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Development of a decision-making system based on the mandala of water and agricultural sustainability

Desenvolvimento de um sistema para tomada de decisão fundamentado na mandala da sustentabilidade hídrica e agrícola

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Resumo
Este trabalho teve como objetivo desenvolver uma inovadora ferramenta de suporte à decisão para gestão sustentável de água e agricultura em bacias hidrográficas, utilizando a Mandala da Sustentabilidade Hídrica e Agrícola. O sistema foi construído com tecnologias como Django e Plotly, permitindo uma interface facilitadora para a gestão de recursos hídricos com tomadas de decisão inclusivas e participativas. Foi criada uma aplicação web gratuita, abrindo caminho para testes de usuários, atualizações com base nos resultados e lançamento final da ferramenta. Acredita-se que isso promoverá maior acessibilidade à informação e envolvimento dos atores sociais na gestão hídrica e agrícola, resultando em decisões mais integradas e sustentáveis.
Palavras-chave: Gestão integrada de recursos hídricos. Sistemas de Indicadores. Software. Instrumento de Diagnóstico.

Abstract
This article aimed to develop an innovative decision support tool for sustainable water and agricultural management in river basins, using the Mandala of Water and Agricultural Sustainability. The system was built with technologies such as Django and Plotly, allowing a facilitating interface for water resources management with inclusive and participatory decision-making. A free web application was created, paving the way for user testing, updates based on results and final launch of the tool. It is believed that this will promote greater accessibility to information and involvement of social actors in water and agricultural management, resulting in more integrated and sustainable decisions.
Keywords: Integrated water resources management. Indicator Systems. Software. Diagnostic Instrument.

1. Introduction

The Brazilian National Water Resources Policy (PNRH), established Law No. 9.433 of 1997, was developed based on the expansion of the European Water Framework Directive (EC, 2000). Notable advances include the emphasis on democratic management and the adoption of hydrographic basins as the unit of management. The law is characterized by its decentralized and participatory nature, as it establishes basin committees as collegial bodies composed of representatives from the government, water users, and civil society (BRAZIL, 1997). However, despite the objectives of public policies aiming at sustainable development and the integration of water management with user sectors, the PNRH has sustainability assessment tools that are developed on a sectoral basis, according to their purpose.

It is crucial to recognize that, despite the progress, the effective implementation of the PNRH faces significant challenges. These challenges are multifaceted and require an integrated approach to ensure the long-term sustainability of water resources management. According to Fisher *et al*. (2011), watershed management instruments that support decision-making without considering the integration of key issues, such as agricultural food production, can hinder the participatory process of these users and, consequently, run counter to sustainable development. Similarly, the difficulty in understanding the data and sustainability diagnoses obtained through these tools can also inhibit the participatory process of water users.

In this context, the challenge of management systems lies in facilitating the engagement of these sectors in issues related to water resources (BROMBAL *et al*., 2018). Therefore, there is a recognized lack of decision support tools, in terms of sustainability, that integrate water management and the agricultural sector and are easily interpretable to stimulate the participation of stakeholders in decision-making processes (EDELENBOS; MEERKERK, 2015). It is believed that the Water and Agricultural Sustainability Mandala (WASM) can be an easily understandable and visual tool to illustrate the sustainability diagnosis of a hydrographic basin, as it is a graphical model designed to support decision-making (MENDONÇA, 2021).

Based on the WASM, the intention is to develop a decision support system. This system will enable greater accessibility to information and encourage the participation of social actors, democratizing water resources management with integrated, inclusive, and effective decision-making towards sustainability.

Section 2 details the methodology used in developing the decision support tool. Section 3 presents and discusses the results derived from the tool's implementation. Finally, Section 4 encapsulates the findings, foresees future steps, and emphasizes the tool's significance in enhancing accessibility to information and engaging social actors for integrated and sustainable resource management.

2. Material and Methods

The choice of technologies for this project was based on specific criteria that addressed the needs and goals of the water resource management decision support tool. To implement the decision support system, software development technologies were used that allow not only the development of a web application but also the use of software libraries for data analysis and visualization. For this reason, the technologies used are described throughout this section.

Django, an open-source framework for rapid web application development written in Python (The Django Software Foundation, 2023), was selected for its robust and efficient platform. Its Model-View-Template (MVT) architecture provides an organized and simplified framework for managing data and user interactions. The Model represents the application's data structure, with a direct connection to a database schema. Additionally, it offers an abstraction layer for performing data inclusion, retrieval, updating, and deletion operations. The View serves as a layer of application controllers, responsible for receiving, processing, and responding to user requests. Lastly, the Template facilitates the interface between the user and the application.

For data analysis and visualization, Plotly (Plotly Technologies Inc., 2023) was chosen for its capability to create high-resolution interactive graphs. The library offers advanced interactivity features like zooming, rotation, selection, and filtering, enabling users to explore data more deeply. This is crucial for a comprehensive understanding of hydrological and agricultural sustainability indicators.

The selection of PostgreSQL as the relational database management system was motivated by its reliability, scalability, and advanced security features (The PostgreSQL Global Development Group, 2023. Its robust and scalable architecture is especially valuable in applications requiring high availability, scalability, and security. Furthermore, PostgreSQL is well-documented and widely used, facilitating long-term support and maintenance.

Figma, a collaborative interface design tool, was utilized for designing user interfaces and prototypes due to its user-friendly interface and comprehensive features (FIGMA, 2023). It enables the creation of intuitive user interfaces, interactive prototypes, and graphic elements for web design projects. Its collaborative nature is especially valuable for distributed development teams.

Render.com was chosen for hosting the application based on its offer of a free plan for setup and testing on dedicated servers. Additionally, Render.com provides a reliable solution for storing data generated by the application, ensuring the security and availability of information.

These choices were made after a careful assessment of the specific project requirements, considering factors such as efficiency, interactivity, security, and scalability. Each technology was selected to make a significant contribution to the success and performance of the water resource management decision support tool.

The development of the virtual platform was carried out according to the following stages:

- Planning: This initial phase involved defining the tool's objectives and functionalities, as well as identifying the specific target audience it aimed to serve.
- Sketching: In this stage, the architecture and system design were conceptualized using wireframes and prototypes. This step allowed for a clear visualization of the platform's structure.
- Development: The selection of the most suitable technologies was crucial. Additionally, this phase encompassed defining the database structure, implementing functionalities, and ensuring the quality of the code.
- Testing: Rigorous testing was conducted, starting with a phase of programmer-driven testing. Subsequently, the platform underwent evaluation by potential future users to identify and address any potential issues.
- Launch: The platform was officially introduced to the public, with efforts focused on its publication and promotion to ensure widespread accessibility.

The decision support system was divided into two modules: administration and information visualization. The administration module allows users to register hydrographic basins and manipulate data related to the indicators provided by the WASM. The information visualization module enables users to easily view the indicators provided by the WASM. To achieve this, a dashboard data visualization model was employed. This model is commonly found in decision support tools.

3. Results and Discussion

With the technology implementation defined, it was essential to create an outline of the tool's functionalities to expedite its development and understand the roles of the involved social actors, such as basin managers, government officials, water users, and communities, within the software.

To plan the program's interface, the choice was made to employ the Figma software (FIGMA, 2023). Figma is a collaborative design tool that allows users to create user interfaces, prototypes, icons, and other graphic elements for web design projects. This facilitated the definition of important functions for the user, such as registration, authentication, creation of organizations, and basin management. Additionally, users can view the evaluative progress of other registered basins, provided they are defined as visible to the public. Figure 1 illustrates the sketch of the tool's interfaces and their connections.

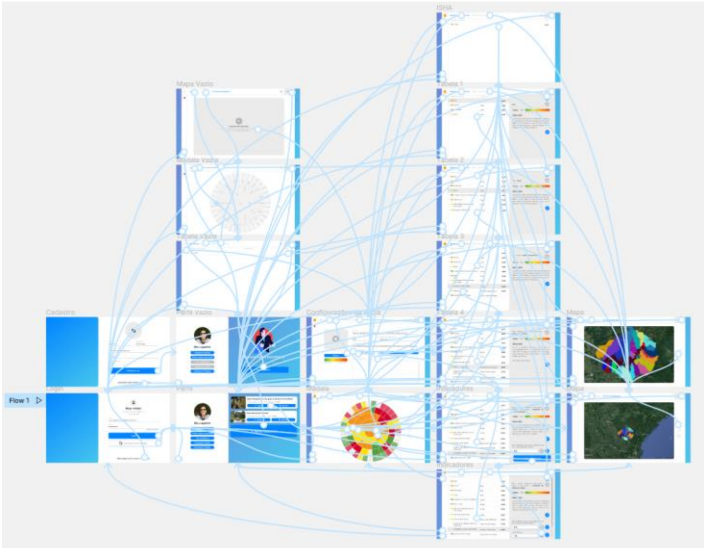

Figure 1 – Interface Sketch of the Tool.

Nielsen's 10 heuristics, which are fundamental principles for the design of effective and efficient user interfaces, were employed in the design of the tool's interface (Nielsen, 1994). Developed by Jakob Nielsen, one of the leading experts in usability and user experience, these heuristics are widely recognized as an important guide for designing high-quality interfaces. By adhering to these heuristics, the aim was to ensure that the tool provides a pleasant, intuitive, and user-friendly experience, allowing users to focus on their tasks and goals without being distracted by usability issues. Nielsen's heuristics include aspects such as clarity in presenting information, consistency in navigation, minimizing user workload, and preventing errors.

The next step in the project implementation involved the development of the software. To accomplish this, the Visual Studio Code IDE was used on a machine running the Windows 10 operating system. Throughout the process, we maintained a private version control directory, enabling us to work in an organized and efficient manner. Additionally, to simulate a local server, we created a Python virtual environment and installed the necessary dependencies for the Django framework and the PostgreSQL database.

For the development of the tool, it was necessary to extract relevant information for the assessment of a basin and model it in a way that the data relate concisely with the important elements for its administration. To achieve this, the work of Mendonça (2021) was utilized, presenting a hierarchical model of indicators for the integrated assessment of watershed sustainability.

As a result, the aspects of analysis and evaluation were divided into two major groups: Attributes and Indicators. In this work, attributes are defined as the information visible in the mandala. They allow for the hierarchical organization of information and adhere to the graphical generation structure of the Plotly library. The chart model found that fits the visualization is of the "sunburst" type, which is rich in documentation for configuration and customization.

On the other hand, indicators are defined as the "invisible" part of the mandala. They are represented this way because they are located at the hierarchical edge of the adopted model, and they serve as the entry panel for mandala values.

After completing the development of the initial system requirements, it was necessary to make the tool available online in order to make it accessible to the public and democratize its use. It's worth noting a barrier encountered during this implementation phase, due to the scarcity of servers that offer free hosting for Django applications. After research, it was identified and decided to use the web service provided by the platform render.com, which offers a free plan for configuration and testing on their dedicated servers.

It is important to highlight that the storage of data generated by the application is crucial, as the tool generates a large amount of information, including organization data, personal information, and change records. The platform provides a database service and uses PostgreSQL for this purpose.

In Figure 2, you can see a functional example of the main decision-making panel, featuring fictional data. On the right-hand side, there is the water and agricultural sustainability mandala, generated with the assistance of the Plotly library. In the center, you'll find some information regarding the basin, such as its title, description, and a legend with the color scales of the mandala. To the left, there is the navigation panel between the important tabs for basin management.

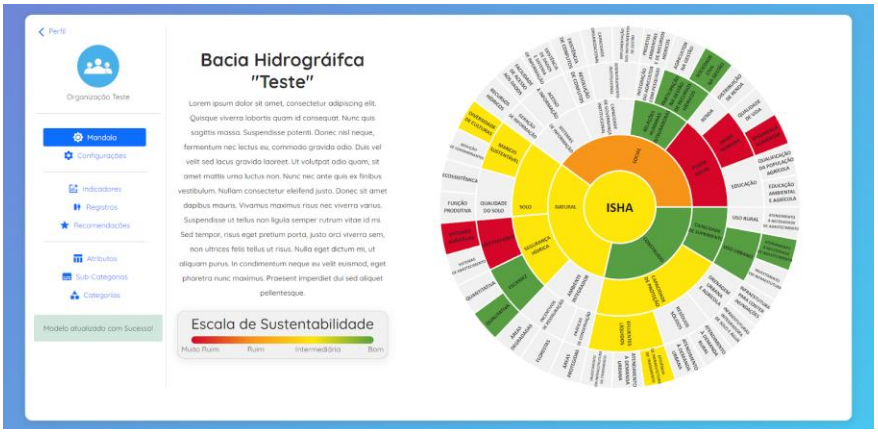

Figure 2 – Basin Management Panel.

In addition to the mandala, the tool is equipped with interactive tables (Figure 3). With them, it is possible to sort and search for data, allowing for a simple and quick search and visualization of information regarding the water and agricultural sustainability of the hydrographic basin.

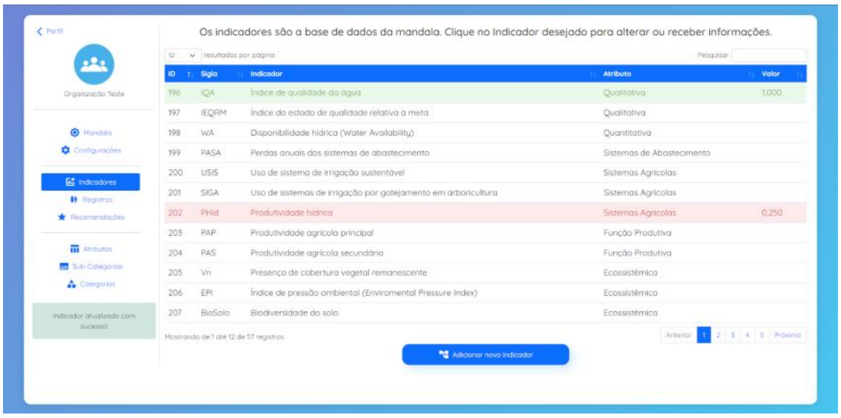

Figure 3 – Indicators in Interactive Tables.

4. Conclusion

The employed methodology proved effective in achieving the objectives of this work, resulting in the virtual release of the tool's first version. Despite the encountered limitations, such as the use of a free dedicated server, which constrained available resources, the tool's implementation was feasible, enabling progression to the next stage of its development. This phase will involve user-perception-based testing and evaluations, culminating in the official launch of the tool.

Looking ahead, the aim is to further refine the tool based on user feedback, with the goal of enhancing user experience and expanding its practical utility. Additionally, we plan to conduct case studies and broader validations to ensure the tool's robustness and reliability across different contexts.

Following the testing and evaluation phase, modifications and additions to the tool will be possible, aiming to reach a broader user base, potentially resulting in significant gains in usability and utilization. This will facilitate the tool's official launch. Moreover, we believe that the tool's availability will lead to greater information accessibility and encourage the participation of social actors, democratizing water resource management through integrated, inclusive, and decisive decision-making for sustainability.

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