentation using appropriate guidelines is also feasible. Thus, issues found in a user’s interaction can be translated into the heuristics above.

2.3 Usability in geoprocessing context

According to Nakić, Kosović and Franić (2022), "visualization of geographic data is part of many widely used solutions that aim to communicate the information to the end user". The authors also note that data is frequently represented through color schemes or ranges in visualization. Furthermore, the use of Geographic Information Systems (GIS) is increasingly significant within the context of the Internet of Things.

Kubíček, Báčová and Stachoň (2015) refer to their publication to "new data sources as well new visualization methods are re-opening the discussion about the user’s ability to read the map and coherently interpret its content". The authors also discuss the challenges inherent in representing and comprehending data in the context of geographic information.

The objective of the study conducted by Rzeszewski and Orylski (2021) was to evaluate a tool that was developed to address usability and accessibility issues in the context of geographic applications. The tool was subjected to user tests with participants having a background in planning and GIS contexts.

For an example of a usability evaluation of maps, Yang, MacEachren and Domanico (2020) conducted a study to assess the usability and usage of intrinsic flag maps. One of their findings was that intrinsic flag maps with non-geographic information performed better in user tests.

Ortega et al. (2019) presented a study that explored a different approach to modelling and visualizing geographic information by developing a prototype integrated into an immersive GIS. The study was conducted in three different contexts, and a user evaluation was carried out with 30 participants to understand user perspectives. As a result, the authors found that the prototype provided a better understanding of the data in some cases, and user preferences were identified after the tests.

Herman (2019) developed a web-based research tool to address the issue that users do not fully understand aspects of 3D visualizations. A pilot test was conducted to evaluate accessibility, followed by a user study to assess usability. The tool was versatile in capturing data and identifying efficiency, effectiveness, and other usability aspects, and can collect quantitative and qualitative data.

Unrau and Kray (2020) aimed to evaluate the usability of WebGIS applications and believe that usability evaluations can benefit from a holistic approach. The authors conducted A/B scenario tests with 60 users and identified usability issues in visualization.

According to Holodinsky et al. (2019), "Geographic visualizations have been used to understand disease since the nineteenth century." Therefore, the study aimed to evaluate the usability of software that creates simple visualizations to support decision-making with 18 participants. Only one participant could not correctly interpret the maps, and three topics emerged from the evaluation: improvement suggestions, user interface comments, and visualization tool perceptions.

The study conducted by Solórzano, Comins and Sendra (2017) was based on the idea that digital and interactive elements in thematic atlases can enhance the usability of cartographic products for visualizing architectural heritage. To validate this concept, the authors performed a usability evaluation with 50 participants, focusing on three measures of usability: effectiveness, efficiency, and satisfaction, in the design process of atlases.

In their paper, Roth et al. (2017) investigate the potential of wireframe design and evaluation using a case study focused on water level visualization. The authors created two sets of wireframes to assess user experience, and user tests were conducted with 18 participants. One of the results obtained relates to potential usability issues in the Lake Level Viewer interface, the water level visualization tool.

The paper by Roo, Bourgeois and Maeyer (2017) discusses a 4D archaeological GIS that integrates 3D representations and analytical functionalities. The research aimed to evaluate a prototype with user tests. Although the application lacks some functionalities, it proved helpful for sharing archaeological information.

Cong (2014) conducted a user test involving 42 participants to evaluate four public web mapping sites. The author also emphasizes the importance of the application's main page, according to users, as it represents the first impression and indicates what can be done in the application.

The study conducted by Manson et al. (2012) aimed to investigate the efficacy of using eye tracking as a tool for measuring the usability of web mapping applications. The authors assert that the study was instrumental in demonstrating how eye-tracking technology can be employed to enhance the design and usability of such applications. The study was executed through two phases of evaluation. In the first phase, participants were recruited to complete an initial survey, undergo a brief training session, engage in web mapping tasks, and then respond to follow-up survey questions. In the second phase, a smaller group of participants completed another round of web mapping tasks, followed by a second survey.

The investigation conducted by Koua, MacEachren and Kraak (2006) introduced a novel approach to evaluate the usability and effectiveness of a visual-computational analysis environment. The assessment methodology highlights the importance of exploratory tasks and the support for knowledge discovery. The author posits that the study's outcomes can be used as a framework for developing geo-visualization tools that incorporate various representations, including maps, parallel coordinate plots, and other information-visualization techniques.

The research conducted by Koua and Kraak (2004) introduced a comprehensive evaluation methodology for gauging the usability and effectiveness of a visual computational analysis environment to aid in examining large quantities of geospatial data. The tool's design emphasizes the optimal implementation of computational algorithms to extract patterns and relationships within geospatial data and the visual representation of the obtained information to enhance knowledge acquisition. The authors indicate that the proposed approach is expected to undergo usability testing in future works.

The investigation conducted by Andrienko et al. (2002) executed a usability test with 17 participants to evaluate five interactive geo-visualization tools incorporated in CommonGIS for learnability, memorability, and user satisfaction. The study aimed to assess the tools, including their implementation specifics and the underlying ideas behind them, specifically the geo-visualization techniques as initially conceived. According to the authors, this approach enabled a comprehensive understanding of the usability of each tool individually. The study's second outcome pertains to the effectiveness of the visual comparison and dynamic linking tools, which were deemed successful, concluding that their respective geo-visualization techniques adequately support the exploratory tasks for which they were developed. Finally, the authors provide general observations about the geo-visualization techniques employed in the study.

The study conducted by Slocum et al. (2001) identified a series of research themes and associated challenges that, in the authors' view, need to be addressed to develop effective geo-visualization methods capable of providing valuable knowledge about geospatial patterns and processes. The authors' approach centers on theory-driven cognitive research and the iterative application of usability engineering principles. As per the authors, the complexity of the identified challenges necessitates a multifaceted approach that draws on methods from both cognitive science and usability engineering principles. The authors argue that geographic information scientists should adopt a similar strategy based on the research challenges they have identified.

The objective of the study conducted by Sedlák et al. (2015) was to utilize a combination of heuristic evaluation and user testing methodologies to engage both expert evaluators and representative users in the evaluation process. These methods are contingent upon the presence of a user interface to be assessed, rendering them suitable for evaluating analogue maps. Additionally, the authors proffered a comprehensive overview of the respective advantages and disadvantages of each approach.

The primary objective of the study conducted by Gao et al. (2008) was to construct a platform predicated on the Canadian Geospatial Data Infrastructure (CGDI) that would facilitate data sharing based on the CGDI framework. In addition, the usability of the CGDI was evaluated for its efficacy in health mapping. It is anticipated that this research will engender the employment of the CGDI in health-related investigations and spur the development of novel web-based services for public health. These services will leverage the CGDI for the purposes of online data sharing and access.

The study's principal objective presented by Beconytė and Beconytė (2002) was to offer an overview of the fundamental challenges involved in the cartographic representation of intricate, uncertain, and notably qualitative geographic information. Moreover, the study aimed to identify the primary difficulties encountered during large-scale thematic cartography projects at Vilnius University and during a conference on this topic. The authors identified three principal issues afflicting cartography projects: Firstly, semiologic errors of cartographic representation manifest as anomalous or erroneous systems of cartographic symbols in visual representation. The second issue relates to communication problems pertaining to the map's function for visually exploring geographic information. The last issue concerns the aesthetic quality of the map, which is inextricably linked to its function as a graphical (and potentially other sensory modalities in the future) representation.

The work presented by Masoodian and Luz (2022) involves conducting a workshop that serves as a platform for researchers and practitioners to converge. Their objective was to assemble individuals whose research focuses on map-based interfaces and interactions, currently dispersed across various disciplines and publication venues. This workshop is a shared space where experts from visualization, user interface design, interaction design, visual design, and cartography can exchange their research expertise and knowledge about maps. Executing workshops like this one underscores the area's significance for discussion and advancement. Additionally, the authors emphasize that maps and map-like visualizations are increasingly serving as foundational components for various interactive tools, services, and applications.

The works comprising this theoretical background present investigations in various contexts related to map-based interfaces. Analyzing the studies presented, it is evident that the authors already perceive this interaction format as a growing trend that demands usability studies and proposals for improvement. Moreover, the interaction between users and geoprocessing tools for decision-making is crucial, with some works proposing platforms for decision-making in environmental contexts based on geospatial data. Thus, research aimed at developing improvements in the design process of these platforms is a significant contributing factor.

2.4 Related work

This section aims to present the identified related works. These works feature investigations closely aligned with the context of this study, thereby enabling supplementation, comparisons, and insights for the development of the proposed work at hand.

The study conducted by Ziegler and Chasins (2023) aimed to gain insights into the challenges confronted by users of geospatial data. To achieve this, a contextual inquiry study was carried out, involving 25 participants from various sectors such as academia, industry, newsrooms, and the public sector. These participants were actively engaged in utilizing geospatial data in their respective work. The study's primary objective was to identify the unfulfilled computing requirements of the diverse and expanding community of geospatial data users. Based on their findings, the authors presented six design opportunities related to 5 categories that could enhance geospatial analysis and visualization systems. These design opportunities are as follows:

a) **solving geospatial data constraints -** according to the findings of the authors, participants in the study faced difficulties in locating geospatial data that satisfied precise spatial and temporal constraints;
b) **assistive tools for constructing geospatial analysis pipelines -** the study findings unveiled that although participants could proficiently express their intended outcomes or target outputs for geospatial analyses, they encountered challenges in formulating the requisite pipelines or workflows essential for successfully achieving those outcomes;
c) **assistive tools for constructing geospatial analysis pipelines -** participants heavily depended on executing operators and engaging in manual inspection of the resultant outputs as a means to grasp the underlying semantics of the operators. Regrettably, this approach exhibited computationally burdensome and time-intensive characteristics;
d) **reproducible, shareable geospatial workfows -** participants engaged in the utilization of Geographic Information Systems (GISs) encountered difficulties in the establishment of geospatial workflows that were reproducible and amenable to sharing. The existing limitations associated with the history interfaces embedded within GIS tools posed challenges for users in terms of retrieving information concerning the present state of their analysis or revisiting past analysis decisions;

e) **exploring the cartographic design space -** participants expressed a desire to visualize their geospatial data through diverse cartographic representations. However, the transition between these representations necessitated the manual construction of each one from the beginning, which imposed a significant engineering burden;
f) **exploring the cartographic design space -** a considerable number of participants employed direct manipulation design software for geospatial data visualization purposes. However, these tools discarded all geographic information, thereby rendering it challenging to restructure an analysis once the visualization work had commenced.

The paper by Nakić, Kosović and Franić (2022) proposed a method to integrate human-centered design principles in the development process. The authors conducted a case study to evaluate the best color scheme to represent and work with geographic maps. They investigated the accuracy difference when using different options of data to be visualized, a certain number of colors, and the color presentation format (ascendant/descendant).

Orémuš et al. (2020) conducted a study to build a human-centered application for a visual analysis tool to extract and analyze data from temporal measurements captured at a polar station, with a focus on facilitating navigation. The prototype generated was tested in a pilot study, and the authors suggest that combining all data in a single application contributed to the positive result. They also propose that their approach could serve as a guideline for domains working with similar contexts.

The study conducted by Wei et al. (2020) aimed to analyze two research categories: Traditional Cartography and Geo-visualization. The objective was to identify the issues and questions when these tools are used, focusing on comparing aspects related to cognition, adaptability, and usability. The authors found that the category used depends on the context, as the second one evolved from the first. Depending on the purpose of use, the benefits and the aspects mentioned before may vary.

The objective of the study by Nagel, Duval and Moere (2012) was to introduce two prototype models that were developed iteratively to improve user comprehension of geospatial networks. The study included 12 participants, and the obtained results were grouped into the following categories: "Rapid Adaptation of Map Styles", "Visual Style of Weighted Connections", "Acceptance of Multitouch Interaction", "Radial Menu for Dense Geospatial Data", "Design Process", and "Outlook".

The study proposed by Kenney, Gerst and Read (2024) aimed to investigate the usability gap in an American water resource management tool using a user-testing approach method.

The usability investigation work comprised three phases: the first involved interviews with experts to understand the main objectives and target audience of the platform. Subsequently, researchers focused on diagnosing potential usability issues, and finally, proposing improvements and redesigning the platform and its visualization methods. As a result, there is an indication of the need to have a clear visualization purpose, to use tests as evidence for processes that need improvement, focusing on the necessity for products to have accessibility and usability.

The work conducted by Vasilev, Petrov and Jordanov (2024) presented an approach for visualizing geographical information within the context of mobile technologies, utilizing GISs for visualization and statistical tools for analysis. According to the authors, "Integrating hybrid mobile applications with GIS backends improves real-time visualization and data collection and enables more efficient data collection, greater public awareness, and scalability for additional data sources".

Popelka et al. (2019) stated that "Big data have also become a big challenge for cartographers, as the majority of big data may be localized". In their paper, the authors evaluated three map-based visual analytics using eye-tracking, with the aim of testing user accessibility, identifying problems and shortcomings, and formulating recommendations for map creators. The main findings, according to the authors, are:

a) "important features (title, legend) should be placed within the GUI on the left side.";
b) "if a user creates a selection based on a selected time range or another attribute value, the value of this selection should be highlighted. The value of the selection should be displayed in the maximum available data views, and the value should be given in a sufficiently large, distinctive font and in a contrasting color.";
c) "all the point symbols in the map should be interactive (“clickable”).";
d) "when selecting values in bar charts or histograms, both mouse-drag and mouse-click should be supported.";
e) "the parallel coordinates plot should be designed and implemented carefully. It is advisable to create tooltips or a help function for it. The parallel coordinates plot serves to identify clusters based on attribute values, so it is advisable to color these groups within the implicit visualization.".

In their study, Victorelli and Reis (2020) suggest a collection of heuristics that pertain to the design of components utilizing human-data interaction, specifically:

a) v1: human-data interaction design guidelines for visualization systems;
   - self evidence in coordinated views;
   - consistency between coordinated visualizations;
   - reversible operations in visualizations.
b) v2: use smooth animated transitions between visualizations states when they can help the user to notice the difference between the data;
c) v3: immediately provide visual feedback on the interaction;
d) v4: maximize direct manipulation with data; interaction;
e) v5: minimize information overload;
   - show information context;
   - avoid requiring data memorization;
f) v6: semantically enrich the interaction;
   - enriched feedback from human incorporated into system;
   - refine and train models through user feedback.

The literature review conducted by Quiñones and Rusu (2017) aimed to identify if there was a common methodology for developing heuristics for usability within a specific domain. The systematic review involved planning, conducting, and documenting the results of the review. However, the study found that different authors used different approaches to develop their heuristics, and most were based on the authors' previous experiences rather than a formal methodology.

Although the reviewed articles did not use a formal methodology, the authors identified a sequence of steps commonly followed in the development of heuristics, including creating heuristics based on existing ones, methodologies, literature reviews, usability problems, process combinations, design guidelines, principles or recommendations, interviews, and theories (QUIÑONES; RUSU, 2017).

Based on the reviewed articles, the authors concluded that the activities most commonly involved in developing heuristics included collecting information on existing heuristics, identifying limitations for assessing usability in a specific domain, exploring information and features related to the domain to be considered in developing new heuristics, and proposing a new set of heuristics (QUIÑONES; RUSU, 2017).

The study conducted by Quiñones, Rusu and Rusu (2018) suggests that traditional heuristics do not encompass all aspects of human-computer interaction and that there is currently no appropriate protocol for conducting heuristics. The author cites the work of Rusu et al. (2011) and other authors who have proposed steps for developing usability heuristics, but acknowledges that these methods still have limitations. Nonetheless, several authors who have implemented these methods have reported a simplified heuristics development process.

When creating new heuristics, authors utilize diverse approaches, but their studies often lack a detailed explanation of these approaches. Therefore, the Quiñones, Rusu and Rusu (2018) proposes a methodology that consists of three inputs for formalizing the methodology, in addition to two interactions with distinct phases to validate and refine the methodology, as presented:

a) systematic Literature Review;

b) experimental Results;

c) methodology of Rusu et al. (2011).

In their investigation, Quiñones, Rusu and Rusu (2018) enhanced the phases initially proposed by Rusu et al. (2011) by incorporating additional phases and validation procedures to ensure the reliability of the collected data. These revised phases served as the foundation for the methodology utilized in this study.

Subsequently, in the research conducted by Quiñones and Rusu (2019), the authors provided an illustrative example of how to implement the methodology introduced in their previous work (QUIÑONES; RUSU; RUSU, 2018).

The work proposed by Marquez, Meirelles and Silva (2021), presents a guideline aimed at facilitating the development and analysis of the quality of interactive web maps, with the intention of addressing the current gap in analyzing user interaction with maps. It seeks to establish domain-specific usability heuristics. This approach entails a comprehensive process that encompasses steps ranging from identifying elements in the existing literature to validating the proposed set of heuristics. The proposed heuristics include:

a) agreement and user-friendliness of the interface;

b) map status indication;

c) compatibility in representation levels;

d) consistency and standardization of cartographic elements;

e) accessible approach to the interactive environment;

f) assistance and recognition in search patterns;

g) adaptability to different devices and browsers;

h) name and structuring of cartographic metadata;

i) consistency in the presentation of information and content;

j) permission to export maps and results obtained.

All experiences that have been documented in relevant literature were considered in the development of this study. As presented in this section, it is evident that various studies have individually focused on the usability evaluation of geoprocessing systems, as well as engaging with specialists to understand their work scope and limitations. However, none of these studies have considered relating the two sets of results to develop specific guidelines for environmental geoprocessing applications. The methodology chapter of this work is going to present the approaches employed in this research that are informed by the related literature.

3 METHODOLOGY

This chapter aims to outline the methodology that was employed to conduct the research. The chapter is organized into six sections, namely: (1) Study Design, (2) Systems Selected for Evaluation, and (3) Procedures for Developing Guidelines Focused on Geoprocessing Applications. Each section provides a detailed account of the research methods employed to achieve the research objectives. The methodology applied for the heuristic evaluation and the specialist interviews is described in their specific chapters, aiming to maintain higher-quality storytelling.

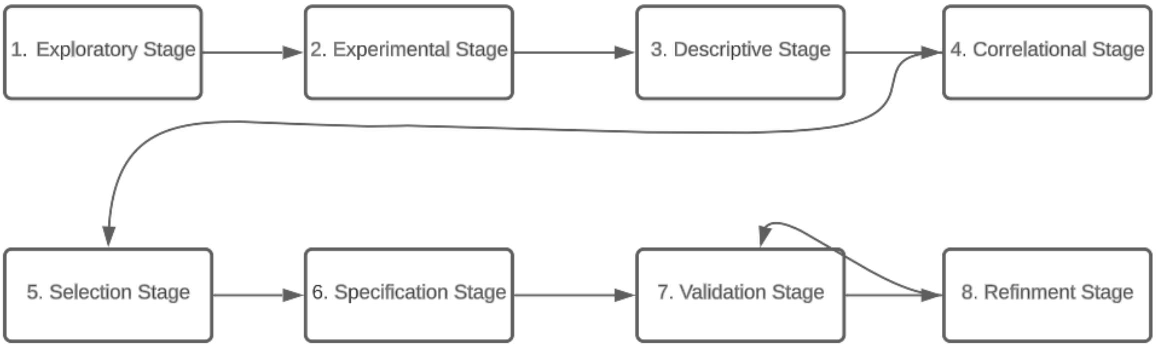
3.1 Study Design

The present investigation has examined inspections in the geoprocessing domain to devise guidelines for enhancing software development and augmenting the user experience of geoprocessing applications focused on the environmental area. The usability studies executed in this research seek to identify and comprehend the factors that hinder user interaction and system interaction. To achieve this aim, the study employed user testing and heuristic evaluation, and interviews with geoprocessing experts were also conducted to understand the relationship between the challenges inherent in the process of developing geoprocessing applications and the usability problems encountered by users.

Despite the existence of various heuristics aimed at assessing the usability of applications and data interaction, none of them offer a targeted and objective approach to evaluating geoprocessing applications for management and data presentation in the environmental context. The lack of information explicitly focused on developing geoprocessing products with optimal usability in this context is a notable gap in the field.

This investigation aimed to devise design guidelines that specifically aid in the development and management of geoprocessing applications focused on the environmental area and its management. In order to accomplish this goal, the methodology proposed by Quiñones, Rusu and Rusu (2018), which comprises eight distinct steps, was employed in the development of the guidelines: (1) Exploratory stage, (2) Experimental stage, (3) Descriptive stage, (4) Correlational stage, (5) Selection stage, (6) Specification stage, (7) Validation stage, and (8) Refinement stage.

Figure 3.1 – Steps of the methodology proposed by Quiñones, Rusu and Rusu



Source: Produced by the author based on Quiñones, Rusu and Rusu (2018)

The "Exploratory stage," which represents the first phase of this study, involves an extensive literature review aimed at investigating the critical factors linked to the creation of innovative guidelines. The overarching research question guiding this investigation is "What are the design guidelines that can facilitate product design and optimize the development and the interaction related to geoprocessing applications for the context of environmental management?"

The "Experimental Stage," representing the subsequent phase, entails the execution of evaluations aimed at identifying gaps or shortcomings in the existing heuristics, thereby facilitating the development of a novel set of design guidelines in the subsequent steps of the study. To achieve this, the current investigation performed usability inspections on four distinct geoprocessing applications related to the environmental area: "SNISB", "SIOUT SC", "P3M", and "Observatório da Agropecuária". The usability tests conducted with users, particularly those involving the SNISB, were pioneering for developing the work published by Capeleti et al. (2023c), which included 18 users aged between 22 and 45 years. For the tests in the other applications, 27 users, divided into three groups of 9 users each, were invited to individually test the "SIOUT SC," "P3M," and "Observatório da Agropecuária" applications. In this second testing scenario, the users ranged in age from 20 to 41 years old and possessed knowledge of how to navigate online websites, as this was a prerequisite due to the remote nature of the tests.

The SNISB tests were not replicated due to a platform availability issue during the usability testing period. Therefore, the decision was made to conduct inspections with fewer users per platform, representing half the quantity of users used in the SNISB pilot test. This decision was made to comply with the ethical committee's request and to maintain the proposed schedule for this master's thesis.

The tests aimed to determine users' primary difficulties when attempting to interact with geoprocessing applications. Each user tested only one of the applications, resulting in each application being tested by seven users (for "P3M," "Observatório da Agropecuária," and "SIOUT SC" context), except for the "SNISB" application, which had 18 users, as explained previously.

In addition, heuristic evaluations were conducted by three specialists in human-computer interaction to ascertain the design and usability issues from the perspective of specialists. Alongside these two inspection methods, geoprocessing technology experts' viewpoints were also taken into account, with a series of interviews to be conducted to elicit their insights. During this phase, the interview involved the participation of 15 specialists, who will be described in detail in the upcoming sections of this document.

The third stage - the "Descriptive Stage," is intended to integrate all of the information gathered during the previous phases to analyze and comprehend the nature of the problems encountered through the various approaches. Furthermore, the outcomes were organized into categories, with related issues grouped under "Unique Problems" to prevent duplication of identical concerns.

The use of the aforementioned research tools aims to verify the degree of synchronization between various perspectives: the view of geoprocessing experts who are familiar with daily production processes, identifying potential areas for improvement and difficulties and limitations they face daily, the perspective of human-computer interaction professionals, to examine the interaction elements with a more technical perspective, identifying more technical usability issues and assigning severity levels, and, in conjunction with this, the perspective of end users, in order to identify important aspects regarding the interaction of end users with geoprocessing tools, as well as to visualize the usability issues they encounter.

Taking into account all perspectives, it was possible to identify which problems are perceived by all methods and which problems are seen by one party as a result of limitations arising from another perspective. The goal is to connect the aspects that involve a geoprocessing application through various viewpoints to create a final product with a high degree of user-friendliness for end users and good quality of work for geoprocessing professionals.

The fourth stage, the "Correlation Stage," involves investigating the relationships between the issues identified in the preceding "Descriptive Stage." This stage entails analyzing the correlation between these issues to determine their interrelatedness. With this information, it was possible to evaluate which identified issues are already addressed by existing heuristic approaches. In the present study, comparisons were made with the works of Nielsen and Molich (1990), Victorelli and Reis (2020), and Marquez, Meirelles and Silva (2021).

The fifth stage, the "Selection Stage," involves synthesizing all of the information gathered from the preceding stages and determining which design guidelines need to be developed. To achieve this objective, the present study focused on developing design guidelines for geoprocessing applications in environmental areas that address issues not covered by existing heuristics.

During the sixth stage, the "Specification Stage," the heuristics were described and specified in detail to enhance comprehension and ensure their practical application in the future.

During the seventh stage, the "Validation Stage," the newly developed guidelines will undergo validation to ensure that they effectively address a significant portion of the usability issues in the context of geoprocessing applications. This validation process will entail the execution of supplementary heuristic evaluations and user tests with an application that differs from the ones used initially. Due to the time constraints imposed by the research involved in completing the master's degree, the validation phase of the proposed design recommendations and guidelines will be part of future work to be conducted, considering the time required for completing the master's degree.

In the eighth stage, the "Refinement Stage," the guidelines will be refined based on the results obtained from the validation stage. The issues identified during the validation process will be addressed to enhance the design guidelines and present the outcome of this study.

The following sections of this chapter will delineate the systems chosen for the initial evaluation phase, the usability inspections carried out, the interviews with specialists, and the procedures employed to develop design guidelines centered on geoprocessing applications.

3.2 Systems Selected for Evaluation

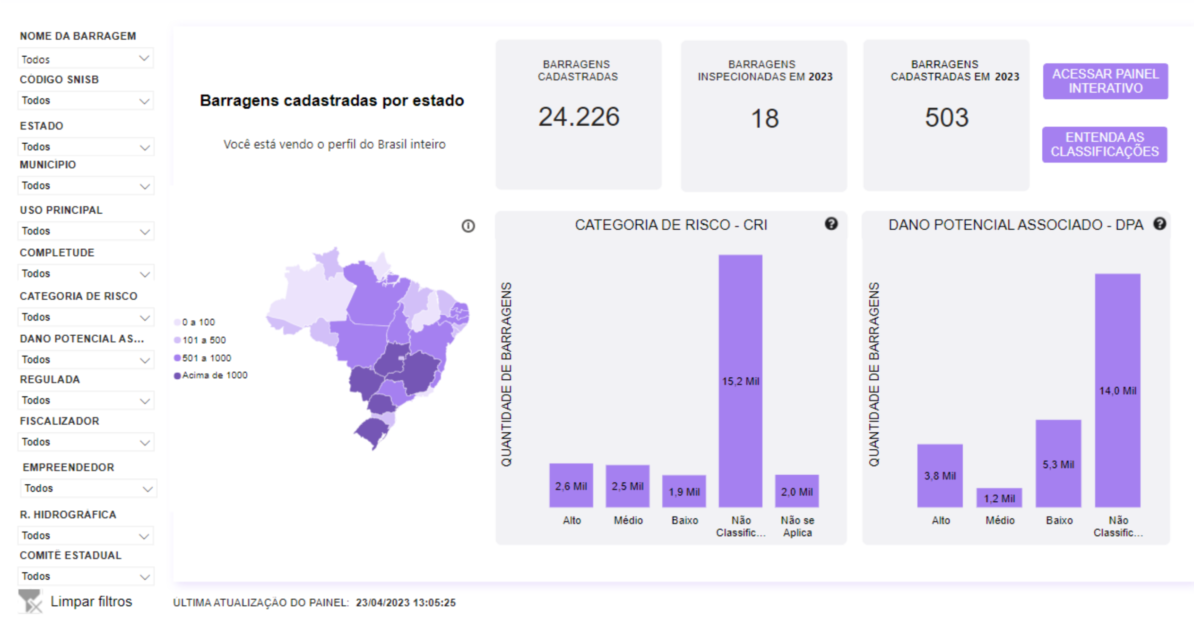
Four applications were chosen for evaluation, taking into account the requirement of including a GIS section.

The first system selected for the initial evaluation stage is called "Sistema Nacional de Informações sobre Segurança de Barragens - SNISB" [1], which emphasizes the use of geopro-

[1] Available on: https://www.snisb.gov.br/portal-snisb/inicio

cessing techniques in the field of dam safety. The system features a dashboard that displays dam inspection information combined with an interactive map, as illustrated in Figure 3.2.

Figure 3.2 – SNISB Environment

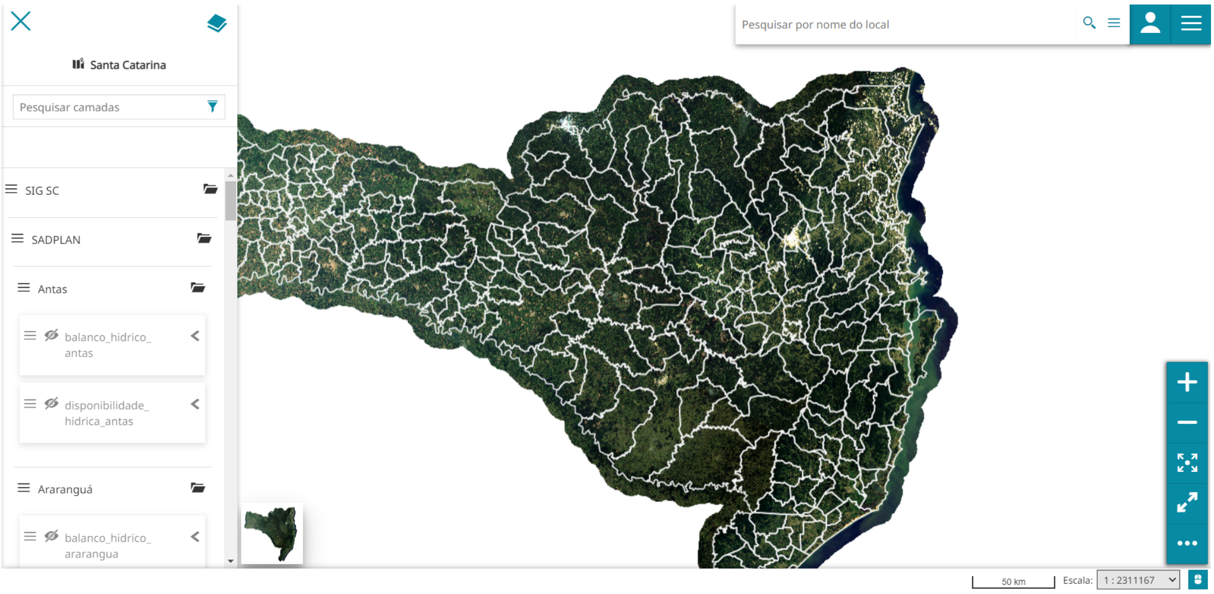


Source: SNISB Website (2023)

The second application, "Sistema de Outorga de Santa Catarina - SIOUT SC" [2], is geared towards the management of water resources in the state of Santa Catarina. This application includes a GIS section that is focused on analyzing the location of water collection points and the water balance, to enable equitable distribution of water to various users, as presented in Figure 3.3.

[2] Available on: http://siout.aguas.sc.gov.br/#/

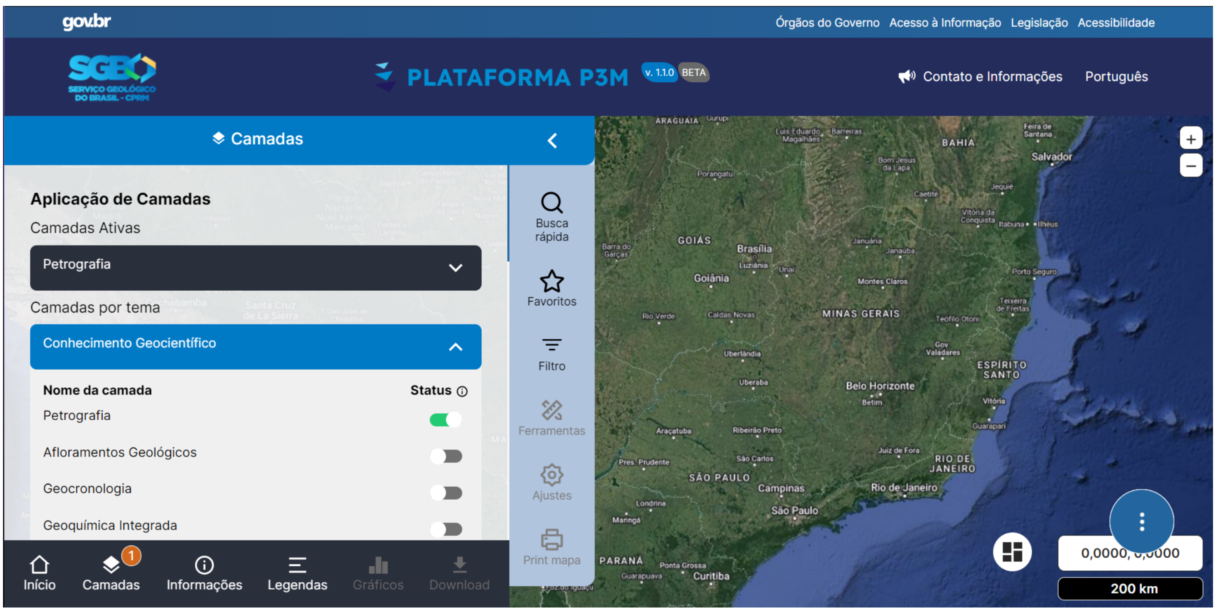
Figure 3.3 – SIOUT Environment



Source: SIOUT Website (2023)

The third system, known as "Plataforma P3M" [3], is designed to support the planning of mineral research and production, enabling the visualization of various information presented in layers. Figure 3.4 presents the map screen.

Figure 3.4 – P3M Environment



Source: P3M Website (2023)

The last application, "Observatório da Agropecuária" [4], has a specific focus on the management of information related to Brazilian agriculture. It includes a geoprocessing application

[3] Available on: https://p3m-beta.sgb.gov.br/#/map
[4] https://observatorio.agropecuaria.inmet.gov.br/plataforma-geoespacial/#/

that enables the integration of data and territorial information relevant to Brazilian agriculture. The geospatial platform is illustrated in Figure 3.5.

Figure 3.5 – Observatório da Agropecuária Environment

Source: Observatório Website (2023)

3.3 Procedures for Developing Design Recommendations Focused on Geoprocessing Applications for the Environmental Context

To arrive at the design recommendations proposal, interviews with geoprocessing experts were conducted, along with usability assessments involving heuristic evaluations and user testing. Thus, obtaining the results of these studies made it possible to identify categories for developing design guidelines for the geoprocessing context.

The interviews were conducted with 15 experts in the field of geoprocessing, each with at least three years of experience in geoprocessing work. The interview consisted of ten questions aimed at understanding the daily work context of the experts in order to identify bottlenecks and challenges they faced. Based on the results obtained from the interviews with the experts, the findings were grouped according to their categories to create a category tree with the main items raised by the geoprocessing experts, serving as a basis for developing the design guidelines proposed in this study.

Two types of usability evaluations were conducted: the first was a collaborative heuristic evaluation, where three human-computer interaction professionals assessed the applications together. Each test lasted 2 hours, during which problems were identified collectively, and applicable heuristics and severity levels were assigned. The second approach used was usability testing involving 45 users, divided to test each of the applications as follows: 18 participants tested the SNISB application (a pilot project that could not be repeated due to the unavailability of the application during the second round of testing), and 9 participants for each of the other applications (SIOUT SC, P3M, and Observatory of Agriculture). Users were asked to interact with the platform and indicate their perceptions and doubts. At the end of the usability evaluation, users were invited to respond to demographic and usability questionnaires to assist in analysing results.

To formulate the design recommendations, a thorough analysis of the collected results were conducted to determine the common issues encountered in the methods. Additionally, the issues identified in the user tests were categorized into unique problems, with consideration given to the number of users who encountered the problem, as well as the number of instances the problem was encountered in the evaluations.

In addition to the initial analysis, the issues were compared with the results obtained from the specialists' interviews to determine whether the limitations of their development pattern are directly linked to the issues discovered in the usability evaluations.

The results enabled a reflection on the issues already addressed by existing heuristics. The heuristics utilized for comparison are those proposed by Nielsen and Molich (1990), Marquez, Meirelles and Silva (2021) and Victorelli and Reis (2020).

The issues not addressed by the existing heuristics formed the basis for a new set of design guidelines, which were developed based on the inspection findings and the specialists' perspectives. After this process, the guidelines will be validated and refined as necessary in future work.

The following chapter provide details about the methodological aspects concerning the interviews with geoprocessing experts (Chapter 4) and usability evaluations (Chapter 5).

4 SPECIALISTS INTERVIEW

The objective of conducting interviews with 15 specialists was to comprehend the major challenges associated with the development of geoprocessing applications and discern the key factors that have the greatest impact on constructing a system with this objective.

4.1 Interview Structure

The objective of the interviews was to deepen our understanding of the product development routine that incorporates geoprocessing and identify the main challenges faced daily by specialists in this field. Furthermore, by analyzing the experts' perceptions, the idea is to contrast them with the problem categories observed during user interactions and heuristic evaluations. This comparative analysis enabled us to identify gaps and improvement opportunities and guide the development of specific guidelines for design in the context of environmental geoprocessing.

The interviews with experts were approved by the Research Ethics Committee for Human Subjects from Federal University of Lavras, under protocol number CAAE 63161422.3. 0000.5148.

For this purpose, the interviews were conducted using a set of ten questions, where the specialists had the freedom to supplement their responses with any information they deemed relevant to the study. The questions are outlined as follows:

a) tell us a little about your experience interacting with geoprocessing data. Also, mention what were the main positive and negative aspects of this interaction;
b) in your opinion, what is the best way to present geoprocessing data?
c) do you believe that the ways of presenting geo information vary according to the context in which it will be used?;
d) in specific areas, what kind of visualization have you worked with? Can you give examples?;
e) have you ever been prevented from making a data presentation due to technological limitations? If so, which ones?;
f) what geolocation data presentation technologies do you use? What are the possibilities for representation with them? What are their limitations? Do current technologies help answer the questions that people/clients want to answer through data exploration?;

g) in general, what techniques do you use to present data when you want to highlight a specific item?;

h) how do you identify user needs when collecting demands in the geolocation systems area?;

i) what are the main difficulties in identifying user needs in demand surveys?;

j) during contact with the client, have you ever had different perceptions about data presentation? If so, tell us a little about how the views were expressed and what consensus was reached.

At the beginning of the interview, the researcher introduced herself, provided an overview of the research context, and gave the user complete freedom to interrupt or supplement the interview at any time. Before the beginning of the interview, participants read the informed consent form and formally provided their consent to participate in the study. The aim was to capture as many perceptions as possible from the experts and address the issues they face daily. The interviews were scheduled for a time slot of one hour. However, on average, the experts used a total of 40 minutes.

Prior to the commencement of the interview and subsequent to the researcher's introduction, participants were invited to sign the Informed Consent Form (TCLE), ensuring anonymity and proper handling of the information provided during the interview.

Furthermore, by ensuring complete confidentiality to the participants, with only the issues and suggestions provided by the experts being extracted for this research, many felt comfortable delving deeper into examples to generate a thorough understanding of their work routine and the challenges they faced, thus making the visualization of the problems much closer to what is actually experienced in reality.

4.2 Participants Profile

The research participants were selected based on specific criteria, including a minimum of three years of geoprocessing experience, focusing on the environmental domain. The interview participants came from diverse backgrounds, including environmental and forestry engineering, as well as courses and specializations in geoprocessing. Additionally, among the interviewees, there were 4 women and 11 men. The level of experience among the interviewees varied from 3 years (the interviewee with the least experience) to 27 years (the interviewee with the most experience). They also had proven experience in mapping projects and actively contributed to developing software involving geoprocessing. Among the main areas of expertise mentioned by the participants were the utilization and analysis of the Rural Environmental Registry (CAR) within the context of environmental mapping and land use analysis. These criteria ensured that the research participants possessed the knowledge and experience to provide valuable insights into the topics under consideration.

Regarding experience and interaction with clients, not all interviewed specialists had direct contact, but they had at least an understanding of how the product discovery process occurred. In these cases, they pointed out communication issues until the demands reached them. In this context, additional complexity was added since their representatives were not always individuals from the geoprocessing field, contributing to identifying another issue within the context of the specialists and their daily work.

4.3 Thematic Analysis

The interviews were analyzed through a qualitative approach, aiming to identify the issues mentioned by the participants during the interview. For this purpose, the recordings obtained from the interviews were anonymously analyzed and transcribed to generate an observation solely based on the data. The analysis followed a thematic analysis, with the emergence of sub-themes and overarching themes (BRAUN; CLARKE, 2006).

The AtlasTI tool was used to analyze the interview transcripts, which allowed the selection of quotes from the participants' statements and assigned representative codes to these quotes. These codes were essential for initiating the process of categorizing the statements and facilitating data organization. In the first phase of categorization, were identified and assigned 96 codes to the highlighted excerpts from the interviews. However, during this initial stage of the study, it was observed that many codes exhibited similar characteristics or conceptual overlaps, prompting the need for a second round of review of the generated code categories. This refinement is crucial to ensure accuracy and consistency in the analysis of the collected data, contributing to the conclusions' robustness.

The categories obtained from the initial analysis were further analyzed, this time with the assistance of the MiroBoard platform, by organizing the 96 categories into sticky notes, which would be grouped into larger subthemes according to their degree of similarity, following the thematic analysis procedure. During the second review process, the subthemes were developed to address the issues highlighted by the experts more comprehensively while maintaining a direct connection to the main core of the codes identified in the first round of interviews. Thus, items that shared contextual similarities were grouped into subthemes that reflected the general context of the problem. This refinement allowed for a more detailed and nuanced analysis of the issues raised by the participants, providing a deeper understanding of the challenges faced in the development of products related to geoprocessing in the environmental field. In this second refinement, the groups comprised 27 code categories.

After the second round of refinement, another analysis was conducted involving an additional team member to confirm the categorization and perceptions regarding what was explained by the users. Following the analysis by the second team member, the ideas were discussed, and a new categorization was conducted, taking into account the second analysis. The goal was to initiate the construction of themes based on the findings from the users' statements in the form of a tree structure of results. Following this validation, the construction of the thematic map began to be modeled. Thus, the 27 categories were organized into six broader sub-themes based on general themes to which the subthemes were related. Considering these general aspects, the six broader sub-themes were further organized into two top-level themes:

a) "characteristics of geoprocessing systems in the environmental context and implications for design", with items related to the geoprocessing process in the environmental context, and ;
b) "development of applications for interaction with geo data in environmental context", aiming to identify items related to the overall geoprocessing product development process.

The relation between these two themes then formed the root node of the tree, "The perspective of experts and implications for the design of human-data interaction in geosystems in the environmental context".

The construction of the thematic map containing the analyzed results involves presenting, from the highest level down to the details, the items mentioned by the experts to understand how these items are related and what common factors contribute to that behavior within the geoprocessing product development process. These details allow us to identify limitations and insights for improvements to be applied from the perspective of the experts.

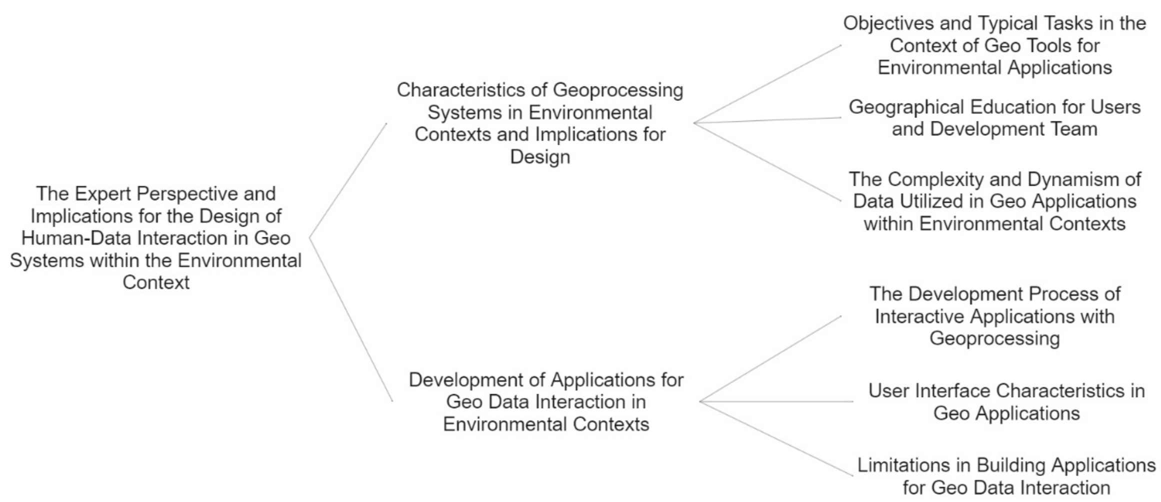
4.4 Results

This section aims to provide an overview of the results obtained through the analysis of responses from the experts, as well as to highlight the refinement process undertaken to generate the thematic map. The identified themes, categories, key characteristics, and relevant insights are presented. This analysis and refinement process enabled us to identify the main challenges faced by environmental geoprocessing experts and, develop strategies and solutions to address these challenges and create design guidelines focused on geoprocessing for the environmental sector.

4.4.1 Thematic map

After conducting interviews with specialists, the recordings were analyzed, and problem categories were extracted, resulting in 96 codes. In the second analysis, with the input of an additional team member, the items were grouped and organized into 27 categories belonging to two overarching themes, generating the thematic map presented in Figure 4.1.

Figure 4.1 – Thematic map



Source: Produced by the author (2024)

The main overarching theme is the root node of the tree, "The Expert Perspective and Implications for the Design of Human-Data Interaction in Geo Systems within the Environmental Context," which represents an overview of the theme of the responses received from the experts. The two main themes following this root node represent the two major themes that further explain the root of the problems, namely "Characteristics of Geoprocessing Systems in

Environmental Contexts and Implications for Design" and "Development of Applications for Geo Data Interaction in Environmental Contexts." Finally, within each of these themes are the grouped subthemes related to the codes categorized from the experts' input. For the "Characteristics of Geoprocessing Systems in Environmental Contexts and Implications for Design" category, the codes include "Objectives and Typical Tasks in the Context of Geo Tools for Environmental Applications," "Geographical Education for Users and Development Team," and "The Complexity and Dynamism of Data Utilized in Geo Applications within Environmental Contexts." For the category "Development of Applications for Geo Data Interaction in Environmental Contexts," the items include "The Development Process of Interactive Applications with Geoprocessing," "User Interface Characteristics in Geo Applications," and "Limitations in Building Applications for Geo Data Interaction."

The following subsections further explain the codes present the subthemes that emerged from the analysis and the categories that compose them.

4.4.2 Characteristics of Geoprocessing Systems in Environmental Contexts and Implications for Design

The main theme "Characteristics of Geoprocessing Systems in Environmental Contexts and Implications for Design" broadly encompasses the points raised by experts regarding the primary uses of geoprocessing, highlighting the fact that geoprocessing data is continuously evolving, becoming increasingly dynamic and complex. In line with this, the main theme also addresses issues related to environmental education and the lack of familiarity among users, clients, and developers with geospatial platforms. Thus, the greatest challenge lies in how to create better user experiences considering the constant evolution of data for proper utilization, as well as adapting presentations to meet and assist in the user and client familiarization process. The following topics delve deeper into each of the identified codes for this main theme.

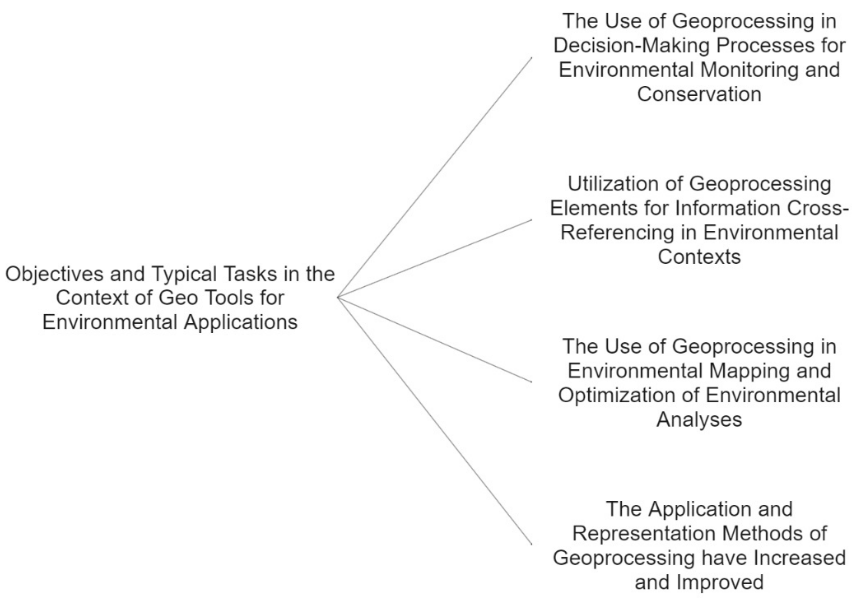
4.4.2.1 Objectives and Typical Tasks in the Context of Geo Tools for Environmental Applications

According to the interviewed specialists, their areas of expertise were related to the use of geoprocessing for decision-making in the context of environmental monitoring and conservation, optimization of environmental analyses, validation of user-submitted data, and cross-referencing of information for environmental report generation. Additionally, the specialists also noted an evolution and shift from traditional cartography to geoprocessing applications, capable of handling larger volumes of data and introducing new challenges to the field.

Regarding this topic, participant P7 presented an example of the use of geoprocessing applications nowadays:

> "If we're going to take a more macro view of the state and everything else, well, nowadays we work a lot with deforestation assessment, right? Like, sometimes on a monthly basis and all that. So, companies, especially in agribusiness, who want to get compliant, it's part of carbon assessment".

Figure 4.2 – Objectives and Typical Tasks in the Context of Geo Tools for Environmental Applications - Detailed



Source: Produced by the author (2024)

The following subsections provide more details on the categories identified from the reports by geoprocessing specialists during the interviews regarding the sub-theme.

The Use of Geoprocessing in Decision-Making Processes for Environmental Monitoring and Conservation

The decision-making process always needs to be data-driven. This applies in the environmental context, where various data and information are collected regarding land use and occupation, crop seasons, dam locations, and water interventions, among other elements relevant to environmental monitoring on a day-to-day basis. According to experts, the use of geoprocessing technologies is necessary to ensure the quality of the transmitted data. Moreover, obtaining data correctly enables effective environmental monitoring. In cases of environmental disasters, such as dam breaches, for example, decision-making processes rely on available data to prevent further issues and promote environmental conservation.

Utilization of Geoprocessing Elements for Information Cross-Referencing in Environmental Contexts

In a context where access to data is increasingly available, geoprocessing has required automation in its processes to ensure that mapping and analysis of geoprocessing data are done adequately. The primary objective concerning data analysis automation is to optimize work and ensure more precise analysis of the transmitted data, as in the environmental context, user-declared data needs to be validated by managing authorities. Additionally, experts also mention the need for visualization using data intersection for map and attribute table visualization.

The Use of Geoprocessing in Environmental Mapping and Optimization of Environmental Analyses

Given the increasing volume of data for analysis in geoprocessing, the use of layers to allow greater interaction with the data and cross-referencing of information becomes increasingly essential. In line with this factor, there is a recognized need for data treatment and standardization, as well as work on its presentation. Before being presented to users, data arrives for specialists purely in mathematical format.

The Application and Representation Methods of Geoprocessing have Increased and Improved

Geoprocessing is recognized as having maps as its primary means of representation and communication. However, the way geoprocessing data is represented has been undergoing significant changes in response to the increasing complexity and volume of data for analysis. Nowadays, different types of information require diverse approaches in geoprocessing use, extending beyond simple visualization on maps. This includes the application of functionalities beyond the map and the use of the attribute table as essential tools. As geospatial datasets become increasingly vast and detailed, analysis is no longer limited to mere visual observation of maps. Instead, geospatial data analysis requires sophisticated methods to handle data complexity and extract meaningful insights.

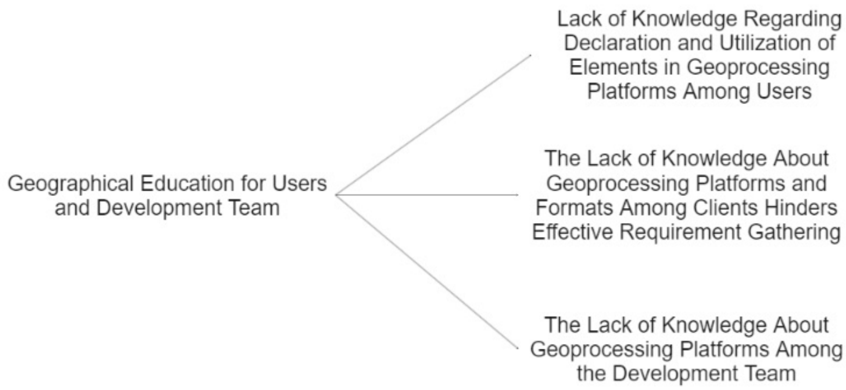
4.4.2.2 Geographical Education for Users and Development Team

Geographical education emerges as an essential factor within the geoprocessing context. In the interviews, the theme of lack of knowledge regarding declaration and utilization of elements in geoprocessing platforms by users, as well as the lack of knowledge about geoprocessing platforms and formats by clients, hindering effective requirement gathering, and the lack of knowledge about geoprocessing platforms by the development team, demonstrate that geographical education is a crucial factor in all stages of product life, from requirement gathering to final use. This is because the complexity of usage and development increases when involved parties are unfamiliar with what is being developed.

About the necessity of geographical education, participant P9 states:

> "When you're dealing with geospatial tools for the average user, what we see today is that this information isn't readily visible, right? So, when you're working with platforms like Google, very few people know what that WGS 84 is all about, you know? And what it signifies. So, it's like, perhaps thinking of a way to provide geographic education to people."

Figure 4.3 – Geographical Education for Users and Development Team



Source: Produced by the author (2024)

The following subsections provide more details on the elements reported by geoprocessing specialists during the interviews regarding the theme:

Lack of Knowledge Regarding Declaration and Utilization of Elements in Geoprocessing Platforms Among Users

As mentioned earlier in this work, some geoprocessing platforms receive data declared by users, which are later verified by employees of the responsible organization for validation. However, there is a lack of knowledge on how to declare data in geoprocessing platforms and a lack of understanding among end users on how to interact with geoprocessing platforms. This indicates that the development of geoprocessing tools is not designed with end users in mind. In this context, there is a need for geographical education to prepare people to interact with geoprocessing applications, in order to ensure a better user experience.

The Lack of Knowledge About Geoprocessing Platforms and Formats Among Clients Hinders Effective Requirement Gathering

Directly linked to the lack of knowledge about the use of geoprocessing platforms, clients also lack understanding of geoprocessing and its formats for requesting demands. Consequently, discussions about the product to be developed become more limited, leading clients to rely on the knowledge of geoprocessing experts, making decision-making difficult and potentially resulting in outcomes different from what they expected. Additionally, experts also mention that communication with the client is complicated in some cases, requiring greater didacticism to design the solution.

The Lack of Knowledge About Geoprocessing Platforms Among the Development Team

In the process of developing a geoprocessing product, there still exists a lack of vision regarding the presentation of a geoprocessing product from a development standpoint. With the increasing volume of data, geoprocessing data increasingly relies on development to produce representations suitable for the context in which spatial data will be used. However, the environmental and development areas are still distant, leading to a lack of understanding of geoprocessing terms by the development team involved in discussions for product development.

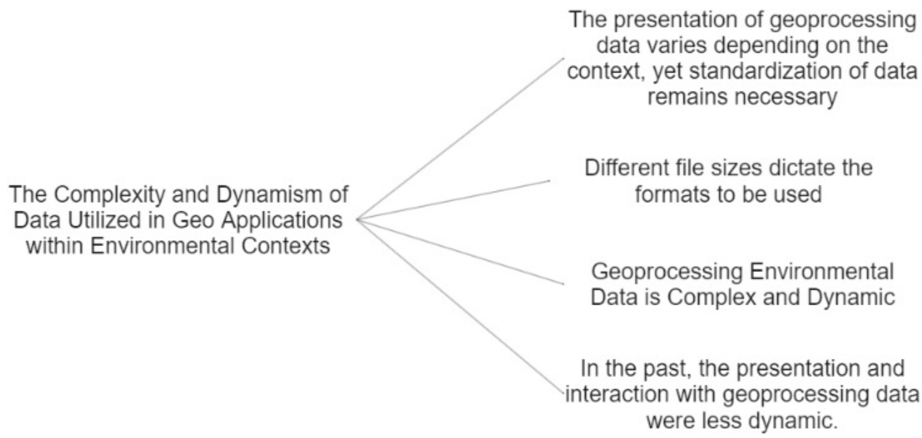
4.4.2.3 The Complexity and Dynamism of Data Utilized in Geo Applications within Environmental Contexts

Another point mentioned in the interviews concerns the complexity and dynamism of data in the context of geoprocessing. Presentations in geoprocessing applications vary according to the presented context. As mentioned earlier, the forms of representation and interaction with geoprocessing have evolved over time, so that in the past, interactions were less dynamic. Additionally, different file sizes can alter the formats that will be used.

Participant P3 mentioned that:

> "in many cases, people believe that geoprocessing is just focused on the environmental area. But it is not. It is something very interdisciplinary."

Figure 4.4 – The Complexity and Dynamism of Data Utilized in Geo Applications within Environmental Contexts



Source: Produced by the author (2024)

The following subsections further explain the codes present the subthemes that emerged from the analysis and the categories that compose them.

The presentation of geoprocessing data varies depending on the context, yet standardization of data remains necessary

Currently, in the context of geoprocessing, various types of data can be presented. However, a common factor among them is the need for standardized data, as this process assists in data analysis and in identifying inconsistencies within the presented data. However, different categories of environmental data require different ways of presenting layer points, as well as the thematic context should be represented in the spatial context to make the data application context clear. Thus, it is clear that depending on the type of data being presented, the presentation format will also vary, ensuring that data utilization and formatting are focused on what needs to be presented, especially in the thematic context.

Different file sizes dictate the formats to be used

Currently, when considering a large volume of geoprocessing data, it is evident that files such as satellite images, for example, may require larger storage space and a different representation format when inserting them into a geoprocessing platform. This difference in representation format and file size necessitates the use of various formats to ensure appropriate representation.

Geoprocessing Environmental Data is Complex and Dynamic

According to experts, environmental analysis data typically consist of a large volume of data and also exhibit significant dynamism, as environmental factors influence the data to be presented. As environmental analysis data increase and require automations and optimizations for better control over information, the optimization of environmental data analysis in the geoprocessing context is a complex process and may require considerable effort to implement.

In the past, the presentation and interaction with geoprocessing data were less dynamic

The specialists also mentioned how data interaction in the context of geoprocessing in the past was less dynamic. Previously, GIS applications referred only to cartography, and not to the collection and interaction of data to tell a story to the user. Additionally, in the past, presentation formats in cartography were square, with no focus on user understanding; the idea was purely to represent information statically.

4.4.3 Development of Applications for Geo Data Interaction in Environmental Contexts

The main theme "Development of Applications for Geo Data Interaction in Environmental Contexts" represents the product development processes. Thus, when considering product development, it is noted that the discovery process doesn't always involve experts in brainstorming the best solutions. Furthermore, interface characteristics are linked to color schemes and the relationship of overlapping items to present information. Similarly, it is also necessary to examine the various limitations within the process to understand how the geoprocessing product development process can be improved. The following topics provide a detailed explanation of each of the identified codes.

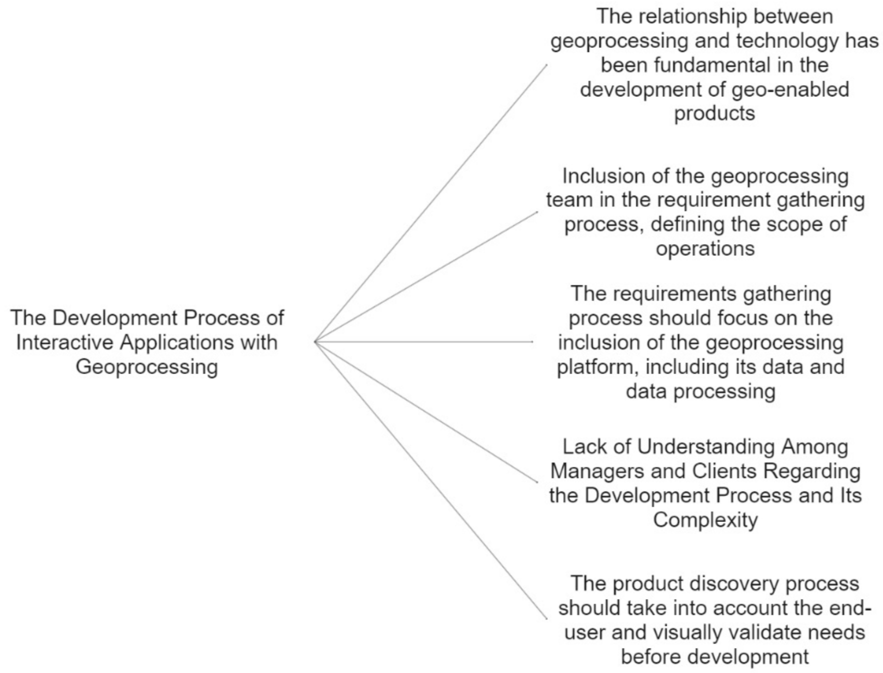
4.4.3.1 The Development Process of Interactive Applications with Geoprocessing

The specialists highlighted concerns in the product discovery process. In many cases, these processes do not involve geoprocessing specialists in understanding the stakeholders' needs. The general requirement document is often delivered to the geoprocessing team without the necessary specifications for building a geoprocessing application. The product scope is another aspect that can hinder the development of geoprocessing applications tailored to users' needs. According to the specialists, until recently, there was little consideration given to how users would interact with the platform. Additionally, there is a lack of understanding among clients and managers regarding the complexity of working with geoprocessing applications.

Participant P11 reinforced the necessity of a multidisciplinary team in the discovery process:

> "When you have a multidisciplinary team that can work together, that's the key, the greatest speed of product development, right? You'll have people interacting and ensuring that each of the components that make up that platform interacts correctly. So, if there's someone who has studied the data, understands the categorizations, and has defined the symbologies, they will approach the developer and say something like, "You're going to have to design about four specific types of subtitles because they need to work differently here with the map colors and the type of categorization that's being displayed" and so on."

Figure 4.5 – The Development Process of Interactive Applications with Geoprocessing



Source: Produced by the author (2024)

The following subsections further explain the codes present the subthemes that emerged from the analysis and the categories that compose the subtheme.

The relationship between geoprocessing and technology has been fundamental in the development of geo-enabled products

As mentioned earlier in this study, geoprocessing applications are dealing with an increasingly larger volume of data, and to assist in automating this process, geoprocessing and technology are used together to achieve the expected outcome. Thus, for the construction of environmental platforms, development and geoprocessing go hand in hand in product production, as geoprocessing data analysis has migrated significantly to the areas of data analysis and programming. Currently, development work spans from the data analysis process for standardization to the presentation for the end user.

Participant P1 mentioned about the necessity of the integration between geoprocessing and development teams, and the increase of the necessity to improve development skills inside the geoprocessing context:

> "But a team that isn't just focused on geoprocessing, right? Today, I see geoprocessing as sort of an arm of IT, you know? They can't do much on their own. Just like we also rely heavily on them. And I see the evolution of geoprocessing in terms of programming, you know? I believe that today, both databases and programming are something that needs to keep up with us."

Inclusion of the geoprocessing team in the requirement gathering process, defining the scope of operations

In the accounts of some of the interviewed specialists, the issue of requirement gathering being done by someone who does not possess extensive knowledge of geoprocessing emerged. Thus, not knowing exactly the scope and complexity of developing a geoprocessing product, the assignment of deadlines and the collection of information can be distorted. The participation of a geoprocessing professional in the requirement gathering process involves establishing the scope of work and the team's scope of action, as well as the interaction of multidisciplinary teams in the product discovery process to assist in production and increase product quality.

The requirements gathering process should focus on the inclusion of the geoprocessing platform, including its data and data processing

Within a requirement gathering process, various pieces of information need to be shared to achieve the ideal outcome. In the case of geoprocessing data, according to the specialists, it's not enough to simply gather requirements; the data needs to be processed for the result to meet expectations. However, the requirement process is not always clear, where lack of context and clarity in the requirements regarding the future use of the platform and its data are encountered. Thus, within a requirement gathering process for geoprocessing context, different document formats contribute to understanding what needs to be developed, along with an application contextualization of the platform and its data allowing for better presentation of environmental information with greater accuracy.

Lack of Understanding Among Managers and Clients Regarding the Development Process and Its Complexity

Due to being a somewhat different software style than conventional ones, often managers and clients fail to recognize that developing applications involving geoprocessing follows the same development standards as any other software. As already outlined in this document, the requirement gathering process for geoprocessing context often has missing information or clients are unable to articulate their needs. However, even faced with some difficulties in this development process, there is a lack of understanding on the part of managers and clients regarding the relationship between deadlines and complexity.

The product discovery process should take into account the end-user and visually validate needs before development

Every software requirement gathering process aims to generate a product that will be used by someone. Therefore, the focus of developing a geoprocessing product should also be on the end user, to understand what can be understood by them, as well as what language is familiar to the user group in question. Often, during the requirement gathering process for geoprocessing, the demand owner only considers the day-to-day operations within the responsible organization, and not the needs of users who will be using the tool without assistance. Therefore, it is of great importance to prototype solutions to reach a consensus solution with the client and validate it with end users.

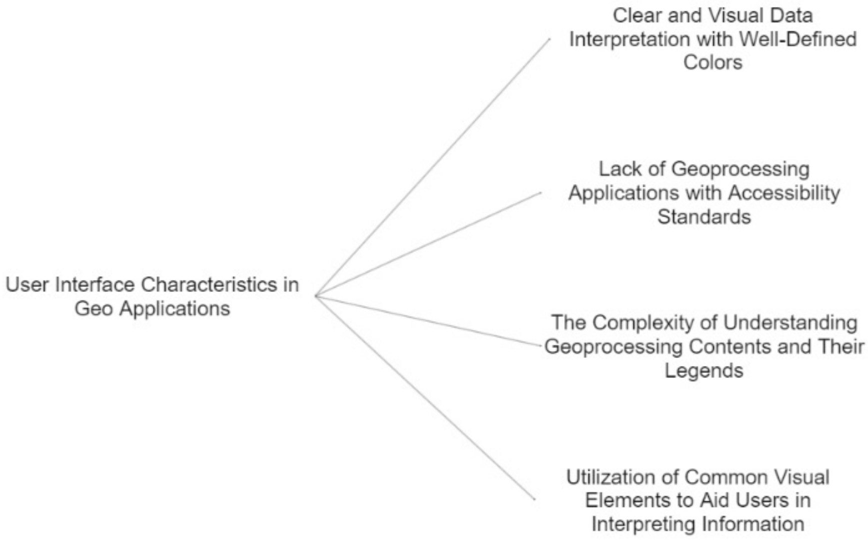
4.4.3.2 User Interface Characteristics in Geo Applications

Regarding the user interface in geoprocessing applications for environmental areas, the specialists emphasized the importance of clear and visual data interpretation, with well-defined colors. They also highlighted the lack of geoprocessing applications with accessibility standards. Another issue mentioned was the difficulty in comprehending geoprocessing content and its legends. As a suggestion, the specialists recommended the use of common visual elements to assist users in interpreting information.

About the color pattern inside the geoprocessing applications, participant P10 stated:

> "It depends on the amount of data, but whenever possible, the information and the colors should have a certain reference to reality, you know? I think that's crucial. If we put vegetation in red, people will automatically associate it with deforestation, so there are already some concepts to work with, you know? So that's important".

Figure 4.6 – User Interface Characteristics in Geo Applications



Source: Produced by the author (2024)

The following subsections further explain the codes present the subthemes that emerged from the analysis and the categories that compose the subtheme.

Clear and Visual Data Interpretation with Well-Defined Colors

When we talk about presenting data through geoprocessing, we are referring to highly visual platforms. Therefore, there is a great need for the presented data to be clear, through the use of colors that highlight what needs to be conveyed and exposed within a certain context. According to experts, there are standards and color norms for representing geospatial information. Additionally, standardized geoprocessing data is easier to analyze.

Lack of Geoprocessing Applications with Accessibility Standards

Applications involving geoprocessing still lack support for accessibility tools. Within the context of geoprocessing, considering the extensive use of colors and shapes, it is necessary to implement tools and functionalities with support for accessibility requirements in order to convey data correctly to all user profiles.

The Complexity of Understanding Geoprocessing Contents and Their Legends

Despite geoprocessing's primary focus being map representation, interpreting data visually and solely through maps can often be complex. Therefore, accompanying legends and their colors are of utmost importance. However, legends need to be clear, easily accessible, and compatible with the information presented to allow users to gain a good understanding of the data being presented.

Utilization of Common Visual Elements to Aid Users in Interpreting Information

Although not widely popularized among the general population, geoprocessing can still utilize techniques to provide users with a good understanding of the data. One way to achieve this is by leveraging the user's existing knowledge, such as the shape of the map of Brazil, for example, as a basis for presenting more complex data. Additionally, it is of utmost importance that users have the freedom to alter elements of the map and interact with it (in a non-permanent way) to better understand the arrangement of the data.

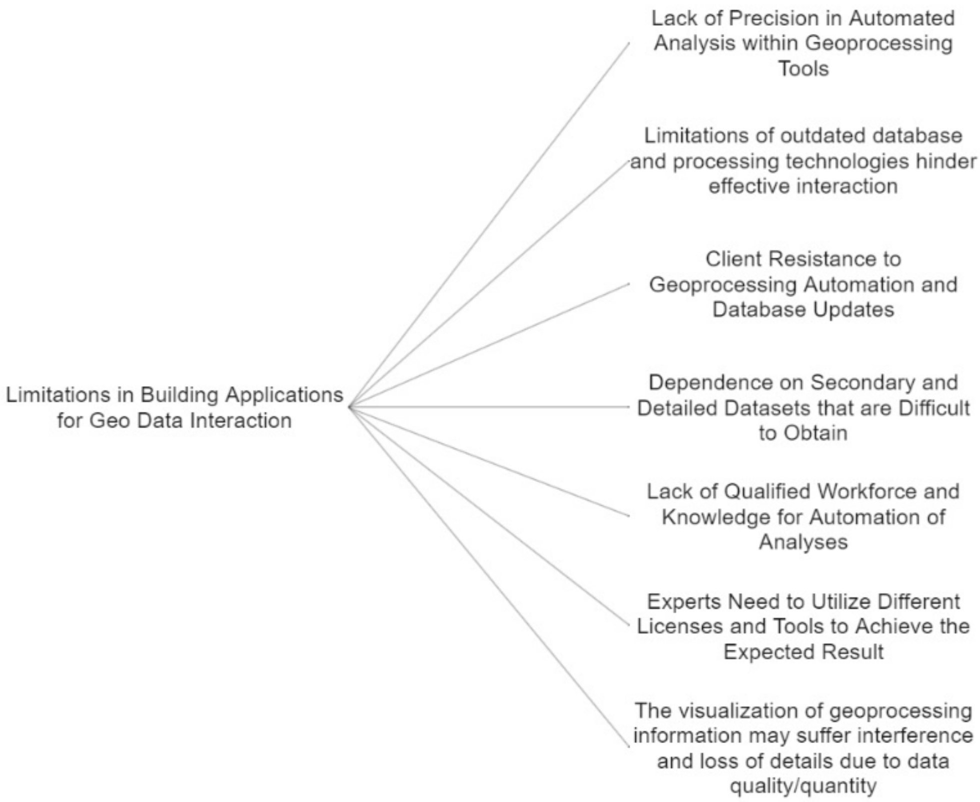
4.4.3.3 Limitations in Building Applications for Geo Data Interaction

Regarding limitations in geoprocessing production, specialists mentioned difficulties in verifying environmental data sent, as well as lack of precision in existing automated geoprocessing analysis tools. Furthermore, challenges exist in development and meeting demands due to limitations in database information, processing limitations due to computational constraints, errors in the database requiring treatment before initiating the process, outdated technologies unable to support data with many details, and different formats supporting them, and lack of standardization in received documentation for analysis. In some public agencies, there is significant client resistance to updating and correcting databases, often due to differing opinions within discussions, making the process slow and costly.

About the limitation due to computional constraints, participant P4 provided an example of a situation involving this topic:

> "A technological limitation, for example, is trying to perform land cover classification without having a machine, such as a GPU, to perform the classification, especially today when I'm working extensively with artificial intelligence models. Many times, an activity couldn't be completed because there wasn't enough structure, infrastructure to support it, whether it's for training a model or having enough disk space to acquire many satellite images, right? Let me give you an example. If you want to classify the state of Mato Grosso, for instance, you need to have at least three hundred gigabytes of space. So often, due to the lack of this, it's pulling down, it's still pulling down".

Figure 4.7 – Limitations in Building Applications for Geo Data Interaction



Source: Produced by the author (2024)

The following subsections further explain the codes present the subthemes that emerged from the analysis and the categories that compose the subtheme.

Lack of Precision in Automated Analysis within Geoprocessing Tools

Even though there is a significant need for automation in processes involving environmental data analysis, a limitation persists: despite the automation of analyses, manual verification of data is still necessary to ensure its quality. Due to incorrect insertion of geoprocessing elements, there is often difficulty in verifying the environmental data sent. This limitation needs to be addressed to improve the level of optimization of analyses within the geoprocessing context.

Limitations of outdated database and processing technologies hinder effective interaction

Database management is one of the most critical factors when it comes to presenting information within the context of geoprocessing. Therefore, databases need to be meticulously designed and optimized to improve the quality and delivery time of a product within the geoprocessing context. Thus, databases with errors or outside a specific standard slow down the process and increase costs for specialists, potentially leading to future problems. Additionally, the limit and size of databases are determined by the financial effort allocated to them, creating limitations in cases where more detailed databases are needed. Finally, considering very large databases, there is also the possibility of encountering processing issues and computational limitations due to the size of the database being worked on. According to experts, the more complex and detailed the database, the more computational power is required, sometimes necessitating the use of graphics processing units for data processing.

Client Resistance to Geoprocessing Automation and Database Updates

Regarding the database model and data analysis sent by users, there is still significant resistance from clients, especially government agencies, in updating the database or automating environmental analysis processes. In this context, due to governmental issues, different political ideas are present in discussions, making the process of building and optimizing the product slower and more costly. Additionally, the involvement of many people in the discussion creates challenges in reaching consensus on what needs to be done and in finalizing the demand itself.

Dependence on Secondary and Detailed Datasets that are Difficult to Obtain

When it comes to producing geoprocessing products, especially in cross-analyses, not all data is always provided by the client. It's often necessary to access secondary databases to gather the complete material for analysis. Secondary databases are not always easy to obtain and may not have the quality or scale suitable for the context being worked on. Therefore, obtaining and processing secondary databases within the product construction process are also limitations.

Participant P2 mentioned about the dependency of secondary databases to perform the work to be done:

> "Often, we work with secondary databases, right? These secondary databases are those that we obtain from other agencies or entities, which they have built, and we use. So, we have to go after these databases, scope them out, and conduct this database survey to see what data is available for us to display. It's like figuring out what we can respond to in this demand".

Lack of Qualified Workforce and Knowledge for Automation of Analyses

The automation processes in geoprocessing data analysis have been growing significantly. As mentioned earlier in this paper, the relationship between geoprocessing elements and programming languages has become increasingly closer. However, there is still a shortage of manpower within teams to carry out all the necessary geoprocessing work. Even when there are professionals and the team is somewhat more robust, experts note that there is still a significant knowledge gap for professionals in the geoprocessing field regarding the lack of programming language expertise to automate and optimize the process.

Experts Need to Utilize Different Licenses and Tools to Achieve the Expected Result

There are various types of data visualization in geoprocessing, and different platforms are used to generate each of them. Therefore, experts need to use different licenses and tools to work with different forms of data presentation (both free and paid software). Additionally, for some specific tasks, it is still necessary to interact between different tools to complete a task, as well as to complement the process by using different libraries to achieve the expected result. However, in this interaction between various tools and libraries, there is still a lack of knowledge on how to use them.

The visualization of geoprocessing information may suffer interference and loss of details due to data quality/quantity

According to the experts, automating geoprocessing analysis processes can lead to loss of relevant details depending on the context. In line with this, the high volume of information in the geoprocessing context can impair information visualization and proper data handling. Finally, the databases used by the experts may have been subject to interference depending on the region they are in, such as satellite images not presenting data clearly due to interferences like clouds.

4.5 Use of the Results

Having the specialist's point of view made it possible to start visualizing points to make adjustments and improvements. These improvements may contribute to the development process focused on geoprocessing for the environmental area, such as negotiating the scope, including adequate technological support for geographic information, better infrastructure, and space to develop and evaluate the product produced.

To propose the final design recommendations, the results obtained from this analysis were combined with the results of heuristic evaluations and user tests to identify common problems related to geoprocessing in the environmental context and the design guidelines proposals generated.

5 USABILITY EVALUATIONS

This chapter presents the usability evaluation methods used in this research and their results. Two usability evaluation methods were applied to compare with what geoprocessing experts indicated: collaborative heuristic evaluation and user testing. The results and usability issues in each method were compared and formed the categories of usability problems presented at the end of this chapter.

The appendix of this work provides a detailed view of the usability issues found in the heuristic evaluations and user tests, aiming to allow a comprehensive visualization of the usability problems encountered. The codes present in the issues found in the appendix were related to the proposed guidelines.

5.1 Heuristic Evaluation

The first evaluation method applied to identify usability issues associated with geoprocessing applications involved conducting a collaborative heuristic evaluation aimed at assessing geoprocessing applications.

The complete results obtained from heuristic evaluation can be accessed in the appendix of this study. The tables containing usability issues found are: A.1 (SNISB), A.2 (Observatório da Agropecuária), A.3 (P3M), and A.4 (SIOUT SC). In this section, the results will be presented in a consolidated manner, providing a synthesis of the main findings.

5.1.1 Methodology Applied

In order to assess the usability of the systems, a collaborative heuristic evaluation was conducted, which involved three professionals from the field of user-computer interaction. This evaluation aimed to identify usability issues collectively, utilizing the heuristics proposed by Nielsen and Molich (1990) (N in the tables), the ones proposed by Victorelli and Reis (2020) (V in the tables), and the map heuristics proposed by Marquez, Meirelles and Silva (2021) (M in the tables). Additionally, the identified heuristics were categorized into different levels of severity, which are presented as follows:

a) a score of 0 was assigned when the evaluator did not consider the item to be a problem;

b) a score of 1 was assigned to cosmetic problems that do not significantly hinder the user's interaction;
c) a score of 2 was assigned to simple problems that have a low impact on the user's interaction;
d) a score of 3 was assigned to serious problems that have a high impact on the user's interaction;
e) a score of 4 was assigned to catastrophic problems that prevent the user from continuing the interaction.

Severity levels were discussed and assigned alongside the problem, reaching a consensus on what value should be attributed. Similarly, the heuristics related to each of the problems found were analyzed together and assigned at the time of evaluation.

The collaborative heuristic evaluation involved the rotating participation of 4 professionals in the field of human-computer interaction (HCI), comprising 3 PhD holders in HCI and 1 master's student also specializing in HCI. Among the PhD participants, one holds a degree in Cartographic Engineering, while the others have average experience with geoprocessing applications. In each evaluation, only 3 professionals participated, with a different trio only in the pilot project (SNISB), excluding the Cartographic Engineer, and consisting of 2 HCI PhDs and the master's student. For the other applications (P3M, Observatório da Agropecuária, and SIOUT SC), the trio also comprised 2 PhDs (one with a background in Cartographic Engineering) and the master's student..

The heuristic usability evaluation sessions for each of the platforms assessed in this work ("SNISB", "Agriculture Observatory", "P3M", and "SIOUT SC") lasted approximately 2 hours each, conducted via the Google Meet platform.

The objective of the inspection was to interact with as many geoprocessing-related elements as possible to verify the flows for accessing functionalities and the usability of the application as a whole. One of the professionals was responsible for screen sharing (as the inspections were done remotely), while all participants indicated possible paths and options to be selected within the system. When a potential error was encountered, the participants discussed it, identified the equivalent heuristics, and assigned appropriate severity levels.

The evaluations followed a consistent standard and aimed to analyze the interaction with geoprocessing data. The subsequent subsections show the findings obtained in the evaluations.

5.1.2 Heuristic Evaluation Results

The heuristic evaluations conducted by the usability experts yielded the following overall results. The SNISB application had 41 issues identified by the experts, the SIOUT SC and the Observatório da Agropecuária application had 52 issues each, and the P3M application had 66 issues. Despite the specificities of each application, the main objective of all tasks was to assess the interaction with geoprocessing sections and maps and the information derived from this interaction, aiming to provide users with a comprehensive understanding of the stored information.

In all evaluated applications, the experts highlighted the presentation of geoprocessing data. The approach used in the applications was non-linear, lacking clarity in guiding users through the necessary steps to accomplish their desired tasks. Furthermore, applications involving geoprocessing still heavily rely on technical terminology, further narrowing their target audience to those proficient in the field of geoprocessing focused on environmental management.

In order to substantiate the claim that the existing heuristics are not specifically tailored for geoprocessing, three of the evaluated heuristics from Nielsen and Molich (1990) that encompassed the identified errors were as follows: Heuristic 2 - "System and Real-World Compatibility", Heuristic 6 - Recognition rather than Recall, and Heuristic 7 - Efficiency and Flexibility of Use.

From the heuristics proposed by Victorelli and Reis (2020), those most related to the problems encountered were linked to: Heuristic 3 - "Immediately provide visual feedback on the interaction", Heuristic 5 - "Minimize information overload", and Heuristic 6 - "Semantically enrich the interaction".

Regarding the heuristics of Marquez, Meirelles and Silva (2021), those most related to the problems encountered were: Heuristic 1 - "Concordance and ease of use of the interface (M1)", Heuristic 5 - "Accessible approach to the interactive environment (M5)", and Heuristic 9 - "Consistency in the presentation of information and content (M9)".

Furthermore, the mentioned heuristics do not specifically describe the errors related to geoprocessing to which they were assigned. We have a broad view of the problem category, but at no point is it possible to identify which aspect of geoprocessing influenced the classification with the respective heuristic.

In the SNISB system, the results obtained for this dissertation have been utilized in a paper published at the conference INTERACT 2023. According to the findings reported by Capeleti et al. (2023c), the results obtained from the SNISB application had a significant number of reported errors primarily due to unclear search filters for navigating through the results. Additionally, there were issues related to the extensive use of technical terms without any explanation to provide users with context regarding the situation of a particular dam. The identified and reported issues were shared with the responsible agency for development. The agency addressed the reported items by implementing the necessary corrections based on the recommendations provided by the experts. The evaluation of SNISB identified 41 issues. Table 5.1 presents a summary of the most severe problems encountered on SNISB.

Table 5.1 – Critical issues found in SNISB with the highest severity level

Critical Issues Found in SNISB	**Heuristics Related**	**Severity Level**
The concept of good or excellent completeness may not be readily understood by individuals unfamiliar with dam operations; an explanation in terms of data significance is necessary.	V5, N7, M5	4
Some terms are specific and difficult to understand for non-experts, lacking an explanation of their primary use.	V5, V6, N6, N7, M1	4
Risk category: Not applicable - can accidents really not occur?	V6, N5, N6, N7, M9	4

Source: Produced by the author (2024)

In the heuristic evaluation conducted on the Observatório da Agropecuária platform, seven usability issues were identified with severity ratings 4. These include the language change function within the platform not affecting its elements; the unclear login process, lacking indication of where users can register; the non-functioning tutorial option; illegible charts lacking a Y-axis; mouse scrolling of the map instead of the search list when the search list generates scrolling; the disappearance of the search list with more names after a while without providing the option to search. Furthermore, other platform-related issues include difficulties in interacting with layers and their dependency orders, lack of information when clicking on the map, the unclear relationship between base layers and specific layers in the interface, and colours used in maps and charts, causing difficulty in interpreting information. The evaluation of the Observatório da Agropecuária identified 52 issues. Table 5.2 presents a summary of the most severe problems encountered on "Observatório da Agropecuária".

Table 5.2 – Critical issues found in Observatório da Agropecuária with the highest severity level

Issues Found in Observatório da Agropecuária	**Heuristics Related**	**Severity Level**
Changing to English or Spanish does not change the layer list.	N1, V6, M9	4
Logging in - the process is unclear. Why log in? How to create an account?	N1, N3, V6, M5	4
The tutorial does not function.	N10, M1	4
The generated bar graph is illegible.	N1, V4, M1	4
The graph lacks a Y-axis legend.	N1, V6, M9	4
When the search list generates scrolling, mouse scrolling moves the map, not the list.	N7, V4, M6	4
A list with more names in search disappears after a while, without providing an option to search further.	N5, V2, M9	4

Source: Produced by the author (2024)

In the heuristic evaluation conducted on the P3M platform, usability issues were identified related to the logic and management of filters, correspondence between indicators and classes, separation of menu elements was confusing as to whether they were related or not, item overlap, excessively long and poorly engaging pop-ups, lack of correspondence between colors and types of indicators, interaction and management of layers, and data retrieval within the platform. While using this tool, the navigation steps were unclear, leading to uncertainty about what should be done next. The evaluation of the P3M platform identified 66 issues. Table 5.3 presents a summary of the most severe problems encountered on P3M.

Table 5.3 – Critical issues found in P3M with the highest severity level

Issues Found in P3M	**Heuristics Related**	**Severity Level**
Filter logic by region/state lacks coherence (can select Acre and southeast, for example).	N2, V2, M6	4
Correspondence between indicators and classes can only be made through colors (could include text as well).	N7, V6, M9	4
What do the percentages mean? Are they in relation to the country? What do they refer to?	N6, V6, M9	4
"View Map" button is hard to find (bottom right corner) - see eye-tracking meta-analyses (dead zone).	N6, V5, M5	4
Search bar - Are horizontal and vertical menus interdependent? Not clear how they work.	N8, V5, M9	4
Quick Search presents data from other countries in autocomplete.	N1, N6, N7, V6, M6	4
"View Dashboard" option overlaps with the coordinate display.	N7, V5, M9	4

Source: Produced by the author (2024)

Regarding the usability assessments of the SIOUT SC platform, the most severe issues were related to lack of communication of the operational flow, tooltips on the map containing technical terms difficult for end-users to understand, activation and management of layers, lack of information about login within the map module, item overlap on the screen, lack of feedback after actions, and incorrect search results for latitude and longitude. Furthermore, there is a lack of explanation of technical terms presented on the platform, delay in returning search results, and lack of confirmation of actions, potentially leading to irreversible actions due to misuse. The evaluation of the SIOUT SC platform identified 52 issues. Table 5.5 presents a summary of the most severe problems encountered on SIOUT SC.

Table 5.4 – Critical issues found in SIOUT SC with the highest severity level

Issues Found in SIOUT SC	**Heuristics Related**	**Severity Level**
The initial screen does not clearly communicate the operation flow.	N1, V6, M5	4
Only mentions storing cookies without explaining what it means in the context where the user must agree.	N2, N10, V6, M1	4
The map outline option becomes illegible - difficult to read due to color contrast.	N1, N8, V3, M4	4
The "manual" icon for help is hard to find and unclear.	N10, V6, M1	4
Tooltip with map point information presents acronyms difficult for the general population to understand.	N2, V6, M9	4
In the layer list, there are several acronyms to select - what do they mean?	N2, V6, M5, M9	4
"balanco_hidrico_antes" - what is it? The description only indicates "blue line" - does not satisfactorily explain.	N2, N10, V6, M9	4
Searching for "São" - shows items up to Russia, but it's only the state of SC.	N3, V4, M6	4
Search by incorrect latitude and longitude shows location "in the middle of nowhere," without feedback.	N9, V5, M4, M9	4
Even when logged in, clicking on the profile icon shows the option to "login," suggesting you are not logged in.	N9, V3, M1	4
Login status does not appear to be working.	N9, M1	4
What is a query? It is not clear whether it is a public consultation or what it is for.	N2, V6, M9	4
Search in the consultation is very slow.	N3, V3, M6	4
When the search is stuck, there is no option to cancel.	N3, V4, M6	4
When clicking on the item to show details, there is an overlay of balloons, and it is difficult to change.	N1, V4, M1	4

Source: Produced by the author (2024)

Table 5.5 – Critical issues found in SIOUT SC with the highest severity level

Issues Found in SIOUT SC	**Heuristics Related**	**Severity Level**
Result point - detail balloon - X button as retract, not as close.	N2, V5, M1	4
When clearing the consultation, it removes the point, but the pop-up with details remains on the screen.	N1, N9, V3, M1	4
Does not give feedback on whether the export was successful or not.	N9, V3, M1	4

Source: Produced by the author (2024)

Analyzing the results obtained from the evaluations of the different systems, it is evident that there were common usability issues related to layer interaction and management, a lack of understanding of technical terms, a lack of feedback and assistance leading to a confusing flow, and a lack of confirmation when performing actions. Additionally, evaluators mention that the severity of errors may be amplified in a real usage context, depending on the user's knowledge of geoprocessing platforms, potentially hindering proper interaction.

The alignment of the issues identified with the three sets of heuristics used in this work highlights the need to complement classic interaction design heuristics with those related to data interaction and map interaction. Thus, the heuristics themselves suggest potential categories of identified issues. The problem categories found through this method were compared with those identified in user testing to establish a relationship among usability problem categories related to geoprocessing applications.

The result obtained in this phase of the research was grouped with feedback from specialists and user tests to enable the development of design guidelines for geoprocessing applications in the environmental context.

5.2 User Tests

The second evaluation method employed was conducting user tests, which aimed to identify usability issues related to interaction with the same geoprocessing platforms evaluated in the collaborative heuristic evaluation.

5.2.1 Methodology Applied

The user tests were performed, wherein the participants were requested to interact with the geoprocessing applications, their map tools, and layers and provide feedback on their experiences. The users were divided into groups based on the application to organize the testing sequence, and each user individually tested only one application. The evaluation was approved by the Ethics Committee of the Federal University of Lavras (UFLA), with the CAAE 72850323.3.0000.5148. The usability tests carried out with users, notably those concerning the SNISB, constituted a pioneering aspect in developing the study presented by Capeleti et al. (2023c), involving 18 participants. In the assessments of the remaining applications, a total of 27 users were recruited, organized into three groups comprising 9 participants each, to individually evaluate the "SIOUT SC," "P3M," and "Observatório da Agropecuária" applications.

At the beginning of the test procedure, the researcher introduced herself and explained the purpose of the study to the participants. The participant then was briefed on the nature and procedures of usability tests, with a specific emphasis on the confidentiality of their personal data. Additionally, participants were informed that the test aims to evaluate the platform's performance rather than their ability to comprehend geoprocessing applications. Participants were also aware of their right to withdraw from the test anytime.

After the initial briefing, participants received a task to perform and were instructed to utilize the Think-Aloud protocol (SOMEREN; BARNARD; SANDBERG, 1994) to articulate their impressions and experiences while using the platform.

The users were tasked to navigate the platform and explore the presented data freely, articulating their understanding of the information and voicing any questions they had. They were also prompted to indicate whether they comprehended the platform's purpose. Thus, users were encouraged to interact with the platform for as long as necessary, sharing their perceptions and inquiries. This task design was based on the premise that these platforms are intended for use by various users, hence aiming to accommodate a wide range of user interactions and inquiries.

Following the test session, participants were asked to complete a demographic questionnaire, which included questions related to their age, computer experience, and familiarity with environmental applications. The questionnaire also included a usability questionnaire to register the users' impressions about their experience.

5.2.2 User Profile

The 27 research participants ranged in age from 20 to 41, with one having low vision and two exhibiting degrees of color blindness. As a prerequisite for participating in the study, users were required to be over 18 years old and knowledgeable in using video call platforms, as the tests were conducted remotely. Furthermore, 32.1% of the interviewed users spent more than 9 hours per day on a computer, while 35.7% used it for 7 to 9 hours daily. Overall, participants rate their computer experience as between medium and high, and the majority primarily use websites on their computers (60.7%). 78.6% of users use the internet to research data on general topics, and 39.9% access maps online, mostly through tools like Google Maps. Regarding the educational level of participants, 57.1% have completed their undergraduate degree, 35.7% were at the postgraduate level, and 7.1% had finished high school.

The first round of the test phase engaged 18 participants, ranging in age from 22 to 45, all of whom had a good level of computer proficiency. User recruitment followed an invitation-based approach, with interested individuals becoming participants upon acceptance.

5.2.3 Data Analysis

For the analysis of the results, the recordings from the usability tests were reviewed, and the usability problems identified and reported by the users were noted. Initially, the initial list of problems was compiled without considering whether the problem had already occurred for other users. After analyzing and collecting information from all participants, the problems were mapped onto "unique problems", considering that different problem instances could occur with different users or with the same user more than once. Following, each unique problem was associated with the number of users who reported the issue. Therefore, the results of the number of problems found per application already reflect the unique problems and the number of users who encountered each item.

Additionally, the information filled out in the usability form served as support for the usability data analysis, providing an overview of users' understanding and perception of the level of difficulty in interacting with the platforms.

The user tests were analyzed by application, consolidating the identified issues into unique problems and noting the number of users encountering each problem. After analyzing the results of each application individually, the findings were compared to identify common usability issues that could be identified as recurring. This process aimed to gather insights to inform the generation of geoprocessing design guidelines for the environmental context.

The results were first analyzed by application so that later, the categories of problems encountered could be created based on the overall results and the comparison between the results found for each application.

5.2.4 Results from User Tests

This section presents the results found in the context of usability tests conducted with users, initially presenting the results by application and then providing an overview of the general results.

The complete results obtained from user testing can be accessed in the appendix of this study. The tables containing usability issues found are: A.5 (SNISB), A.6 (Observatório da Agropecuária), A.7 (P3M), and A.8 (SIOUT SC). In this section, the results will be presented in a consolidated manner, providing a synthesis of the main findings.

The usability issues identified by users who tested SIOUT SC resulted in 56 unique problems. Among the usability issues encountered by users were confusing field formats for input, lack of understanding of presented technical terms, slow loading of results, disabled buttons and functions in the application, difficulty interacting with layers and their folders, and confusion in using available map tools. Table 5.6 presents a summary of the main problems encountered by users on SIOUT SC.

Table 5.6 – Issues found in SIOUT SC more identified by users

Issues Found in SIOUT SC	Number of Users
The application is heavy and takes time to load.	6
The data presented in map tooltips is not in user-friendly language.	6
What do the layers signify? What data do they intend to present?	4
Map tools cause confusion about their function and usage.	4
What does "regularized interference" mean?	4

Source: Produced by the author (2024)

The "Observatório da Agropecuária" application had 54 unique problems identified by users. Among the problems with the highest number of instances reported by users are: layer and color schemes not clearly indicating how interaction should occur, items automatically activated in interaction causing confusion due to lack of feedback, difficulty interacting with provided geoprocessing elements and tools, and failure to load legends. Table 5.7 presents a summary of the main problems encountered by users on Observatório da Agropecuária.

Table 5.7 – Issues found in Observatório da Agropecuária more identified by users

Issues Found in Observatório da Agropecuária	**Number of Users**
Layers, their meanings, and colors are not intuitive (1 user with color blindness)	5
It is not intuitive how to enable the municipalities (names) layer	4
When searching for a specific municipality, the municipalities layer is automatically activated, and after the search, it is not de-activated	5
Reports do not generate results; it remains blank	4

Source: Produced by the author (2024)

The P3M application had 48 unique problems identified, including the lack of clarity in the application that filters can only be used when a layer is enabled, missing search results for a location causing confusion, issues with the relationship between layers and their functionality, lack of indication of active layers, and failure to direct users to the correct location on the map. Table 5.8 presents a summary of the main problems encountered by users on P3M.

Table 5.8 – Issues found in P3M more identified by users

Issues Found in P3M	**Number of Users**
It is not clear what the layers are and how they function.	5
Active layers are not evident and create confusion in interaction.	5
When searching for a location, suggestions start with a comma, not bringing the searched element.	5
It's not intuitive that the filters can only be used with the layers turned on and search based on them.	7

Source: Produced by the author (2024)

The SNISB evaluation encountered 27 usability issues reported by users. These issues include instances where selecting a specific filter causes the graph to readjust, resulting in screen overlap, as well as challenges with readability due to the map being too small. Additionally, clicking on a specific item on the map gives the impression that filters will be automatically updated. Furthermore, filter icons, such as focus mode, overlap with the filter information itself. The most prevalent issue encountered during interaction with the dashboard was the perceived lack of interactivity in the map of Brazil (reported by 14 users), where the ability to select and isolate data about a specific state by clicking on it was absent. Table A.30 presents a summary of the main problems encountered by users on SNISB.

Table 5.9 – Issues found in SNISB more identified by users

Issues Found in SNISB	**Number of Users**
Dashboard map does not seem interactive.	14
Filter font size is small.	7
Filter operation generates a lot of confusion about how to use it.	8
The term "ICI" in the table has no explanation, which may raise questions.	3
"Filter focus mode" sometimes opens in the middle of the screen, giving the impression that the screen is blank.	3

Source: Produced by the author (2024)

Analyzing the data collected from the usability questionnaire and considering the interaction with the platforms overall, 42.9% of the participants reported fully understanding the information presented on the platforms. 53.6% of users indicated a partial understanding of the information presented. 46.6% of users felt that the difficulty in understanding the data was moderate. Despite some challenges in interaction, 48.1% of users indicated that they would use the platforms for research and study purposes.

Based on the analysis of usability test results, it is evident that there are similarities among the issues encountered by users. Among the main problems repeatedly found in usability tests are difficulty interacting with geoprocessing tools, particularly in managing and interacting with layers; interactions lacking feedback for users, whether due to slow loading or activation of unwanted items; use of technical terms within the platform without assistance or explanation provided; lack of precision in indicating searched terms; and issues with search formats.

Therefore, user tests provide guidance for the development of guidelines focused on data formatting in geoprocessing, handling technical terms, interaction with geoprocessing elements, and layer management. Additionally, there is a need for increased feedback within the platform and clearer help sections. The search formats used within the platforms should be explained, and examples of how users can obtain information should be provided. Furthermore, various functionalities were unavailable on the platforms, and in such cases, they should not be displayed to users during interaction.

5.3 Categories of Issues Found

This section aims to present categories of issues identified in both the heuristic evaluation and usability tests. Each identified category listed was associated with the problems reported most frequently in the obtained results.

Lack of familiarity with geoprocessing elements - This category represents a significant challenge during the interaction process. Due to the nature of geoprocessing tools and functionalities, which are often uncommon or unfamiliar to users, there was an initial sense of unfamiliarity regarding what should be done next and what the possibilities for data visualization within this context were. This lack of familiarity can be attributed to the complexity of geoprocessing tools, which may involve technical concepts and procedures unfamiliar to users.

For example, interacting with layers, as well as accessing tools for manipulating geospatial data. Additionally, the variety of data visualization options available in the geoprocessing context is vast for users, especially for those who are not accustomed to working with this type of technology. To overcome this challenge, it is essential to provide users with clear guidance and support resources, such as tutorials and detailed documentation, to help them become familiar with geoprocessing tools and functionalities. Figure 5.1 shows an example of this issue on the P3M platform.

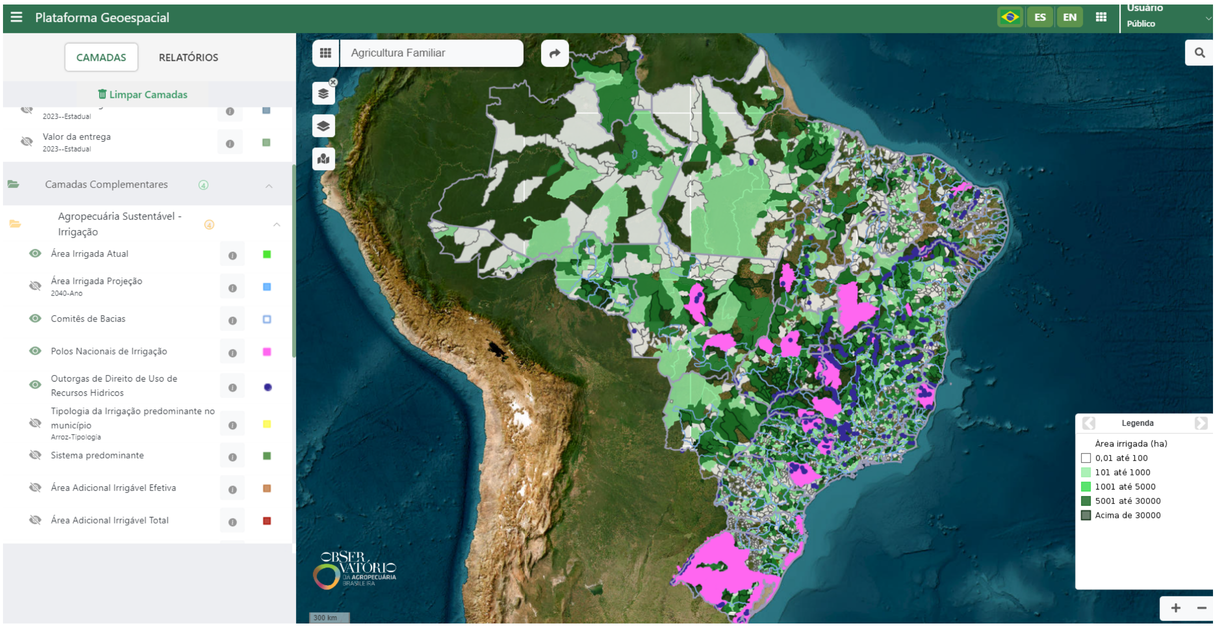
Figure 5.1 – Excessive simultaneous functionality and lack of familiarity with geoprocessing elements

Source: P3M Website (2024)

Colors and overlay of elements - As mentioned earlier in this study, geoprocessing tools heavily rely on visual elements, so colors and on-screen elements need to interact to present the data story to end-users. Therefore, the presented colors and their meanings must be clear to users, and similarly, the relationship and blending between the colors of layer elements need to interact harmoniously without loss of information. Similarly, in the context of some of the tested applications, there is a need to better organize the presentation of information on the screen, as various important pieces of information end up being omitted due to the display of other information.

In this example, multiple layers are activated, leading to overlapping and an overwhelming color scheme, thereby hindering users' ability to visualize the information fully. Additionally, the legend only displays information for the last activated layer, as shown on Figure 5.2.

Figure 5.2 – Interaction between colors and overlaid elements on the map

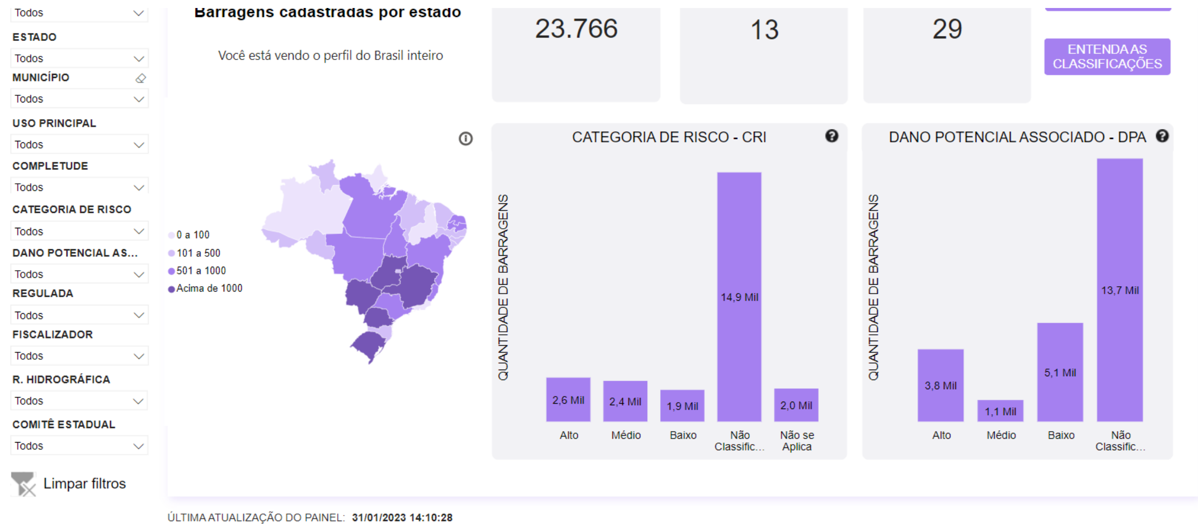


Source: Observatório Website (2024)

Position of key elements to interact with data - In order to interact with data, certain elements serve as keys to unlock specific information. Hence, these keys must be easily discernible and prominently visible to users. For instance, when working with data visualization accompanied by filters that necessitate parameter adjustments, the key for initiating this transition should be within the user's visual field.

An illustrative example, identified during user testing and heuristic evaluation within this category, pertains to the button's location to clear search filters ("Limpar filtro" in Portuguese). This button is situated in an inconspicuous position, erasing the selected filters and initiating a new search more challenging. Furthermore, depending on the user's computer screen size, the button may not be immediately visible until the user scrolls down the page, as shown in Figure 5.3.

Figure 5.3 – Element "Limpar Filtro" with position not visible

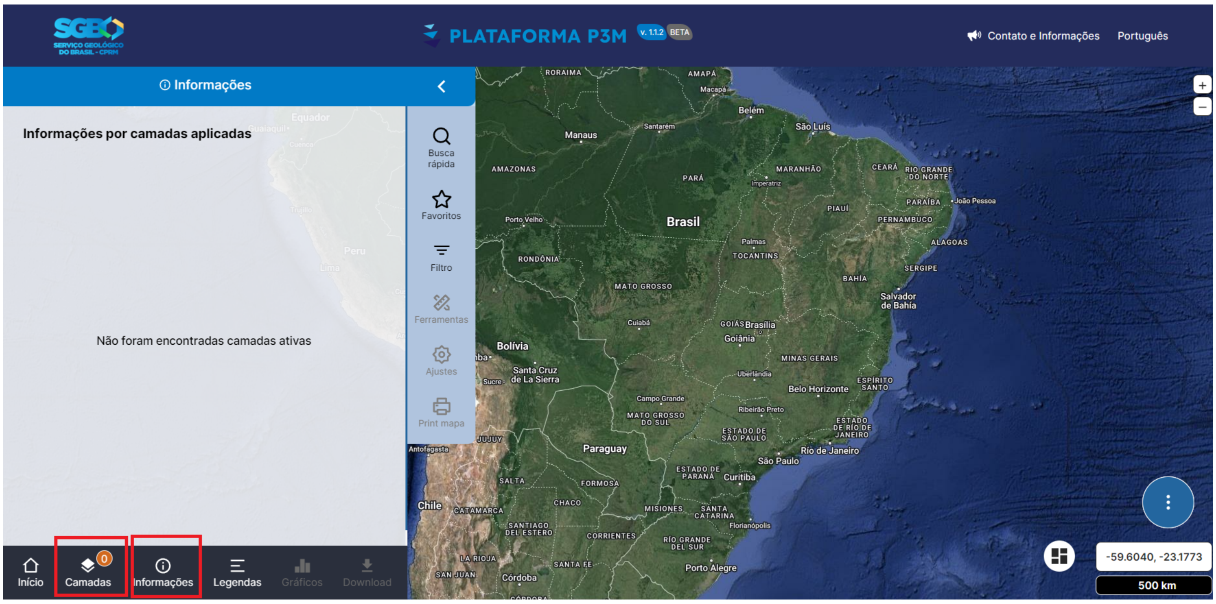


Source: SNISB Website (2024)

Data presentation pattern - Another facet of data interaction pertains to the presentation of information. Is there a discernible pattern in data presentation, or is it seemingly random? This category aims to capture this aspect, encompassing information clarity and its organisational structure's comprehensibility. Additionally, the pattern must be coherent, enhancing understanding and ease of interaction with the data narrative.

In the P3M application, the user can only access information about what the name of a particular layer represents when the layer is active. Therefore, the user first needs to locate the layers and then find out where the information is available, as it is not in the same location as the layers, as shown in Figure 5.4.

Figure 5.4 – To visualize a layer meaning, the user must go to another section of the application

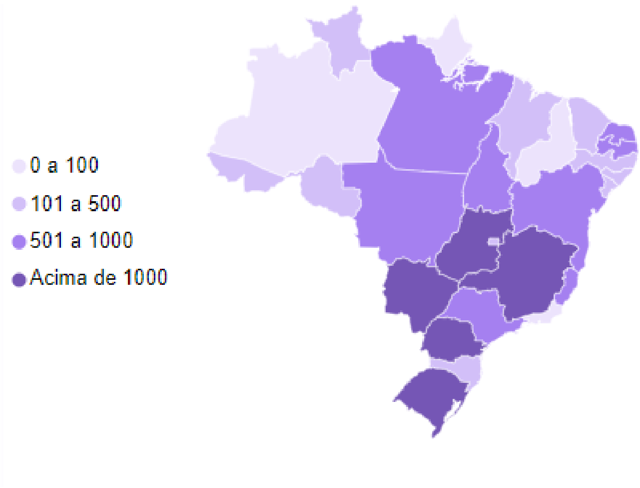


Source: P3M Environment (2024)

Visibility about how to interact with data - When data requires a specific path to be accessed, it is imperative for the steps involved in obtaining the information to be transparent. The category "Visibility about how to interact with data" encompasses issues about quickly locating and comprehending the pathway to access data and its corresponding details. This category is proposed to facilitate user interaction with the data application, enabling efficient data exploration.

An instance illustrating an issue within this category was observed in both inspections, wherein the heatmap displayed on the dashboard failed to convey its interactive nature. Despite the intended functionality of optimizing searches beyond Brazilian states, it did not function as anticipated. Furthermore, upon users' realization that the map could be interacted with and an area was selected, the remaining parts of the map disappeared, lacking a clear option to reset the previously made selection, as shown in Figure 5.5.

Figure 5.5 – SNISB Heatmap does not seem interactive

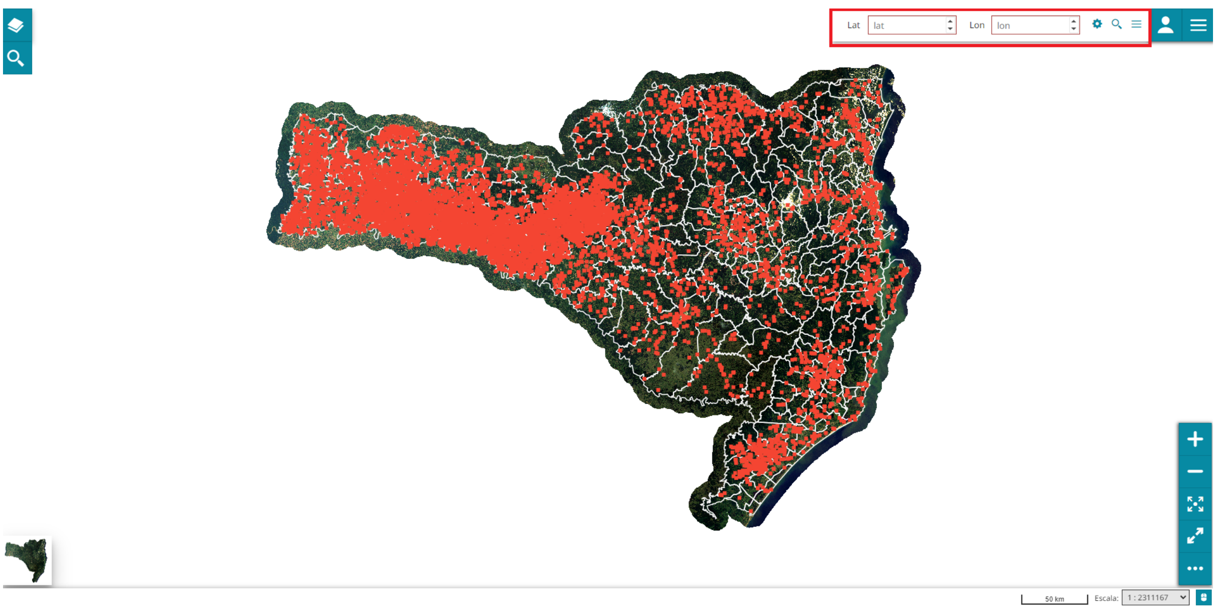


Source: SNISB Website (2024)

Spelling errors and system bugs - No application is exempt from the possibility of spelling errors or bugs. The system development process is complex and ongoing, so even after the product is launched, bugs and issues need to be addressed. However, it is worth noting that the appearance of bugs and spelling issues can disrupt users' interaction with the platform, depending on the severity of the problem at hand.

In SIOUT SC, the fields for latitude and longitude appear in red as soon as they are focused, indicating an error in the fields where no data entry has started yet. Even after filling in the information correctly, the outline remains red, suggesting to the user a potential input error, as shown in Figure 5.6.

Figure 5.6 – Fields for latitude and longitude show errors even before any input has started.

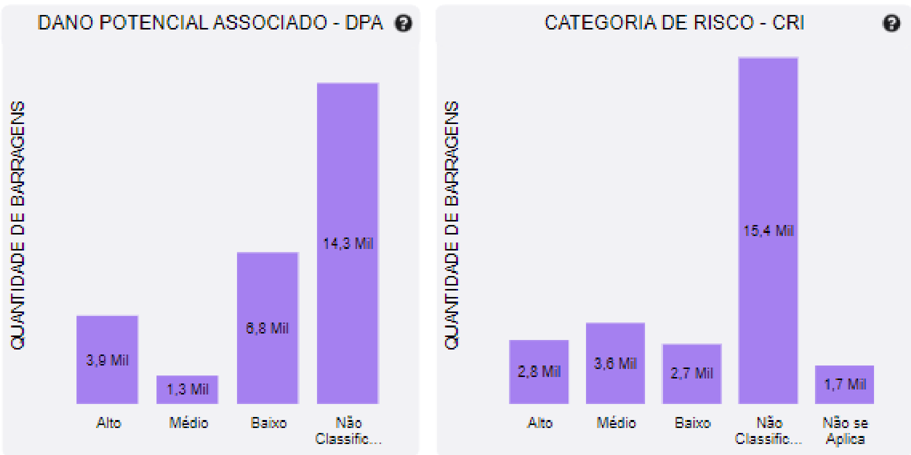


Source: SIOUT SC Website (2024)

Lack of clarity in explaining technical terms - When dealing with platforms involving geoprocessing focused on presenting environmental data accessible to users of various profiles, it is necessary for technical terms to be clear and well-explained. This is because the majority of users are not familiar with these terms and may have difficulty understanding the presented data due to a lack of translation of technical terms into language closer to that used by users.

In Brazil, dam safety policies incorporate specific terms to indicate the risk level of a potential dam failure, the associated risks in case of a breach, and the completeness of information about a particular dam. While these terms were devised to enhance safety inspection management, they may be unfamiliar to users. Hence, it is imperative to "translate" this information for users, ensuring their comprehension and alleviating concerns arising from potential misinterpretation, as shown in Figure 5.7.

Figure 5.7 – Usage of technical terms inside the platform without explanation to the users regarding what it means



Source: SNISB Website (2024)

This chapter showed the main results from the usability inspection by experts and user evaluations of the four applications sampled for this study. The following chapter presents the general discussion of the results from this study.

6 DISCUSSION

In this discussion chapter, the perspectives obtained from each of the studies conducted in the methodology of this work are presented, along with comparisons and supplements to related studies, as well as the identified limitations.

6.1 Study Overview

The interviews with the specialists brought various perspectives on the working methods and limitations of geoprocessing specialists in their daily context. Thus, the first important point raised by the experts concerns the dynamic nature of geoprocessing data and the interaction between different pieces of information to obtain the desired result.

The experts also raised several relevant topics for discussion, such as the need to include geoprocessing professionals in the product discovery context, geographical education for end-users and the development team, and the increasing need for programming language knowledge among developers.

Additionally, several limitations were indicated by the experts, such as difficulty in obtaining secondary databases, resistance to updating databases by clients, and technological limitations for carrying out specific tasks. In light of a comparison with the results obtained from user testing, it is possible to visualize a direct impact of this with the lack of clarity in presenting the data, since often the information cannot be obtained in its entirety, as well as delays in loading elements within the application.

The heuristic evaluations provided insights into the flow of operations in geoprocessing applications, highlighting the need for steps in task execution and information access to be streamlined. Additionally, there are numerous design issues for visualization during data exploration.

The results obtained from the heuristic evaluations complement the other inspection methods used very well. While the heuristic evaluations highlight more specific design issues to be improved to enhance interaction (such as clarity on what to do next, clarification of technical terms presented, well-defined user journey, and presentation of only available tools, for example), the user tests confirm the difficulty of interacting with the data platforms and accessing the provided information. At the same time, the specialists report problems with scope, deadlines, and limitations of technologies for geoprocessing product development.

Furthermore, as an advantage of applying heuristic evaluation, we have the severity ratings assigned to the usability issues identified. This allows us to identify the items that are most likely to hinder the interaction between users and geoprocessing platforms and prioritize them for resolution first, enabling the conduct of new tests to validate new aspects of interaction.

The user tests demonstrated the need for more geographic knowledge among the population. When faced with a map with multiple layers, users often feel lost about where to start or where to find relevant information. Considering that the tested applications are public and available to everyone, the steps to be followed for the platform to fulfil its purpose must be clear. Additionally, user tests corroborate the specialists' statements regarding the need for geographic education. Within this context, a challenge arises concerning how to ensure that this geographic education takes place.

Furthermore, map formats, tools, and possibilities are still relatively new to users. It is necessary to streamline access to data within the platform so that tasks can be completed and users can fully understand the information provided. Additionally, we confirm the specialists' view that certain elements on the map with specific colors (green for vegetation and red for deforestation, for example) are easily identified by users. However, user tests bring us the perspective that even with layers and their information represented by colors familiar to users, the interaction scheme and color overlay should be better addressed to avoid confusion or misunderstanding of the data due to incorrect interpretation.

User tests also bring to light an important issue regarding the use of technical terms (an aspect also addressed by the other two methods). Often, during the construction of application requirements, the focus is not on end users, but rather on those demanding the action. As a result, applications as a whole contain numerous technical terms, making it difficult for users to interact since these terms are not explained and may be crucial for certain interactions.

To answer the research question presented in the methodology chapter of this work, "What are the design recommendations that can facilitate product design and optimize the development and interaction related to geoprocessing applications for the context of environmental management?" human-centered design approaches were used. The objective was to map the various perspectives among geoprocessing experts, human-computer interaction professionals, and end-users to verify the items that could compose the guidelines to assist in the development and interaction with products with geospatial data in the environmental context.

6.2 Comparison with Related Work

In the study conducted by Ziegler and Chasins (2023), a contextual inquiry investigation was undertaken, engaging 25 participants from diverse sectors, including academia, industry, newsrooms, and the public sector, and design prospects were delineated. The points highlighted in this work are related to facilitating interaction with geoprocessing data by exploring design and cartographic space, assisting users in finding what they want, and indicating the expected outputs. Similarly, this master's project also comprised interviews with geoprocessing experts but also expanded the analysis with results from user and heuristic evaluations. The findings derived from the investigation applied in this study align with the design prospects identified by Ziegler and Chasins (2023), and the objective now is to broaden the discourse by suggesting a set of design guidelines to aid in geoprocessing design.

The study conducted by Nakić, Kosović and Franić (2022) aimed to investigate a human-centered design approach in the geospatial domain for representing temperature data. Within the study, various presentation formats and color palettes were examined, alongside their structural implications. When evaluating the structure of geoprocessing elements and their interactions, the study identified how colors and overlapping elements influenced visualization, potentially aiding or impeding users' data perception. Similarly, in this study, the influence of colors on information perception and their impact on the ability to adequately visualize and interpret data was observed. Furthermore, the study revealed instances where certain information failed to be conveyed due to the overlapping of visual elements on the screen..

The study conducted by Orémuš et al. (2020) aimed to build a human-centered application to extract and analyze data from temporal measurements captured at a polar station, with a focus on facilitating navigation. The prototype generated was tested in a pilot study, and it was concluded that concentrating information within a single application contributed to a positive outcome. However, the results obtained in the study conducted for this work indicate that even when elements exist within the same application, they must be organized and follow a logical presentation format to ensure that users understand the presented data and information.

The study conducted by Wei et al. (2020) aimed to analyze two different categories: Traditional Cartography and Geo-visualization. The researchers aimed to identify when each of these approaches was used. As a result, the use of Traditional Cartography depends on the context, while Geo-visualization varies from the former. Comparing the results with the study conducted in this work, we validate that Geo-visualization is an evolution of Traditional

Cartography. Therefore, according to the context and manner of use, the benefits and forms of interaction may vary, as mentioned by the interviewed geoprocessing experts.

The objective of the study by Nagel, Duval and Moere (2012) was to introduce two prototype models that were developed iteratively to improve user comprehension of geospatial networks. As categories, the researchers found "Rapid Adaptation of Map Styles", "Visual Style of Weighted Connections", "Acceptance of Multitouch Interaction", "Radial Menu for Dense Geospatial Data", "Design Process", and "Outlook". Complementing the findings of this master's thesis, the researchers bring new aspects related to interaction that are relevant, introducing new forms of visualization and interaction with geoprocessing elements to make the process of interacting with maps even easier for users, not identified in the usability tests conducted in this work.

In the study conducted by Kenney, Gerst and Read (2024), a three-phase investigation process was carried out to identify usability gaps in an American water resource management tool. The steps undertaken closely resemble those in this study (interviews with experts, diagnosis of usability issues, and platform redesign). While this study does not propose a redesign for the four evaluated applications, it provides an overview of usability problems, comparing the context of four applications with different types of geospatial data visualization.

The work presented by Vasilev, Petrov and Jordanov (2024) introduced an approach for visualizing geographical information within the context of mobile technologies, utilizing GISs for visualization and statistical tools for analysis. Taking a mobile-only approach may result in overlooking several usability issues that cannot be visualized. In this context, the approach used by the researchers provides insight into a limitation of this study, namely that geoprocessing applications in the mobile context should also be evaluated and have design guidelines proposed for their specific context.

The work conducted by Popelka et al. (2019) also provides another perspective on studying geoprocessing applications: evaluating three map-based visual analytics using eye-tracking, with the aim of testing user accessibility, identifying problems and shortcomings, and formulating recommendations for map creators. The points raised by the authors complement the suggestions made in this work and also highlight a limitation of this study: the lack of eye-tracking usage due to the remote testing approaches.

The work presented by Quiñones, Rusu and Rusu (2018) served as the methodological foundation for the development of this study. The steps proposed for the development of heuristics were employed and adapted (excluding the validation and refinement stages) to meet the deadline set for this master's dissertation.

The heuristics proposed by Nielsen and Molich (1990) are known for focusing on human-computer interaction, addressing only general aspects of design. On the other hand, the heuristics proposed by Victorelli and Reis (2020) are centered around human-data interaction, serving as a complement to the former set of heuristics. Finally, the heuristics proposed by Marquez, Meirelles and Silva (2021) represent the most recent set of heuristics focusing specifically on the concept of maps. In the context of geoprocessing, it is crucial that human factors are closely related to interaction with both the computer and the data. Additionally, there is an even greater need for attention to the presented elements in the context of geoprocessing. Therefore, the design guidelines propositions presented in this study aim to complement and address the specificities of usability in the geoprocessing context, catering not only to end users but also to the product development process.

6.3 The relevance of using design recommendations for interactive environmental geographical systems

Guidelines are important to cover more specific aspects of interaction that may not have been addressed by the heuristics used in this study. Given that the inspections involve geoprocessing and platforms accessible to the public, it is necessary to closely examine aspects related to these interactions to ensure a higher degree of usability within geoprocessing applications.

Therefore, the development of guidelines within the process of applications involving geoprocessing can be approached in two ways: focused on the product for presenting geospatial data itself and also on the development process.

By addressing both the process and the product, we aim to provide broader coverage of the issues and needs identified and mapped by users and experts, with the goal of improving the overall process. The chapter "Proposed Guidelines" will outline the guidelines proposed for this context based on the results obtained in this study.

6.4 Limitations and Future Work

This study faced some limitations during its execution. The first point to highlight is that all evaluations and interviews were conducted remotely, which did not allow the use of certain tools that could be relevant for map studies, such as eye-tracking. Another limitation encountered was the fact that the tests were conducted only for web applications, excluding the Mobile model. Additionally, during the user testing period, the SNISB platform was offline, resulting in the use of data obtained from previous user tests for an initial publication, thus causing the difference in the number of users as mentioned earlier.

Additionally, the steps of reviewing and refining the guidelines as indicated by Quiñones, Rusu and Rusu (2018) could not be followed due to time constraints for completing the work. As future work, the idea is to carry out these steps by conducting tests to validate the guidelines on a larger group of geoprocessing platforms.

Another limitation concerns the user profiles involved in the user testing phase, as this research did not include older age groups who may have different interaction patterns with geoprocessing platforms.

The results obtained and the guidelines proposed in this research were also based on an analysis of the findings and perspectives of both experts and users. Therefore, a limitation of this study is also the small number of experts in the human-computer interaction field involved (only three) and the limited number of applications tested. Different environmental applications involving geoprocessing could provide new insights for this study.

Considering future work, new tests will be conducted involving different user profiles and other types of environmental geoprocessing applications, including Mobile, in order to validate the proposed guidelines. Tests with the SNISB platform will also be repeated to follow the same metrics used for the other tests. The guidelines proposed in this study will need to be validated and undergo a process of refinement and testing to validate the propositions, as proposed by Quiñones, Rusu and Rusu (2018) and arrive at a final list of design guidelines focused on the interaction of geoprocessing applications.

7 PROPOSED DESIGN RECOMMENDATIONS

The main objective of this study was to investigate the usability issues encountered in applications utilizing geoprocessing, as well as to understand the perspectives of geoprocessing experts, their daily challenges, and the bottlenecks faced in the development process of products utilizing geoprocessing. Thus, it was possible to identify two fronts of proposed design guidelines: in the development process and elaboration of products using geospatial elements, as well as in the interaction with products involving maps.

7.1 Design Recommendations for Interactive Geoprocessing Systems in the Enrivonmental Domain

Well-defined color scheme and overlays - The visual elements of maps should allow users to discern information, ensuring that the application or overlay of colors does not lead to incorrect interpretations or errors in data reading. Therefore, the visual elements applied and used in maps should follow a standard and have colors that relate harmoniously, without impairing users with low vision or color blindness.

Recognition of context and content in geoprocessing applications - Geospatial data can have a high volume and complex interpretation. Therefore, it is important to clarify the context being addressed in the platform, the visualization possibilities, and interaction with the data. The content needs to be presented in a way that effectively conveys the entire storytelling in an easily understandable manner for end users.

Map options with accessibility - Geoprocessing applications need to provide built-in tools and support for external tools to assist users in understanding the data presented in case of disability or limitation - the data storytelling must exist in alternative formats to ensure user comprehension and access.

Clear map elements with explanations - To ensure the best possible interaction with geoprocessing elements, the presentation of data on the map must be organized so that the elements and features interact, allowing for direct interaction and manipulation of the data. Similarly, when technical terms are necessary, they should be translated and made available to users to ensure better utilization of the information.

Help functions and tutorials - Considering the complexity of geoprocessing elements, help functions should be available in the application. In case of errors and incorrect application of geoprocessing tools, users should have assistance available, either through explanatory texts or videos. Additionally, for the initial interaction with geoprocessing, it is recommended to have an interactive step-by-step tutorial in the application so that users can understand the functions of the elements and their roles, with the option to skip if the user is already familiar with the topic.

7.2 Design Guidelines for the Development Process for Geoprocessing Products

Involving geoprocessing experts in the product development process - To ensure a better approach to geoprocessing-related topics, the participation of team members specialized in geoprocessing is essential. Therefore, during the requirements gathering and client engagement phase, it will be possible to establish a better scenario for discussion, taking into account possibilities regarding financial feasibility, computational power, and deadlines.

Working on data processing, standardization, and translation - To conduct proper data analysis, it is necessary for the data to be standardized, as mentioned by geoprocessing experts. Therefore, in addition to standardizing the data, it is necessary to check for the presence of technical terms related to geospatial data and translate them into simpler and more easily understandable language.

Using "common sense" elements for environmental representations - There are certain elements with which users are already somewhat familiar, such as colors found in nature and even the outline of the map of Brazil. Therefore, conducting research involving the target audience of the application can be carried out to determine the "common sense" understanding of information within that user group, and then incorporating these elements into the construction of the geoprocessing product.

Client training for decision making - During the requirements gathering phase, clients may not always have knowledge about the geoprocessing tools that can be used, as well as their representation possibilities. Therefore, after an initial briefing by the client about their needs, it is ideal to present to clients the possibilities that geoprocessing tools offer, enabling client comprehension and better decision-making.

Organizing data according to context and volume - Depending on the context and the volume of data loaded into a database, its presentation format may vary. Therefore, it is important to assess the best way to represent the information found for end users, using familiar and common elements, as well as translating technical terms. Additionally, the visual elements used in data representation should tell a story and enable a comprehensive understanding of the data storytelling from start to finish.

Quadro 7.1 and Quadro 7.2 provides a better visualization of the relationship between the categories of usability problems found during the usability evaluations and the categories related to the statements of the geoprocessing specialists for the development of the design guidelines proposed in this study. For a more detailed view of the usability problems linked to the guidelines, please refer to the appendix of this work.

Quadro 7.1 – Design Recommendations and their Sources of Evidence

Proposed Design Recommendation	**Source of Evidence - Usability Issues**	**Source of Evidence - Specialists Interviews**
Well-defined color scheme and overlays	Colors and overlay of elements	Clear and Visual Data Interpretation with Well-Defined Colors
Recognition of context and content in geoprocessing applications	Lack of clarity in explaining technical terms	The Complexity of Understanding Geoprocessing Contents and Their Legends
Map options with accessibility		Lack of Geoprocessing Applications with Accessibility Standards
Clear map elements with explanations	Lack of familiarity with geoprocessing elements	Geoprocessing Environmental Data is Complex and Dynamic; Lack of Knowledge Regarding Declaration and Utilization of Elements in Geoprocessing Platforms Among Users
Help functions and tutorials	Lack of familiarity with geoprocessing elements; Lack of clarity in explaining technical terms	"Lack of Knowledge Regarding Declaration and Utilization of Elements in Geoprocessing Platforms Among Users
Involving geoprocessing experts in the product development process		Lack of Qualified Workforce and Knowledge for Automation of Analyses; The requirements gathering process should focus on the inclusion of the geoprocessing platform, including its data and data processing; Inclusion of the geoprocessing team in the requirement gathering process, defining the scope of operations

Source: Produced by the author (2024)

Quadro 7.2 – Design Recommendations and their Sources of Evidence

Proposed Design Recommendation	**Source of Evidence - Usability Issues**	**Source of Evidence - Specialists Interviews**
Working on data processing, standardization, and translation	Data presentation pattern; Spelling errors and system bugs	The visualization of geoprocessing information may suffer interference and loss of details due to data quality/quantity; Dependence on Secondary and Detailed Datasets that are Difficult to Obtain; Limitations of outdated database and processing technologies hinder effective interaction; The relationship between geoprocessing and technology has been fundamental in the development of geo-enabled products; The Lack of Knowledge About Geoprocessing Platforms Among the Development Team
Using "common sense" elements for environmental representations	Visibility about how to interact with data	Utilization of Common Visual Elements to Aid Users in Interpreting Information
Client training for decision making		Client Resistance to Geoprocessing Automation and Database Updates; The product discovery process should take into account the end-user and visually validate needs before development; Lack of Understanding Among Managers and Clients Regarding the Development Process and Its Complexity; The Lack of Knowledge About Geoprocessing Platforms and Formats Among Clients Hinders Effective Requirement Gathering; The Use of Geoprocessing in Decision-Making Processes for Environmental Monitoring and Conservation
Organizing data according to context and volume	Position of key elements to interact with data	Experts Need to Utilize Different Licenses and Tools to Achieve the Expected Result; Lack of Precision in Automated Analysis within Geoprocessing Tools; Different file sizes dictate the formats to be used; The presentation of geoprocessing data varies depending on the context, yet stan- dardization of data remains necessary

Source: Produced by the author (2024)

The objective of the presented design recommendations is to contribute to the improvement of development and implementation of geoprocessing elements in everyday contexts, assisting in the understanding of the storytelling created with the data, and enabling new practical and usable visualization methods.

8 CONCLUSION

This master's thesis aimed to investigate the aspects involved in interacting with geoprocessing data in the environmental context, in order to understand the usability issues faced by users, conduct heuristic evaluations to identify improvement opportunities, and comprehend the process of designing geoprocessing interactive systems by experts in the field. By obtaining and comparing the results, the objective is to develop design guidelines that can be relevant and assist in the development and creation process of geoprocessing systems.

To develop the design recommendations, the methodology used was based on the study by Quiñones, Rusu and Rusu (2018), following the proposed steps for heuristic development, which are: 1) Exploratory Stage, 2) Experimental Stage, 3) Descriptive Stage, 4) Correlational Stage, 5) Selection Stage, 6) Specification Stage, 7) Validation Stage, 8) Refinement Stage. By following these steps, the intention is to identify existing studies related to this area through a literature review. Subsequently, the process involves conducting the proposed tests and interviews, followed by an analysis of the obtained results. After analyzing the results, the aim is to identify common themes and relate them to create a new set of design guidelines focused on geoprocessing for the environmental domain.

From interviews with 15 specialists, it was possible to outline a thematic map containing the main themes raised and commented on by them. Among these themes, we have "Objectives and Typical Tasks in the Context of Geo Tools for Environmental Applications," which discusses the uses of geoprocessing in daily contexts, as well as its main functions, such as environmental mapping and assistance in environmental enforcement processes. The second identified aspect, "Geographical Education for Users and Development Team," discusses the need to increase environmental knowledge for end-users, clients, and development teams. When it comes to geoprocessing, it is important to consider that this topic is not common for everyone, and access to information related to the subject often does not reach all users. The category "The Complexity and Dynamism of Data Utilized in Geo Applications within Environmental Contexts" addresses the complexity and dynamic nature of data, indicating that geoprocessing data undergo frequent changes and may require constant adjustments in interaction and visualization methods, depending on the volume of information. To discuss the development process of a geoprocessing product, we have "The Development Process of Interactive Applications with Geoprocessing," where we can identify some needs arising from the product development process and requirements gathering, such as greater involvement of geoprocessing specialists in requirements gathering and the need for requirements to be more focused on geoprocessing needs when the product requires the use of geoprocessing elements, in order to establish boundaries and deadlines. When discussing "User Interface Characteristics in Geo Applications," specialists emphasized the importance of having a well-defined sequence of colors and elements, while also using elements that are common sense for the target user group of the application. Additionally, among other challenges mentioned by specialists, there is the complexity in understanding geoprocessing elements and their legends, as well as the lack of accessibility standards to be used in maps. Finally, the category "Limitations in Building Applications for Geo Data Interaction" presented the main limitations encountered by specialists, such as processing problems due to computational power depending on the volume of data, lack of precision in automated analyses, and loss of important details when automating data with a very high volume, as well as resistance from clients to update databases that are not always correct. With this, it was possible to have an overview of the context and limitations of working with geoprocessing specialists, especially for the environmental context.

In this study, four applications involving geoprocessing were evaluated, namely "SIOUT SC," "SNISB," "Agriculture Observatory," and "P3M," all of which are government platforms providing unrestricted access to environmental information.

The heuristic evaluation involved four human-computer interaction researchers, involved a rotation of participants in the tests, ensuring that each application was evaluated by three participants to assess the usability and interaction with geoprocessing data. The professionals identified usability problems together and assigned severity ratings to each of the problems encountered. In the heuristic evaluations, the "SIOUT SC" platform had 52 usability problems identified, "SNISB" had 41 usability problems found, "Agriculture Observatory" had 52 usability problems, and finally, the "P3M" platform had 66 usability problems encountered.

Regarding usability testing, 27 users were divided into 3 groups to test the "SIOUT SC," "Agriculture Observatory," and "P3M" applications. In the results related to the "SNISB," 18 users conducted the pilot test to assess the usability of the application. Due to platform availability issues, it was not possible to conduct a new evaluation along with the other applications. The users' tasks involved interacting with the geoprocessing platform and indicating their understanding of the platform's objectives and the presented data.

Based on the problems identified in both usability evaluation methods, it was possible to map categories of issues regarding interaction with geoprocessing platforms. The category

"Lack of familiarity with geoprocessing elements" represents the difficulty of interaction for users since the tools and elements present in geoprocessing applications are unfamiliar to them. Concerning colors and overlay of elements on the screen, which can cause incorrect interpretations or confusion for users, they are represented by the category "Colors and overlay of elements." Regarding the category "Position of key elements to interact with data," which means that key elements for data interaction should be available and displayed on the screen to facilitate interaction. Concerning the lack of standardization of the presented data, the category "Data presentation pattern" aims to present that data need to be standardized to ensure good interaction. Similarly, applications need to provide users with visibility on how to interact with the data, and therefore, the category of problems "Visibility about how to interact with data" was considered. Considering that every system is prone to have bugs and spelling errors, this was also considered as a category under "Spelling errors and system bugs." Finally, the category "Lack of clarity in explaining technical terms" exemplifies that the number of technical terms used in geoprocessing applications complicates interaction.

As results, the proposed guidelines are divided into two groups: 1) Design Guidelines for Geoprocessing Products and 2) Design Recommendations for the Development Process for Geoprocessing Products. The proposed guidelines focused on improving interaction with geoprocessing systems include:

a) well-defined color scheme and overlays;

b) recognition of context and content in geoprocessing applications;

c) map options with accessibility;

d) clear map elements with explanations;

e) help functions and tutorials.

Based on the usability issues identified and insights from domain experts, this study proposes five recommendations to aid in the design and production of geoprocessing products with an environmental focus. These recommendations are as follows:

a) involving geoprocessing experts in the product development process;

b) working on data processing, standardization, and translation;

c) using "common sense" elements for environmental representations;

d) client training for decision making;

e) organizing data according to context and volume.

This work and the proposition of design guidelines for applications with geoprocessing in the environmental context contribute to supporting the development of platforms and tools that use this resource, aiming for greater availability of data for users. Thus, by applying the results obtained in this study, the contribution is to generate greater familiarity for users with geoprocessing terms and tools, as well as to provide specialists and developers with a better understanding of how to organize the development process of geoprocessing products. With geoprocessing data more accessible and user-friendly, users can better understand if they are in a risky situation due to environmental characteristics. Additionally, it enables managers to anticipate decisions and raise awareness among the population about the risks involved.

The preliminary results of this study have led to the following publications:

a) usability evaluation of a brazilian dam safety data exploration platform: a consolidation of results from user tests and heuristic evaluation - Capeleti et al. (2023c);
b) human-data interaction in geoprocessing applications: design implications from the perspective of specialists - (CAPELETI; FREIRE, 2023);
c) interação humano-dados: análise de dados no contexto de geoprocessamento - Capeleti et al. (2023a);
c) avaliação de usabilidade de uma plataforma para exploração de dados de segurança de barragens: uma consolidação de resultados de testes com usuários e avaliação heurística - Capeleti et al. (2023b).

The limitations of this study encompass the unavailability of one of the applications during the testing phase, necessitating a revised strategy for user-based usability analysis of the applications. Furthermore, time constraints prevented the adherence to the steps of reviewing and refining the guidelines, as advocated by Quiñones, Rusu and Rusu (2018). Consequently, these steps remain pending and represent an avenue for future exploration. Subsequent work will involve conducting tests to validate the guidelines across a broader spectrum of geoprocessing platforms.

Furthermore, as part of future endeavors, the guidelines proposed in this study will undergo validation and refinement processes, culminating in comprehensive testing to validate the proposed principles. The objective is to derive a finalized set of design guidelines tailored specifically to the interaction dynamics of geoprocessing applications.

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A APPENDIX - TESTS RESULTS

Table A.1 – Issues found in SNISB in Heuristic Evaluations

Issue Code	Issues Found in SNISB	Heuristics Related	Severity Level
SNH-01	It was not evident whether dams registered in 2022 were part of the total (clarification is needed to indicate that among the registered dams, x were registered in 2022).	V6, N8, M1	2
SNH-02	The total number of registered dams and those registered in 2022 are distantly positioned.	V6, N1, N8, M1	1
SNH-03	The purple buttons fail to clearly indicate their inactive status.	V3, N7, N8, M5	2
SNH-04	The content to be shared is not explicitly specified - is it the entire page or just a single data point?	V3, N1, N7, M1	3
SNH-05	The term "Last update" is ambiguous - does it refer to the last time the page was loaded or the most recent update entered into the system?	V3, N1, N7, N8, M9	3
SNH-06	"Last update" should not be present as it may suggest outdated information - it might be preferable to have a separate timestamp for each graph.	V5, N6, N7, M9	2
SNH-07	Dams with good or excellent completeness - "You are viewing Brazil as a whole" - a large blank space - is it located below or to the right? Is it a single graph or the entire dataset?	V2, N1, N7, N8, M1	2
SNH-08	Upon mouse hover, the state, classification, and number of dams are displayed - but are these related to dams with good or excellent completeness?	V4, V5, N7, M5	3
SNH-09	The concept of good or excellent completeness may not be readily understood by individuals unfamiliar with dam operations; an explanation in terms of data significance is necessary.	V5, N7, M5	4
SNH-10	It is not evident that the map is clickable and capable of displaying data for a specific state.	V3, N1, N6, N7, M1	3
SNH-11	Upon clicking a state, others are faded, but some states remain clear due to the type of information displayed.	V3, N7, N8, M2	2

Source: Produced by the author (2024)

Table A.2 – Issues found in SNISB in Heuristic Evaluations

Issue Code	Issues Found in SNISB	Heuristics Related	Severity Level
SNH-12	The sole indication of the current state is by color - an alternative form of display (such as text) might enhance clarity.	V6, N5, N6, N9, N10, M8	2
SNH-13	There is no feedback indicating changes in the graphs on the right when a state is clicked.	V3, N1, N7, N8, M5	3
SNH-14	In instances where no data is available, "blank" is displayed instead of "not registered" or a similar phrase, potentially causing confusion.	V6, N6, N8, N9, M1	3
SNH-15	There is a lack of consistency in font type and size across filters and illustrations.	N8, M1	2
SNH-16	The font size of filters does not increase with CTRL+.	N8, M5	2
SNH-17	There is no clear option to clear a filter by state clicked on the map ("clear filters" does not seem to apply).	V1, N1, N3, N6, N7, N8, M5	2
SNH-18	The "clear filters" option is located outside the field of view.	V1, N1, N3, N6, N7, N8, M4	2
SNH-19	Clicking on a bar alters the displayed data without showing the status for verification.	V3, N6, N7, M9	3
SNH-20	There is no indication that the bars are clickable.	V3, N7, N8, M5	2
SNH-21	Once the mouse is removed, there is no visible indication of the currently selected state.	V3, N1, N6, N8, M9	3
SNH-22	The map and bar graphs do not facilitate the establishment of connections between the data.	V6, N1, N6, M4	3
SNH-23	The list of dams is positioned out of the viewer's immediate field of vision.	V3, N4, N6, M1	2
SNH-24	Regarding search results - what is searched for if no search is conducted?	V6, N6, N7, N8, N10, M6	3
SNH-25	There are no instructions on how to obtain more information about a dam.	V6, N6, N7, M5	3

Source: Produced by the author (2024)

Table A.3 – Issues found in SNISB in Heuristic Evaluations

Issue Code	**Issues Found in SNISB**	**Heuristics Related**	**Severity Level**
SNH-26	Some terms are specific and difficult to understand for non-experts, lacking an explanation of their primary use.	V5, V6, N6, N7, M1	4
SNH-27	After expanding the filter, the option to revert is difficult to identify.	V6, N6, N7, N8, M2	3
SNH-28	The expand button lacks a clear meaning.	V6, N6, N7, N8, M1	2
SNH-29	The affordance of the checkbox suggests that multiple selections can be made, although only one is accepted at a time.	V5, N1, N5, N6, N7, M1	2
SNH-30	"You are viewing the profile of Brazil as a whole" persists even after filtering.	V5, N6, N7, N8, M6	2
SNH-31	After filtering, it is not possible to determine the locations of the dams - only in the final list.	V5, N6, N7, N8, M6	3
SNH-32	The heatmap map does not change after filtering.	V3, N1, N6, N7, N8, M4	3
SNH-33	The titles of the graphs are not updated to reflect the applied filters, leading to potential misinterpretations.	V6, N6, N7, N8, M9	2
SNH-34	There is no legend identifying the classifications of dams.	V3, N1, N6, M9	3
SNH-35	A question mark is needed to indicate explanations at other points, not just technical items.	V6, N2, N6, M1	2
SNH-36	Only the menu is translated into Spanish, but not the data visualization.	V3, N2, N4, N6, N7, N8, M5	2
SNH-37	It should be available in English.	V6, N2, N5, N8, M5	1
SNH-38	Dams accessed more frequently since when? Since it has been online?	V6, N6, M9	2

Source: Produced by the author (2024)

Table A.4 – Issues found in SNISB in Heuristic Evaluations

Issue Code	Issues Found in SNISB	Heuristics Related	Severity Level
SNH-39	Prior to the name, a chart could be included showing the dams and time.	V5, N1, N7, M2	1
SNH-40	Risk category: Not applicable - can accidents really not occur?	V6, N5, N6, N7, M9	4
SNH-41	There is no explanation or label indicating what each item represents.	V6, N6, N9, N10, M5	3

Source: Produced by the author (2024)

Table A.5 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	**Issues Found in Observatório da Agropecuária**	**Heuristics Related**	**Severity Level**
OBH-01	Background animations impair readability.	N1, V5, M1	2
OBH-02	Actions for reading are difficult to locate.	N1, N6, V6, M5	3
OBH-03	The contrast between elements is dark against a dark background.	N1, V5, M1	3
OBH-04	Inconsistency in navigation - some panels lead directly to the map, while others do not.	N4, V1, M9	2
OBH-05	Lack of standardized nomenclature - "Geospatial," "Geospatial Platform."	N4, V6, M1	2
OBH-06	Functions with the same name redirect to different locations.	N4, V2, M5	2
OBH-07	Entering a thematic panel does not provide feedback indicating selection.	N5, V3, M5	2
OBH-08	No instructions on what to select to activate layers.	N1, N6, V6, M1	3
OBH-09	In the layer list, there is an info button that seems clickable but is not.	N6, V3, M1	3
OBH-10	Colors are informative only, with no explanation of their meaning.	N1, N6, V6, M5	2
OBH-11	Color legends are only displayed when the layer is activated.	N3, N5, V3, V6, M9	2
OBH-12	The activation button (eye icon) is unclear to users.	N1, N6, V6, M5	3
OBH-13	The button in "Planted Area" with sub-options is too small and unclear.	N8, N3, V5, M4	3
OBH-14	Activating a layer displays a number (active layer counter) without explanation.	N1, N6, V3, M9	3
OBH-15	Layer title suggests button functionality but is not a button.	N1, N6, V4, M1	2

Source: Produced by the author (2024)

Table A.6 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	Issues Found in Observatório da Agropecuária	Heuristics Related	Severity Level
OBH-16	Clearing layers lacks button affordance.	N1, V6, M1	2
OBH-17	In filters, "culture" with a gray background appears disabled but is not.	N1, N4, V3, M9	2
OBH-18	In filters, municipal layers appear activated (in white) when they are not.	N1, N4, V3, M4	2
OBH-19	The difference between clearing layers at the top of filters and clicking filters below is unclear.	N1, N6, V5, M1	3
OBH-20	Clearing filters leaves municipal layers active without selecting a culture.	N2, N7, V6, M4	2
OBH-21	The order of interaction and field dependency in filter application is unclear.	N1, N6, V3, M5	3
OBH-22	The play button for advancing time is too fast, not allowing images to load.	N1, N7, V4, M1	3
OBH-23	The button to change speed does not clarify whether it will increase or decrease speed.	N2, N7, V6, M5	3
OBH-24	Changing to English or Spanish does not change the layer list.	N1, V6, M9	4
OBH-25	Logging in - the process is unclear. Why log in? How to create an account?	N1, N3, V6, M5	4
OBH-26	Clicking on the map raises expectations of area details, but no information is provided.	N2, V3, V4, M9	3
OBH-27	Clicking the sandwich menu to return to the filter takes you back to the main menu of the Observatory.	N5, V6, M1	3
OBH-28	The tutorial does not function.	N10, M1	4
OBH-29	The "forward" button's purpose (share?) is unclear.	N6, V6, M1	3
OBH-30	Social media contrast makes reading difficult.	N1, V5, M9	3
OBH-31	Why is there such a lengthy process to reach social media sharing icons?	N7, M5	2

Source: Produced by the author (2024)

Table A.7 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	Issues Found in Observatório da Agropecuária	Heuristics Related	Severity Level
OBH-32	The button on the left with "squares" - label - does it open the main modal? It does not communicate effectively with the user.	N2, V6, M5	3
OBH-33	Theme names suggest they are layers, but layer names do not match themes.	N1, N10, V6, M9	3
OBH-34	It is unclear whether it is possible to intersect layers from different themes.	N3, V4, V6, M4	3
OBH-35	The relationship between base layers and specific layers is unclear.	N5, V6, M9	3
OBH-36	No option to clear the theme.	N2, M5	3
OBH-37	Selecting more than one theme does not seem possible in the interface.	N4, M1	3
OBH-38	The area for report details has poor contrast options - white letters on light backgrounds.	N1, V5, M9	3
OBH-39	The function should be to delete the report, not remove the theme.	N3, V6, M5	3
OBH-40	The generated bar graph is illegible.	N1, V4, M1	4
OBH-41	The process to generate graphs is overly complicated.	N2, V4, M5	3
OBH-42	The graph lacks a Y-axis legend.	N1, V6, M9	4
OBH-43	An icon commonly used for sorting is used to change the period.	N6, M1	3
OBH-44	Graph color changes randomly during exchanges.	N4, M2, M9	3
OBH-45	Latitude, longitude, and location options only work if an unidentified function is enabled.	N6, V5, M2	3
OBH-46	Activating zoom options does not provide feedback.	N5, V3, M2	3
OBH-47	Specifying the desired zoom level is difficult.	N7, M5	3
OBH-48	Options with search results are displayed with poor contrast.	N1, V5, M6	3

Source: Produced by the author (2024)

Table A.8 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	**Issues Found in Observatório da Agropecuária**	**Heuristics Related**	**Severity Level**
OBH-49	Searching for a municipality only centers the map on the city without visually identifying the contour.	N1, N9, V2, M6	3
OBH-50	Searching does not allow pressing enter.	N6, V4, M5, M6	3
OBH-51	When the search list generates scrolling, mouse scrolling moves the map, not the list.	N7, V4, M6	4
OBH-52	A list with more names in search disappears after a while, without providing an option to search further.	N5, V2, M9	4

Source: Produced by the author (2024)

Table A.9 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	**Issues Found in P3M**	**Heuristics Related**	**Severity Level**
PMH-01	Popup with data usage terms has too much text; people probably won't read it.	N2, V5, M9	3
PMH-02	Option 'Do not show this screen again' has a color that doesn't suggest it is clickable.	N6, M1	2
PMH-03	Popup resembles an error message and may instinctively lead people to want to close it.	N5, V2, M1	3
PMH-04	V 1.0.0 and Beta appear clickable due to the layout.	N3, V6, M1	1
PMH-05	CPRM logo has its name in English.	N2, M9	2
PMH-06	Contrast of the CPRM logo and title hinders readability (blue on blue).	N7, V5, M9	3
PMH-07	Top-left icon (resembling a hamburger but is a filter) isn't actually a menu.	N4,N7, M5	3
PMH-08	Filter icon appears at the beginning, even before entering advanced options.	N6, V6, M4	2
PMH-09	Scroll bar in the filter is too thin and hard to click.	N7, N8, M1	3
PMH-10	Why is there a country filter if only Brazil is available?	N5, N6, V5, M6	3
PMH-11	When there's only one country, feedback is hard to comprehend - do I need to do something?	N5, N6, V6, M6	3
PMH-12	List of options stemming from the filter option is 'attached' and with a color that doesn't suggest it is clickable.	N8, V4, M6	3
PMH-13	There's no standardization among scroll bars - some are thicker, some thinner, and in different colors.	N4, V5, M5	1
PMH-14	Municipality list becomes too long when there's no previous filter (allow listing even without a filter).	N6, V5, M6	2
PMH-15	It doesn't allow typing options in large lists (municipality and mineral) to facilitate searching.	N3, V4, M6	2
PMH-16	Filter logic by region/state lacks coherence (can select Acre and southeast, for example).	N2, V2, M6	4

Source: Produced by the author (2024)

Table A.10 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	Issues Found in P3M	Heuristics Related	Severity Level
PMH-17	Why is there such a large space between filters and selected indicators? It gives the impression that they're not part of the filter list.	N6, V5, M6	1
PMH-18	Indicator filters have their own scroll - seems to belong to another element.	N1, V5, M1	1
PMH-19	Filter modal overlaps a data column, hindering visualization.	N7, V5, M5	3
PMH-20	No clear correspondence between colors and types of indicators when many are selected.	N1, V2, M9	3
PMH-21	Correspondence between indicators and classes can only be made through colors (could include text as well).	N7, V6, M9	4
PMH-22	Filter application is slow.	N1, N5, M6	3
PMH-23	What are the icons for dashboard and hamburger in the corners of the boxes for? They're not clear.	N6, V6, M5	1
PMH-24	When hiding a chart, it's not clear that the action can be reversed in 'Hidden Charts'.	N3, N5, V4, M5	3
PMH-25	When clicking 'favorite,' there's no apparent feedback on the screen itself (could include an icon, for example).	N1, N5, V3, M1	3
PMH-26	What do the percentages mean? Are they in relation to the country? What do they refer to?	N6, V6, M9	4
PMH-27	There's no feature to explain what the percentage is.	N6, V6, M9	1
PMH-28	Links to data sources redirect to the homepage, not where the data is located.	N3, V3, M5	1
PMH-29	What does the mark on the line chart represent?	N6, V6, M4	2
PMH-30	Doesn't contextualize charts according to the selection - why show regional charts when only one state is selected? -Pie chart doesn't illustrate storytelling well.	N8, V5, M9	3

Source: Produced by the author (2024)

Table A.11 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	Issues Found in P3M	Heuristics Related	Severity Level
PMH-31	Coverage of surveys has resolution without cedilla and tilde.	N2, V6, M1	1
PMH-32	No color standardization in charts.	N6, V5, M1	2
PMH-33	Coverage of lithostratigraphic surveys - what is the number on the bar? Legend mentions percentage.	N5, N6, V6, M5	3
PMH-34	No explanation for specific technical terms for lay users - could include a glossary or external document.	N9, N10, V5, V6, M5, M9	3
PMH-35	No feedback on the existence or absence of data for selected indicators.	N1, V3, M5	3
PMH-36	Colors of chart boxes for relating to indicators are difficult to identify (thin bar).	N3, N7, V5, M9	2
PMH-37	'View Map' button overlaps data, hindering visualization.	N7, V5, M2	3
PMH-38	'View Map' button is hard to find (bottom right corner) - see eye-tracking meta-analyses (dead zone).	N6, V5, M5	4
PMH-39	Only the map is clickable; 'View Map' text is not clickable.	N3, V4, M1	3
PMH-40	When clicking on the map, it only shows options according to the previously applied filter, even though it gives the impression it would be a clean view (maybe come with the filter open).	N1, N6, V3, M6	3
PMH-41	No visual feedback showing applied filters.	N1, N7, V3, M6	3
PMH-42	When clicking on a point, attribute modal doesn't show the clicked color.	N1, N3, N6, V2, M5	2
PMH-43	Attribute modal has scrolling even when not needed.	N8, V5, M1	1
PMH-44	Search bar - Are horizontal and vertical menus interdependent? Not clear how they work.	N8, V5, M9	4
PMH-45	Horizontal bar is cut off at certain screen resolutions.	N3, V5, M9	3
PMH-46	'Home' link - what does it mean?	N6, V6, M1	3

Source: Produced by the author (2024)

Table A.12 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	**Issues Found in P3M**	**Heuristics Related**	**Severity Level**
PMH-47	In the layer filter (themes), only the first one comes with a detailed layer list, the others come closed.	N6, N7, V4, M5	3
PMH-48	Transparency applies only to one layer or everything? Not clear.	V3, V6, M4	3
PMH-49	When navigating by theme, the list shown with the open theme, but it's at the bottom, making it difficult to view.	V1, M1	3
PMH-50	Legends - Description is out of formatting standard.	N6	1
PMH-51	Legend scroll isn't visible.	N1, N3, N6, V5, M1	3
PMH-52	When showing the legend, there are two scroll levels, which can cause confusion.	N1, N3, N6, V5, M5	3
PMH-53	When clicking on legend items, it doesn't highlight on the map and doesn't relate map information to the legend.	N1, N6, V6, M2	3
PMH-54	When clicking on 'Quick Search,' it loses all context and opens another search field.	N3, N5, N6, V3, M6	3
PMH-55	Quick Search presents data from other countries in autocomplete.	N1, N6, N7, V6, M6	4
PMH-56	Quick Search doesn't offer a clear option to clear.	N3, N7, N9, V4, M6	3
PMH-57	While performing quick search, it resizes the map several times for no apparent reason.	N1, N6, N7, V2, M2	3
PMH-58	500km in the bottom right gives the impression it's a button (black background on dark blue screen).	N4, N6, M1	2
PMH-59	'View Dashboard' option overlaps with the coordinate display.	N7, V5, M9	4
PMH-60	Zoom + and - are in the top right corner - an area with little focus.	N6, M9	3
PMH-61	'Change Base Map' icon is not clear.	N6, V6, M5	2

Source: Produced by the author (2024)

Table A.13 – Issues found in Observatório da Agropecuária in Heuristic Evaluations

Issue Code	**Issues Found in P3M**	**Heuristics Related**	**Severity Level**
PMH-62	Favorite option - does it only	N3, N6, N7, V6, M5	3
PMH-63	Layer list - list showing active layers first - it wasn't clear what active layers are and the layers by theme that can be activated.	N1, N6, V6, M2	3
PMH-64	Number alongside layers has a mobile notification affordance - gives the impression that clicking the number will make it disappear.	N4, N6, V2, M1	2
PMH-65	Information identification is solely based on colors - may impair understanding for other users.	N2, N4, N6, V6, M5	2
PMH-66	Contact and information - without 'ç'.	N2, V6, M1	1

Source: Produced by the author (2024)

Table A.14 – Issues found in SIOUT SC in Heuristic Evaluations

Issue Code	Issues Found in P3M	Heuristics Related	Severity Level
SIH-01	The initial screen does not clearly communicate the operation flow.	N1, V6, M5	4
SIH-02	What does GIS mean? Will everyone understand?	N2, V6, M5	2
SIH-03	The flag at the bottom is not well-aligned.	N8	1
SIH-04	"Home Page" title - is it clickable? It has the same color scheme as the menu.	N6, M1	2
SIH-05	"Loading mapstore" - loading is in English while the system is in Portuguese.	N2, V3, V6, M5	3
SIH-06	Only mentions storing cookies without explaining what it means in the context where the user must agree.	N2, N10, V6, M1	4
SIH-07	The map does not contextualize the state of Santa Catarina with the others - could at least show the borders.	N2, V2, M4	3
SIH-08	The button in the lower left corner to change the background does not clearly indicate that it is clickable.	N6, V6, M5	3
SIH-09	The map outline option becomes illegible - difficult to read due to color contrast.	N1, N8, V3, M4	4
SIH-10	The "manual" icon for help is hard to find and unclear.	N10, V6, M1	4
SIH-11	"No information available for this point" when clicking on an item outside the map - should not be considered clickable.	N9, N1, V3, V6, M9	3
SIH-12	Tooltip with map point information presents acronyms difficult for the general population to understand.	N2, V6, M9	4
SIH-13	In the layer list, there are several acronyms to select - what do they mean?	N2, V6, M5, M9	4
SIH-14	Layers - in the layer list - "Antas" has a subtle shift in relation to "SADPLAN" - hard to see that it is a sub-item.	N8, N1, V2	3

Source: Produced by the author (2024)

Table A.15 – Issues found in SIOUT SC in Heuristic Evaluations

Issue Code	Issues Found in P3M	Heuristics Related	Severity Level
SIH-15	What is "balanco_hidrico_antes"? No clear description provided.	N2, V6, M9	3
SIH-16	"balanco_hidrico_antes" - what is it? The description only indicates "blue line" - does not satisfactorily explain.	N2, N10, V6, M9	4
SIH-17	Toggling the layer visibility - a term difficult for users to understand.	N2, N10, V6, M4	2
SIH-18	Line with percentage of line contrast - difficult to understand how it works.	N3, N6, V5, M9	2
SIH-19	Difficult to understand what the explaining balloon refers to - only by the lower arrow? (to which point on the map is this related?)	N6, V6, M5	3
SIH-20	When deactivating municipal boundaries, the divisions still appear in the layer list.	N2, V2, M2	3
SIH-21	Capture and classification layer - what is it? How to use?	N6, V6, M5	3
SIH-22	The layer icon is a menu (hamburger), but does not act like a menu.	N6, N2, V3, M1	3
SIH-23	Menu icon shows "capture" and "grab..." - distinct descriptions for different functions for the same icon.	N10, N4, V6, M9	3
SIH-24	Searching for "São" - shows items up to Russia, but it's only the state of SC.	N3, V4, M6	4
SIH-25	Auto-complete items do not prioritize the context of Santa Catarina in the search.	N4, V3, M6	3
SIH-26	Menu icon is used to offer choices of search types (coordinate or place name).	N2, N10, V6, M5	3
SIH-27	Searching by coordinates - lat / lon - non-descriptive names.	N9, V6, M5, M9	3
SIH-28	lat/lon in search by coordinates is outlined in red, as if it had already been filled in incorrectly before.	N9, V5, M5	2
SIH-29	What do "degree gms/degree decimal" mean? In settings.	N2, V6, M4	3

Source: Produced by the author (2024)

Table A.16 – Issues found in SIOUT SC in Heuristic Evaluations

Issue Code	Issues Found in P3M	Heuristics Related	Severity Level
SIH-30	X icon to clear field - does not correspond to common use (amid other icons).	N6, V3, M1	3
SIH-31	Search by incorrect latitude and longitude shows location "in the middle of nowhere," without feedback.	N9, V5, M4, M9	4
SIH-32	Even when logged in, clicking on the profile icon shows the option to "login," suggesting you are not logged in.	N9, V3, M1	4
SIH-33	Login status does not appear to be working.	N9, M1	4
SIH-34	"Drop your map context" - translation does not make sense.	N2, V6, M5	2
SIH-35	Mouse icon shows the option to hide/show layers (bottom right corner) - the icon does not make sense.	N6, V5, M4	1
SIH-36	What is a query? It is not clear whether it is a public consultation or what it is for.	N2, V6, M9	4
SIH-37	SIOUT Consultation - it is not clear that selecting an item affects the list of subsequent ones.	N5, V3, M6	3
SIH-38	Search in the consultation is very slow.	N3, V3, M6	4
SIH-39	When the search is stuck, there is no option to cancel.	N3, V4, M6	4
SIH-40	The result does not indicate how many results were listed.	N1, V3, V4, M9	3
SIH-41	There is no explanation about the numbers or types of results - does not explain what the items in the results are.	N2, V6, M5	3
SIH-42	When clicking on a result in the consultation list, it shows the point but does not leave a visual indication of which is currently selected.	N1, V3, M2	3
SIH-43	When clicking on the item to show details, there is an overlay of balloons, and it is difficult to change.	N1, V4, M1	4
SIH-44	Result point - detail balloon - X button as retract, not as close.	N2, V5, M1	4

Source: Produced by the author (2024)

Table A.17 – Issues found in SIOUT SC in Heuristic Evaluations

Issue Code	Issues Found in P3M	Heuristics Related	Severity Level
SIH-45	Result point - detail balloon - some items show with empty details.	N1, V3, M9	3
SIH-46	When clearing the consultation, it removes the point, but the pop-up with details remains on the screen.	N1, N9, V3, M1	4
SIH-47	When exporting, it does not ask for confirmation, and immediately starts the automatic download of a .zip file.	N5, V3, V4, M9, M10	3
SIH-48	When exporting, a read me in English says the result is empty.	N9, V6, M9	3
SIH-49	When exporting, it does not explain that the data will come in shape files.	N5, V3, V6, M5	3
SIH-50	Does not give feedback on whether the export was successful or not.	N9, V3, M1	4
SIH-51	Consulting objects on the map (local icon) only shows the map.	N2, V6, M4	2
SIH-52	The upper right corner shows two menu (sandwich) icons very close together - what are they for?	N4, V5, M1	3

Source: Produced by the author (2024)

Table A.18 – Issues found in SNISB by User Tests

Issue Code	Issues Found in SNISB	Number of users who have reported the issue
SNU-01	Dashboard map does not seem interactive.	14
SNU-02	When clicking on the dashboard, it gives the impression that the filters will also be updated.	1
SNU-03	"Clear filters" button is not very visible on the screen.	2
SNU-04	Filter font size is small.	7
SNU-05	"Filter icon only shows which filters have been selected, when in fact it gives the impression that it is possible to select a filter through it."	1
SNU-06	When expanding the "Dam name" filter, dam codes were listed.	1
SNU-07	Depending on the selected filter, the charts displayed on the dashboard overlap the titles.	1
SNU-08	When opening a list of filters for selection, the system gives the impression that it is possible to select more than one piece of information from the same filter, when in fact only one can be selected.	1
SNU-09	When checking the data presented in the table (which may appear in large volume), there is no option to return to the top of the table display.	1
SNU-11	The term "Search Result" causes some confusion, as what is presented are the results from filter selection, there is no actual search.	1
SNU-12	Map is too small, if it were larger it would make interaction easier.	1
SNU-13	Filter operation generates a lot of confusion about how to use it.	8
SNU-14	Filter does not close after selecting an option.	1
SNU-15	The term "ICI" in the table has no explanation, which may raise questions.	3
SNU-16	The "Most accessed dams" do not make clear what parameter is being counted (year, months).	1

Source: Produced by the author (2024)

Table A.19 – Issues found in SNISB by User Tests

Issue Code	Issues Found in SNISB	Number of users who have reported the issue
SNU-17	Filtered information should have its relation to the total displayed.	1
SNU-18	It is not clear that filters can be selected together.	1
SNU-19	The map title is too far from the image, it is not possible to understand if it is related to the map or the dashboard information.	1
SNU-20	For some dams, the information appears as "Blank", leaving the understanding confusing.	1
SNU-21	Just by looking at the dashboard, it is not possible to know which filters are active.	1
SNU-22	When interacting with the map, and clicking on a specific state, it does not always seem selected on the map due to the heatmap color scheme.	1
SNU-23	Filter information is cut off when opening options.	2
SNU-24	"Filter focus mode" sometimes opens in the middle of the screen, giving the impression that the screen is blank.	3
SNU-25	When hovering over the title of an information, it disappears.	1
SNU-26	Filter icons (such as focus mode) overlap filter information.	2
SNU-27	When selecting an option on the map, it is not updated in the filters.	2
SNU-28	In the "Find dams by" option, it gave the impression that it was a search field.	1

Source: Produced by the author (2024)

Table A.20 – Issues found in Observatório da Agropecuária by User Tests

Issue Code	Issues Found in Observatório da Agropecuária	Number of users who have reported the issue
OBU-01	Layers, their meanings, and colors are not intuitive (1 user with color blindness)	5
OBU-02	Layer application results were presented incompletely	2
OBU-03	The application has a check to keep the user within Brazil, but it disrupts interaction at times	2
OBU-04	At times, the reference to the states turns off, making it harder to locate on the map	1
OBU-05	It is not intuitive how to enable the municipalities (names) layer	4
OBU-06	When searching for a specific municipality, the municipalities layer is automatically activated, and after the search, it is not deactivated	5
OBU-07	Zoom is limited, making interaction difficult	1
OBU-08	Criteria for presenting APP areas	1
OBU-09	When activating a layer, the results were not displayed	2
OBU-10	Color scheme in layers/legends is confusing	2
OBU-11	In the legend, the layer name comes with the legend elements, causing doubt if it is data to be presented	2
OBU-12	It is not clear that when navigating through the legend, the highlighted layers change according to the selected item	2
OBU-13	Clicking on the legend title switches from one legend to another without being requested	1
OBU-14	Layer overlap can lead to interpretation doubts due to transparency (it seems to create a representation that does not actually exist)	1
OBU-15	When activating certain layers, archipelago information appears with a non-conventional representation, generating doubts	1
OBU-16	What is the difference between layers and base layers? Why are they separated?	1

Source: Produced by the author (2024)

Table A.21 – Issues found in Observatório da Agropecuária by User Tests

Issue Code	**Issues Found in Observatório da Agropecuária**	**Number of users who have reported the issue**
OBU-17	When applying the layer, it is difficult to identify where to clear the applied layers	1
OBU-18	Reports do not generate results; it remains blank	4
OBU-19	Geo tool buttons do not make their functions clear	1
OBU-20	It is not possible to extract map data	1
OBU-21	The share icon does not clarify its function	2
OBU-22	Slow loading, and when loaded, it shows "no information"	1
OBU-23	The hydrography legend does not follow the standard of other legends	1
OBU-24	When selecting one of the themes, the application does not load and remains blank	1
OBU-25	Layers are organized into folders, which causes confusion in activation - the expectation was that the layer would already be activated	1
OBU-26	When trying to interact with the profile, the application started displaying several blank tooltips on the screen	1
OBU-27	Some legends do not load	3
OBU-28	In the filter, activated options appear with the layout of deactivated ones and vice versa	2
OBU-29	Platform operation is confusing	1
OBU-30	The platform has very technical terms, difficult to understand	1
OBU-31	The theme selection location is not clear	1
OBU-32	"Opens a modal" - a more technical term from computing	1
OBU-33	Geo tool functionality is not clear	1
OBU-34	Theme identification looks like a search bar	1
OBU-35	It is not clear that the hydrography has levels to be accessed	1

Source: Produced by the author (2024)

Table A.22 – Issues found in Observatório da Agropecuária by User Tests

Issue Code	**Issues Found in Observatório da Agropecuária**	**Number of users who have reported the issue**
OBU-36	To navigate the legend data, scrolling is not easily done (and does not follow the mouse)	1
OBU-37	Even with no active layers, it was indicating that there was an active layer	1
OBU-38	In the reports, there is a section with data filled in only with "null"	1
OBU-39	In the filter, activated options appear with the layout of deactivated ones and vice versa	1
OBU-40	"No information" in the legend does not clarify what it means	1
OBU-41	The application does not clarify how to interact with the platform	1
OBU-42	Layer and information activation location can be confused	1
OBU-43	The layer name shows one color, and in the legend, another - which one is correct?	1
OBU-44	After clearing the layers, some stopped working	1
OBU-45	Coffee layers do not load and are not displayed	1
OBU-46	Map tools cause confusion about their function and usage	1
OBU-47	Search button is hidden, and when clicked, it does not perform the search, needs to be done through the keyboard	1
OBU-48	Greens from OpenStreetMap and Layers cause confusion in information interpretation	1
OBU-49	The platform takes too long to present the information	3
OBU-50	The platform has very technical terms, difficult to understand	1
OBU-51	When trying to scroll through the screen, autocomplete options close	1

Source: Produced by the author (2024)

Table A.23 – Issues found in Observatório da Agropecuária by User Tests

Issue Code	**Issues Found in Observatório da Agropecuária**	**Number of users who have reported the issue**
OBU-52	When activating a layer by mistake, the options were presented, and the system did not make it clear that there was an enabled layer	1
OBU-53	What do I share? If there are active layers, will everything be shared?	1
OBU-54	Field selection information in the filter remains only loading and does not allow interaction	1

Source: Produced by the author (2024)

Table A.24 – Issues found in P3M by User Tests

Issue Code	Issues Found in P3M	Number of users who have reported the issue
PMU-01	When refreshing the page, the terms are presented again, even if the user has selected not to see them again.	1
PMU-02	Icons to the right of the map do not make it clear that they provide access to the dashboard.	1
PMU-03	Icons are confusing; in some cases, words might be more helpful.	1
PMU-04	It is not clear what the layers are and how they function.	5
PMU-05	It's complicated to identify the theme on which the tool works.	1
PMU-06	Layer on/off button could have an explanation of how it works.	3
PMU-07	Active layers are not evident and create confusion in interaction.	5
PMU-08	It is not clear that there is information about the layer.	4
PMU-09	After viewing information from a layer, there is no button to return to the layers.	3
PMU-10	If there is a way to access the information screen, why is it possible to access it in two different ways? It doesn't make sense.	2
PMU-11	It's confusing to click on a layer item and open another tab, such as information or legend. Ideally, there should be only one access point.	2
PMU-12	When zooming in to better visualize a point on the map, it drastically decreases with the map scale, making it impossible for better viewing.	1
PMU-13	When clicking on the map, it opens an attribute modal that had no indication it could be opened.	1
PMU-14	Opened attribute modal does not translate the language.	1
PMU-15	When searching for a location, suggestions start with a comma, not bringing the searched element.	5

Source: Produced by the author (2024)

Table A.25 – Issues found in P3M by User Tests

Issue Code	Issues Found in P3M	Number of users who have reported the issue
PMU-16	The search option is enabled for the whole world, but the information only works in Brazil.	1
PMU-17	When applying the filter, there is an option to select the country, which does not make sense since the only option to select is Brazil.	2
PMU-18	When applying the filters, the map zooms without giving feedback if the search parameters are correct.	2
PMU-19	It's not intuitive that the filters can only be used with the layers turned on and search based on them.	7
PMU-20	Selected items in the filter are not easy to remove; the option is 'hidden'.	1
PMU-21	When trying to clear the filters, they all clear at once.	1
PMU-22	The platform started presenting attribute modals in a loop.	1
PMU-23	The 'do not show again' button can be confused with accepting the terms of use.	1
PMU-24	When activating a layer, the application froze and only showed parts of the map.	2
PMU-25	When viewing information from a layer, there is no option to return to the previous step.	2
PMU-26	Button and icon are misaligned.	1
PMU-27	It's not possible to search for a municipality; a search bar would be helpful.	1
PMU-28	Development tools are presented, disrupting interaction.	2
PMU-29	The option to clear layers is not easily visible.	1
PMU-30	It's not possible to identify which of the sub-items are selected - there's no feedback.	1
PMU-31	When focusing on a municipality, the search froze and prevented navigation.	1
PMU-32	Search did not direct the user to the correct location on the map.	4

Source: Produced by the author (2024)

Table A.26 – Issues found in P3M by User Tests

Issue Code	Issues Found in P3M	Number of users who have reported the issue
PMU-33	Legends are not easily identifiable.	2
PMU-34	Legends use similar colors for different elements, causing confusion.	1
PMU-35	When enabling a layer, it did not load on the screen and provided no feedback.	2
PMU-36	When trying to load the filters, no results were loaded, and there was no feedback.	1
PMU-37	The map has little initial guidance on how to use it and what it is for.	2
PMU-38	Technical terms are difficult to understand.	3
PMU-39	When applying zoom, the application froze and only showed parts of the map.	3
PMU-40	Having only one button to activate the search makes the task longer.	1
PMU-41	The map takes a long time to render and display results.	1
PMU-42	Even with an active layer, legends were not presented in the legend section.	2
PMU-43	There is no feedback when some information is loading.	1
PMU-44	After applying the search filter, the visualization became very small and difficult to see.	1
PMU-45	Zoom for visualization does not zoom in much.	1
PMU-46	What is the purpose of each of the base maps?	1
PMU-47	When performing the search, it brings locations from outside Brazil even though the application is only for Brazil.	2
PMU-48	When there is no active layer, the legend does not explain how to enable a layer.	1

Source: Produced by the author (2024)

Table A.27 – Issues found in SIOUT SC by User Tests

Issue Code	Issues Found in SIOUT SC	Number of users who have reported the issue
SIU-01	The application is heavy and takes time to load.	6
SIU-02	It is challenging to identify locations on the map.	2
SIU-03	When conducting a search, the application does not offer any help options to complete the search.	1
SIU-04	"The data presented in map tooltips is not in user-friendly language."	6
SIU-05	What does "Quantity of hours" in the presented tooltip mean?	1
SIU-06	The latitude and longitude formats are confusing for completion.	2
SIU-07	The search filter does not retrieve some specific locations.	1
SIU-08	When activating the SIOUT Query and clicking again on the map, the tooltip information stops appearing.	2
SIU-09	The SIOUT Query search results take too long to load, and there is little feedback.	1
SIU-10	Records are loaded all at once; if they were loaded by pagination, it would be better.	1
SIU-11	When exporting data, the file format is not common to users.	2
SIU-12	Cookie messages are not displayed correctly.	1
SIU-13	It is not clear about which state the data is from.	1
SIU-14	When clicking to view map information, at one point, the background map disappeared, showing only the tooltip.	1
SIU-15	If I try to insert a point from another state, will it work? Is there any verification?	2
SIU-16	The hydrological balance layers raise doubts as to whether they are interactive or not.	1
SIU-17	When scrolling the screen, all layers are selected together.	1
SIU-18	The folder hierarchy does not make interaction clear.	3

Source: Produced by the author (2024)

Table A.28 – Issues found in SIOUT SC by User Tests

Issue Code	Issues Found in SIOUT SC	Number of users who have reported the issue
SIU-19	The insert point button on the map does not function.	1
SIU-20	When removing the background map, there is no feedback on the location.	1
SIU-21	The OpenStreetMap shows the whole world, and it does not come focused only on SC, as the platform's objective.	1
SIU-22	When searching for a state outside SC on OpenStreetMap and then returning to orthophoto visualization, the information disappears, and no feedback is given.	3
SIU-23	What do the layers signify? What data do they intend to present?	4
SIU-24	After applying the search filter, the layer of registered interferences stops being displayed.	1
SIU-25	The open and close options button gives the impression of importing files.	1
SIU-26	The layers make it unclear whether it is a watershed or a municipality.	1
SIU-27	Due to not having visible legends, the layers make understanding the content difficult.	1
SIU-28	Map tools cause confusion about their function and usage.	4
SIU-29	"No queriable layer active" - gives the user the impression that something has been turned off.	1
SIU-30	When zooming in on the page, the icons do not adjust with the zoom, making it difficult to view.	1
SIU-31	When attempting to accept cookies, the page provides no feedback on the action.	1
SIU-32	The method of changing the order of the layers is confusing.	3
SIU-33	When trying to move a layer, nothing happens.	1
SIU-34	Legends are hidden and have their names in English.	1

Source: Produced by the author (2024)

Table A.29 – Issues found in SIOUT SC by User Tests

Issue Code	**Issues Found in SIOUT SC**	**Number of users who have reported the issue**
SIU-35	Each basin has two layers: what is the difference between them?	1
SIU-36	What does "regularized interference" mean?	4
SIU-37	At what point do I have some of the "terms" on hand to perform the search?	3
SIU-38	Location name - are they only cities?	1
SIU-39	The map change option is not clear.	1
SIU-40	When entering latitude and longitude, the map size decreased, and the map was replicated 5 times on the screen.	1
SIU-41	Selecting water usage only works with one of the "search for" options. This hierarchy should be clearer.	1
SIU-42	The tooltip with the information opens "cut off" on the screen, impairing visualization.	2
SIU-43	River information is only linked with the active layer, generating confusion for visualization.	1
SIU-44	The SIOUT Query is not highlighted with the layers open, going unnoticed.	1
SIU-45	When the OpenStreetMap is active, elements of the map are confused with layers.	1
SIU-46	It is not possible to view the names of municipalities on the default map.	1
SIU-47	When clicking in the blank area outside the map, the system presents an error, but does not explain how to use the platform.	1
SIU-48	Items seem interactive but are not.	1
SIU-49	When activating a hydrological balance layer with zoom enabled, the layer may not be perceived if applied to another section of the map.	1
SIU-50	What is the difference between the hydrological balance and availability?	1

Source: Produced by the author (2024)

Table A.30 – Issues found in SIOUT SC by User Tests

Issue Code	Issues Found in SIOUT SC	Number of users who have reported the issue
SIU-51	Balloons presented after the query generate confusion about what they represent.	1
SIU-52	Balloons do not seem clickable.	1
SIU-53	Even when closing the option, the functionality continues the search, making it impossible to cancel the action.	1
SIU-54	With the result centralized, when trying to click on the plotted point, no result is returned on the map, and the result disappears.	1
SIU-55	It does not make sense to have a login on the platform if I cannot log in.	1
SIU-56	When clicking on a balloon, the application distorted the sizes, and interaction was blocked.	1

Source: Produced by the author (2024)

B APPENDIX - GUIDELINES AND ISSUES

Table B.1 – Guidelines Proposed

Guideline Proposed	Source of Evidence - Usability Issues
Well-defined color scheme and overlays	SNH-06, SNH-11, OBH-01, OBH-03, OBH-10, OBH-40, OBH-44, OBH-49, PMH-02, PMH-06, PMH-12, PMH-19, PMH-21, PMH-32, PMH-36, PMH-37, PMH-42, PMH-45, PMH-48, PMH-59, PMH-65, SIH-04, SIH-09, SIH-28,SIH-43, SNU-07, SNU-23, SNU-26, OBU-01, OBU-07, OBU-10, OBU-14, OBU-23, OBU-43, OBU-48, PMU-34
Recognition of context and content in geoprocessing applications	SNH-01, SNH-05, SNH-08, SNH-18, SNH-19 , SNH-30, SNH-33, SNH-34, SNH-40, OBH-04, OBH-06, OBH-07, OBH-11, OBH-18, OBH-20, OBH-21, OBH-23, OBH-29, OBH-33, OBH-34, OBH-37, OBH-46, OBH-52, PMH-03, PMH-10, PMH-11, PMH-17, PMH-18, PMH-20, PMH-25, PMH-26, PMH-28, PMH-33, PMH-40, PMH-43 PMH-47, PMH-54, PMH-58, PMH-64, SIH-01, SIH-06, SIH-07, SIH-11, SIH-14, SIH-15, SIH-19, SIH-22, SIH-23, SIH-26, SIH-30, SIH-34, SIH-36, SIH-37, SIH-41, SIH-42, SIH-46, SIH-49, SIH-50, SIH-52, SNU-02, SNU-05, SNU-11, SNU-14, SNU-15, SNU-16, SNU-17, SNU-19, SNU-20, SNU-24, SNU-25, SNU-28,OBU-06, OBU-08, OBU-11, OBU-12, OBU-13, OBU-16, OBU-22, OBU-24, OBU-26, OBU-27, OBU-29, OBU-30, OBU-32, OBU-35, OBU-40, OBU-42, OBU-50, PMU-02, PMU-05, PMU-07, PMU-10, PMU-11, PMU-13, PMU-20, PMU-23, PMU-24, PMU-29, PMU-33, PMU-38, SIU-02, SIU-05, SIU-08, SIU-09, SIU-13, SIU-17, SIU-20, SIU-23, SIU-26, SIU-27, SIU-29, SIU-32, SIU-33, SIU-34, SIU-36, SIU-38, SIU-41, SIU-43, SIU-49, SIU-50, SIU-54, SIU-55, SIU-56
Map options with accessibility	SNH-10, SNH-11, OBH-30, OBH-38, OBH-48
Clear map elements with explanations	SNH-03, SNH-04, SNH-09, SNH-17, SNH-20, SNH-23, SNH-24, SNH-28, SNH-31, SNH-41, OBH-02, OBH-09, OBH-12, OBH-14, OBH-15, OBH-16, OBH-27, OBH-32, OBH-35, OBH-39, OBH-43, OBH-45, PMH-39, PMH-44, PMH-53, PMH-57, PMH-61, PMH-62, PMH-63, SIH-02, SIH-08, SIH-16, SIH-18, SIH-20, SIH-21, SIH-27, SIH-29, SIH-35, SIH-47, SIH-51, SNU-01, SNU-06, SNU-08, SNU-09, SNU-13, SNU-18, SNU-21, SNU-22, OBU-03, OBU-05, OBU-15, OBU-17, OBU-19, OBU-21, OBU-25, OBU-31, OBU-33, OBU-34, OBU-36, OBU-41, OBU-52, OBU-53, PMU-04, PMU-06, PMU-12, PMU-18, PMU-19, PMU-25, PMU-28, PMU-31, PMU-35, PMU-36, PMU-39, PMU-46, PMU-48, SIU-04, SIU-06, SIU-11, SIU-16, SIU-19, SIU-25, SIU-28, SIU-37, SIU-45, SIU-48, SIU-51, SIU-52

Source: Produced by the author

Table B.2 – Guidelines Proposed

Guideline Proposed	Source of Evidence - Usability Issues
Help functions and tutorials	SNH-13, SNH-16, SNH-21, SNH-25, SNH-27, SNH-29, OBH-08, OBH-25, OBH-28, OBH-36, PMH-24, PMH-27, PMH-34, PMH-35, PMH-41, PMH-56, PMH-60, SIH-10, SIH-39, OBU-46, PMU-03, PMU-08, PMU-09, PMU-30, PMU-37, PMU-43, SIU-03,SIU-15, SIU-22, SIU-31, SIU-39, SIU-44, SIU-47
Involving geoprocessing experts in the product development process	
Working on data processing, standardization, and translation	SNH-12, SNH-14, SNH-22, SNH-26, SNH-35, SNH-36, SNH-37, OBH-05, OBH-13, OBH-19, OBH-24, OBH-41, OBH-51, PMH-04, PMH-05, PMH-13, PMH-15, PMH-22, PMH-29, PMH-30, PMH-46, PMH-50, PMH-51, PMH-55, SIH-05, SIH-12, SIH-13, SIH-17, SIH-31, SIH-38, SIH-44, SIH-45, SIH-48, SNU-04, SNU-12, SNU-27, OBU-02, OBU-04, OBU-09, OBU-18, OBU-20, OBU-38, OBU-44, OBU-47, OBU-49, OBU-51, OBU-54, PMU-01, PMU-14, PMU-21, PMU-22, PMU-32, PMU-40, PMU-41, PMU-47, SIU-01, SIU-07, SIU-10, SIU-14, SIU-24, SIU-30, SIU-35, SIU-40, SIU-42 , SIU-53
Using "common sense" elements for environmental representations	OBH-17, OBH-26, OBH-31, OBH-47, OBH-50, PMH-07
Client training for decision making	
Organizing data according to context and volume	SNH-02, SNH-07, SNH-15, SNH-32, SNH-38, SNH-39, OBH-22, OBH-42, PMH-01, PMH-08, PMH-14, PMH-16, PMH-38, PMH-49, PMH-52, SIH-24, SIH-25, SIH-40, SNU-03, OBU-28, OBU-37, OBU-39, OBU-45, PMU-15, PMU-16, PMU-17, PMU-27, PMU-42, PMU-44, PMU-45, SIU-18, SIU-21, SIU-46

Source: Produced by the author

C APPENDIX - USER TESTS METHODS

C.1 Demographic Questionnaire

1) Age:

2) Do you have any disabilities or injuries? If yes, which?

3) How many hours on average per day do you use websites on the computer?

() Never

() 1-3 hours

() 4-6 hours

() 7-9 hours

() More than 9 hours

4) What rating would you give for your level of experience with computers?

No experience 1 / 2 / 3 / 4 / 5 / 6 / 7 Very experienced

5) How many hours on average per day do you use websites on your smartphone?

() Never

() 1-3 hours

() 4-6 hours

() 7-9 hours

() More than 9 hours

6) What rating would you give for your level of experience with smartphones?

No experience 1 / 2 / 3 / 4 / 5 / 6 / 7 Very experienced

7) How long have you been using the internet?

() Less than 6 months

() 6-12 months

() 1-3 years

() 4-6 years

() More than 7 years

8) How often do you use the internet to access data on any topic?

Never 1 / 2 / 3 / 4 / 5 / 6 / 7 Always

9) How often do you use the internet to search for and access maps?

Never 1 / 2 / 3 / 4 / 5 / 6 / 7 Always

10) Have you participated in usability tests before? If yes, how many times?

11) What is your educational level?

() Elementary School

() High School

() Undergraduate

() Postgraduate

C.2 Usability Questionnaire

1. Overall, I was able to comprehend the information presented in the data:

( ) Strongly Disagree

( ) Partially Disagree

( ) Neutral

( ) Partially Agree

( ) Strongly Agree

2. Overall, the readability of the data was easy:

( ) Strongly Disagree

( ) Partially Disagree

( ) Neutral

( ) Partially Agree

( ) Strongly Agree

3. I would use the presented data for conducting studies:

( ) Strongly Disagree

( ) Partially Disagree

( ) Neutral

( ) Partially Agree

( ) Strongly Agree

4. I would recommend the page containing the data to friends:

( ) Strongly Disagree

( ) Partially Disagree

( ) Neutral

( ) Partially Agree

( ) Strongly Agree

5. I believe that the presentation of the data was easy to interpret:

( ) Strongly Disagree

( ) Partially Disagree

( ) Neutral

( ) Partially Agree

( ) Strongly Agree

6. I think the information is useful in my life:

( ) Strongly Disagree

( ) Partially Disagree

( ) Neutral

( ) Partially Agree

( ) Strongly Agree