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A Web-GIS for decision making to achieve water quality standards of water bodies through collaborative watershed modeling

Web-GIS como suporte à decisão para enquadramento dos corpos de água através de modelagem colaborativa na bacias hidrográfica

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ABSTRACT

Ensuring compliance with the minimum Water Quality Standards stipulated by law demands the implementation of strategic measures within the watershed. Water pollution modeling serves as a tool to guide the formulations of effective pollution control strategies. However, the inherent complexity of calibration, spatial-temporal variability, and uncertainty, in addition to effective communication of technical information to decision makers, makes it challenging to prioritize actions, implement them, and allocate resources efficiently. This paper presents the implementation of a Web-GIS for decision making support which combines collaborative hydrological and hydrodynamic modeling results with an interactive visualization of the Paranapanema river basin in the South of Brazil. The Web-GIS aimed to overcome the difficulty of presenting scientific results to decision-makers, gathering and harmonizing diverse datasets. Combining information from the watershed, the pollutant loads estimations for three substances (phosphorus, nitrogen, and BOD), the resulting concentrations in rivers and reservoirs, as well as the results for different future scenarios into a unified platform. It is expected that decision-making regarding water bodies framework will be facilitated by identifying the primary sources and pathways of pollution, prioritizing basins with the highest load production, an determining realistic possibilities of load reduction through effective measures.

Keywords: Web-GIS; Water framework; Water quality standards; Decision making; Paranapanema.

RESUMO

Garantir o cumprimento dos padrões mínimos de qualidade de água estabelecidos por lei exige medidas estratégicas na bacia afluente. A modelagem da poluição de água serve como ferramenta para orientar a formulação de estratégias eficazes de controle de poluição. No entanto, a complexidade inerente à calibração, à variabilidade espacial-temporal e a incerteza, aliadas ao repasse ineficaz de informações técnicas para os tomadores de decisão, dificultam não apenas a priorização se não a própria efetivação das ações e aplicação dos recursos eficientemente. Sendo assim, este estudo apresenta o desenvolvimento de um Web-GIS que reúne os principais resultados das modelagens hidrológicas para conceder uma visão interativa da bacia do Rio Paranapanema no sul do Brasil. O sistema supera a dificuldade de apresentação de resultados científicos para o gestor, reunindo e harmonizando conjuntos de dados diversos. Combinando informações da bacia hidrográfica, estimativas de carga de poluentes para três substâncias (fósforo, nitrogênio e DBO), as concentrações resultantes em rios e reservatórios, bem como os resultados para diferentes cenários futuros em uma plataforma unificada. Espera-se que a tomada de decisão em relação ao enquadramento de corpos d'água seja facilitada pela identificação das principais fontes e vias de poluição, priorizando as bacias com maior produção de carga e determinando possibilidades realistas de redução da carga por meio de medidas eficazes.

Palavras-chave: Web-GIS; Enquadramento dos corpos d'água; Padrões de qualidade da água; Suporte à decisão; Paranapanema.

INTRODUCTION

The formulation and implementation of strategies in the basin depend on the agility in decision-making processes to establish goals that ensure water quality in rivers, even for the most demanding uses. In Brazil, the Water Quality Standards (WQS), depend on the agreement between water users at the watershed, including the landowners, government agencies, non-governmental organizations, and communities members (Agência Nacional de Águas e Saneamento Básico, 2007). Nevertheless, there are several challenges related to it and the first one is to achieve a consensus among these groups who have different backgrounds and interests, which requires a good understanding of the impacts of human activities on water bodies (Pahl-Wostl et al., 2007). The second is the substantial time required for the stakeholder to understand and analyze the multiple stages involved in this process such as i) the basin diagnosis that implies the understanding of the current conditions characteristics and challenges of the basin, ii) the basin prognosis, that refers to the assessment and projection of future conditions, trends, and scenarios for a river basin or watershed; iii) the elaboration of a framework proposal that involves the development of a structured plan or set of guidelines to manage and improve the quality of water resources, and finally iv) the analysis and deliberation by the basin committee and the Water Resources council that includes the revision of the proposal and review scientific data, technical reports, stakeholder inputs, and other relevant information for take a decisions referent to the viability of the goals proposed (Agência Nacional de Águas e Saneamento Básico, 2009, 2020; Machado et al., 2019). Another challenge lies in effectively assimilating the models that support the decision for defining WQS goals, ensuring their relevance and achievability. This interpretation depends on the expertise of technicians and scientists to communicate relevant and simplified information dynamically to all the stakeholders in the basin. To overcome these challenges, it is crucial to utilize tools or frameworks that can effectively synthesize scientific information. In the present context, Web-GIS (Web Geographic Information Systems) tools are employed as intuitive interfaces for results interpretation, providing systematic visualization of different alternative scenarios and their implications on water quality, resulting in adequate information for decision-making (Lins et al., 2012; Machado et al., 2019; Quinn et al., 2022). Recent studies have explored the potential regarding the use of Web-GIS for visualization and sharing geospatial data highlighting the possibility of simplifying access to information for decision-making processes (Botha et al., 2023; Quinn et al., 2022; Bedair et al., 2022 & Kourgialas et al., 2022). A Web-GIS allows the incorporation and understanding of various biophysical processes, such as land use and land cover patterns, slope, soil types, or geology distribution, and the relationships between these factors and water quality. Furthermore, it enables the establishment of spatial relationships between the impact of chosen actions and scenarios involving contaminants that can reach rivers (Quinn et al., 2022). Another study describes an approach that can facilitate the real-time management of water quality based on forecasts using the WARMF (Watershed Analysis Risk Management Framework) (Dinar & Quinn, 2022). The methodology combines a Multi-Criteria Decision Analysis (MCDA) with the GIS environment. This approach allows different basins to be assess and prioritize based on multiple factors that are relevant to improve water quality, including point and diffuse pressures and landscape metrics. By applying this methodology, they can rank the basins that should be targeted for interventions to improve water quality and mitigate the risk of contamination (Fernandes et al., 2021). Likewise, the engagement of partners, even in the development of a sediment model, can be very important for decision-making, as those involved can have more transparency and understanding of the processes, thus generating more confidence in the results (Cho et al., 2019).

In this context, the objective of this research was the implementation of a Web-GIS for decision-making support which combines collaborative hydrological and hydrodynamic modeling results with a geospatial visualization of the basin. By integrating and summarizing the complexity of the models within the prioritization of actions it enables a better interpretation of the relationship between an action and the maintenance or improvement of water quality. This research is part of a larger project that developed a set of models to estimate pollutant loads in the watershed and hydrodynamic models for rivers and reservoirs. These models serve as the foundation for defining progressive goals, as well as prioritizing actions and ranking basins to maintain or achieve the defined quality standards for each section of the water body.

Case study

In Brazil the definition of WQS was based on the stipulation of two federal resolutions: CONAMA Resolution nº 357/05 and CNRH Resolution nº 91/08. CONAMA Resolution nº 357/05 classifies rivers into four classes (ranging from Class 1 as highest quality to Class 4 as the lowest quality), and establishes specific limits for various parameters within each class. These standards serve to assess and classify the environmental quality of rivers according of their preponderant uses (Brasil, 2005).

The National Council of Water Resources Resolution CNRH nº 91/08 presents the steps to be followed in a framing study. The framework should be based on the quality stablished by the required water uses (current and future), and should not just be based on the current quality presented by the river (Brasil, 2008). In this way, the instrument should ensure that the water quality is compatible with the most demanding water users located in the basin, thus ensure pollution reductions according to the needs established by society (Machado et al., 2019).

The study area is the Paranapanema River basin (Figure 1), which is about 900 km long, with a drainage area of about 100,800 km^2 (Agência Nacional de Águas e Saneamento Básico, 2016). It is an interstate basin of great economic importance for two Brazilian states (São Paulo and Paraná). It contains almost 4.7 million habitants, who are mainly concentrated in urban areas. The main economic activities are agriculture and cattle ranching (which occupies almost 70% of the basin), and forestry (with 8% of the basin). The natural areas are composed of 14% forest cover and 4% grassland. The remaining territory, which corresponds to 4%, presents other types of activities such as industries, urban areas, and water bodies.

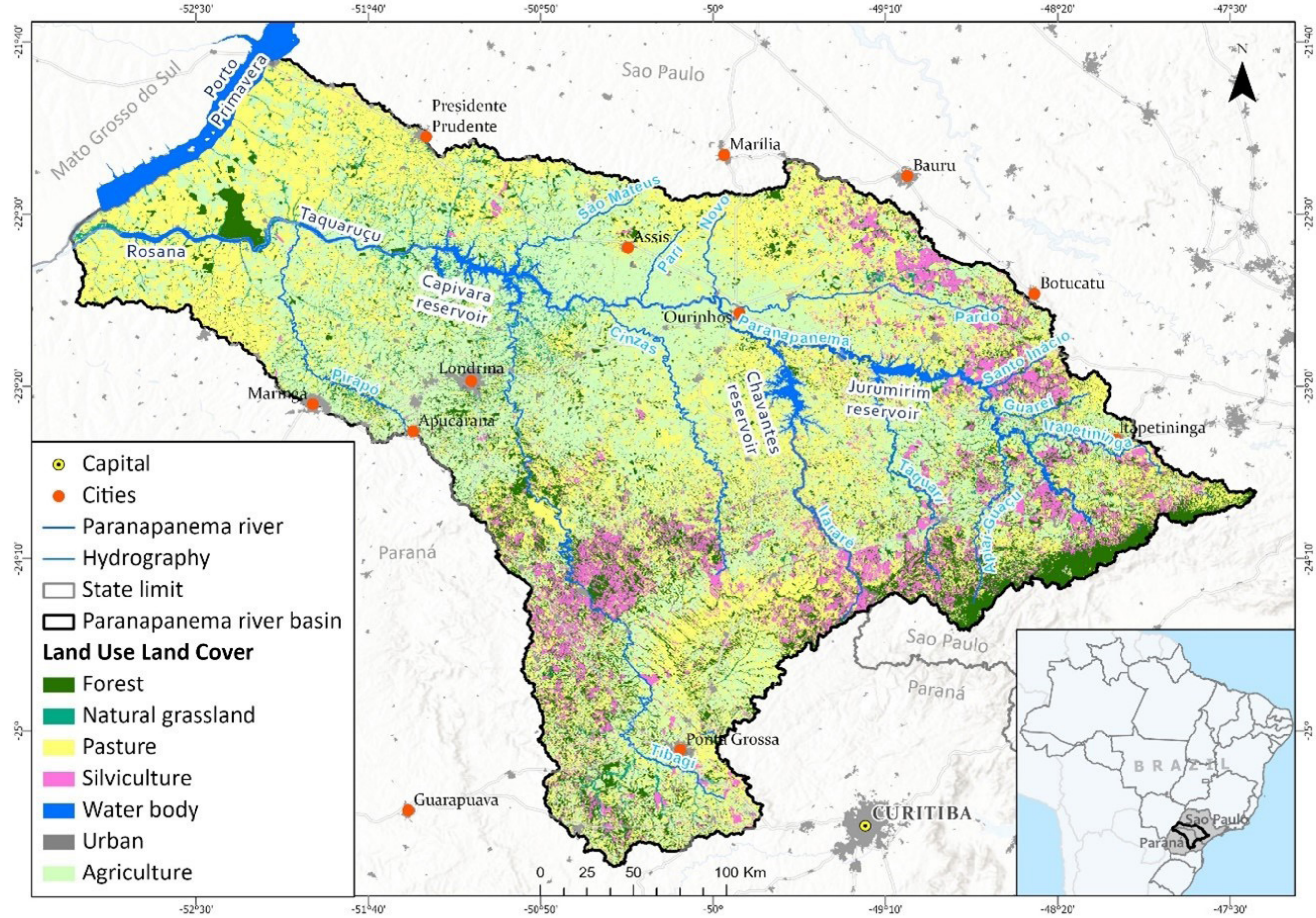

Figure 1. Study area: Paranapanema river basin.

The Paranapanema Basin is part of Brazil's interconnected electric power production and transmission system, contributing to approximately 6% of the capacity of the southeast/central-west subsystem (Operador Nacional do Sistema Eléctrico, 2022). Three large multipurpose hydroelectric plants have been installed, as follow: Jurumirim, Chavantes, and Capivara, which modified the riverbed and, along with human activities, require good basin management to guarantee water quality for all users.

METHODS

The Web-GIS was developed as part of the project called "Modelling of Water Quality in the Paranapanema Basin: Base for the water quality standards", between ANA and UFPR (Agência Nacional de Águas e Saneamento Básico, 2022), and it was created with the aim of harmonizing and visualizing the results of the modeling of the basin load emission estimates, hydrodynamic modeling of rivers, and substance concentration estimates in the reservoirs. This section presents a brief description of the previous stages, data preparation and modeling, and the development of the Web-GIS platform to support decision-making. The models are available for future research in the following repository (Carvalho, 2023) and the Web-GIS is available at Brasil (2023).

Data preparation and modeling

The steps involved for the development of the Web-GIS are illustrated in Figure 2. The process was divided into four phases. The first step, or intelligence phase, involves the compilation of a spatial database, climate data and water quality data. Additionally, during this stage the parameters Total Nitrogen (TN), Total Phosphorus (TP) and BOD (Biochemical Oxygen Demand) were selected as indicators of water quality. These indicators were chosen based on data availability and their significance as sources of information about pollution. The year 2012 was selected as the baseline due to the availability of data encompassing land use and land cover, socioeconomic factors, as well as monitoring data. The second step was the formulation phase, that involved the modeling of rivers, reservoirs, and basins. This modeling aimed to organize complex environmental and biophysical information, estimating the basin loads, their propagation in rivers and reservoirs. The third part or evaluation phase, consists in the evaluation of future scenarios that could influence the water quality, as well as evaluating measures aimed at reducing pollutant loads. Two scenarios were selected for presenting in the Web-GIS, a trend scenario, and an accelerated scenario. The scenarios were based on the projections proposed for the long term (2035) in the Integrated Water Resources Plan of the Paranapanema Basin Management Unit (Agência Nacional de Águas e Saneamento Básico, 2016).

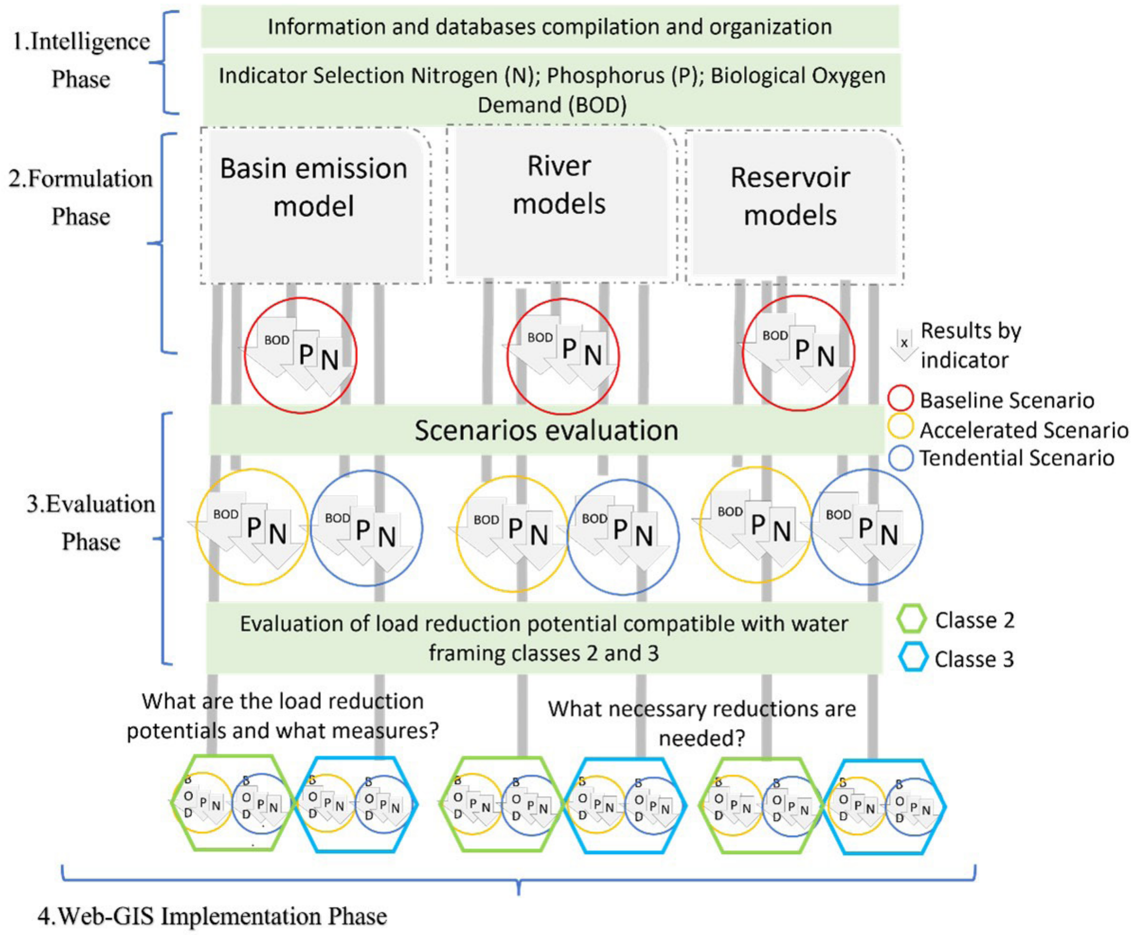

Figure 2. Phases of data processing and modeling necessary to implement the Web-GIS.

The trend scenario under the assumption that public policies and the cultural socioeconomic framework will not differ from the current ones, and that the economy maintains a recovery process. The accelerated scenario, on the other hand, considers a combination of favorable conditions such as economic growth which later will increase the demands on water resources. The final and fourth phase refers to the WebGIS implementation which consists in build a series of interactive panels to be used in the decision-making process.

Intelligence phase: preparing the database

The Paranapanema Basin already had a large amount of spatial information that was produced in the studies of the Integrated Plan of Water Resources of the Paranapanema River (PIRH Paranapanema) and the Study/Report of the Integrated Group of Aquaculture and Environmental Studies – GIA (Agência Nacional de Águas e Saneamento Básico, 2022).

Data collection was conducted to gather information representing the main biophysical characteristics of the basin. First, the geospatial data was organized according to the following steps: i) evaluation of geospatial data, ii) systematization by topics, iii) quality control and iv) application of the database. These four steps generated a functional arrangement with a Geospatial Databases (BDG) structure following the methodology previously described by other authors (Souza da Paz et al., 2020).

This process involved identifying and recognizing various data sources such as land use, land cover (LULC), topography, hydrology, soil types, vegetation cover, socioeconomic and other relevant environmental factors for the basin model. Additionally, the diagnoses and categorization of areas with land use restrictions and special designations areas such as ecological reserves or with some environmental requirement, were also conducted (Nowatzki et al., 2021). Climate and rainfall data was collected to calculate rainfall erosion as well as quality data from monitoring wells to assess pollutant load from groundwater. Data regarding water flow and water quality was analyzed and used to define which stations would be used for calibration and validation of the models. The river models were calibrated using 11 fluviometric stations and 8 water quality monitoring stations available in the National System of Information on Water Resources (SNIRH) for the base year (2012). For the hydrodynamic and the water quality simulation in reservoirs, water level and water discharge data available in the Reservoir Monitoring System (SAR), and meteorological data from the Avaré station (A725), Joaquim Távora (A821) and Nova Fátima (A842) of INMET were used (Goulart et al., 2023) as well as the load results provided by the

Modeling of Regionalized Emissions - MoRE basin modeling (Lassen et al., 2021; Acosta et al., 2021), and the synthetic series generated from the available monitored data (Universidade Federal do Paraná, 2020a).

Formulation phase: basin-river-reservoir modeling

The formulation phase, which involves understanding the sources of pollution and their pathways, was carried out using a collaborative modeling approach. This approach incorporated three models for river, reservoir, and loads estimation from the watersheds.

To prepare the pollutant load estimation, the *Modeling of Regionalized Emissions* - MoRE (Fuchs et al., 2012) was customized to align with the data availability and physical processes specific to Brazil. With the ArcGIS Model Builder, a total of eight algorithm routines were generated including three routines focuses on point sources such as effluent from treatment stations, industrial effluent, and aquaculture and five routines to estimate the diffuse sources (soil erosion, surface runoff, atmospheric deposition and groundwater loads). More details can be found in a study carried out by Lassen et al., (2021) and Acosta et al., (2021).

The flow and concentration river estimates were carried out using the Hydrodynamic Simulation and Water Quality models – SihQual (Ferreira et al., 2020, 2021) and the Hec-Ras model (Ferreira et al., 2021; Ferreira & Fernandes, 2022) more details of the process can be found in previous studies (Ferreira et al., 2021).

The Paranapanema river is characterized by the presence of eight reservoirs, including five run-of-river (usually lotic systems) and three storage reservoirs (usually lentic systems). In order to select the appropriate approach for each section, the water residence time was used as a determining factor (Goulart et al., 2023). Sections with residence time greater than 40 days were modelled as lentic water bodies, thus Jurumirim, Chavantes and Capivara reservoirs followed this classification (Agência Nacional de Águas e Saneamento Básico, 2022). To evaluate the spatial variations, a computational simulation was carried out using the Delft3D model (Deltares, 2014). Additionally, the need for reservoir zoning was assessed, using remote sensing and a load ranking approach to define a classification. These classifications correspond to sectors that needed different strategies for reducing pollutant loads (Goulart et al., 2023).

Assessment phase: load reduction estimative in basins, rivers, and reservoirs

The scenarios were simulated by the UFPR-ANA project team using three models (basin, river, and reservoir) to assess three indicators: TN, TP and BOD. Two different scenarios along with a baseline scenario were considered. Based on the simulations results, the required load reduction in the basin, river and reservoir was determined.

To estimate load reduction and strategies for prioritization of actions in the sub-basins, the results from scenarios were compared with future scenarios that incorporating different measures (Equation 1).

$$Potential\ reduction\ of\ loads\ in\ basins\left(\frac{kg}{dia}\right) = Loads_{i,j} - Loads_{i,j,m} \quad (1)$$

where $Loads_{i,j}$, is the estimate of loads in the basins for each scenario "i" and for each parameter "j"; $Loads_{ij,m}$, is the load estimate resulting from the application of alternative pollution control measures in the basins "*m*", for the scenario "i" and each parameter "j".

Four types of interventions were applied to carry out the evaluation, such as: improvements in the efficiency of effluent treatment stations (ETE's) and treatment of untreated sewage (97%, 70% and 70% for removal of BOD, TP and TN, respectively), as well as improvements in the treatment of industrial effluents (load reduction by 50% for the 3 parameters) and for agricultural areas, a 30% reduction in diffuse loads due to the adoption of good practices (Agência Nacional de Águas e Saneamento Básico, 2022). The results of this process showed the ranking of sub-basins where loads reduction is feasible. Identifying the sub-basins with the highest load reduction potential provides valuable guidance on where the most significant reductions in pollutant loads can be achieved.

For the evaluation of the necessary load reduction in rivers to achieve or maintain the target class of water framework, duration curves of the hydrodynamic modeling results were constructed for each parameter *"j"* and for each *"i"* scenario, as well as suitable duration curves for each section of river (Agência Nacional de Águas e Saneamento Básico, 2022). The duration curve, derived from the hydrodynamic model, was compared to the maximum tolerable load curve corresponding to different water quality classes (Agência Nacional de Águas e Saneamento Básico, 2022). This analysis resulted in the determination of the percentage of load reductions necessary to attain the desired water quality class *"k"* for the scenarios *"i"* as follows in Equation 2:

$$Reduction\ percentage = 100\ .\left(1 - \frac{Permissible\ Load_{i,j,k}}{Calculated\ Load_{i,j}}\right) \quad (2)$$

where, $Permissible\ Load_{i,j,k}$ is the load duration curve calculated for each parameter *"j"* is for each water quality class "*k*"; and the $Calculated\ Load_{j}$; is the load calculated from the hydrodynamic modeling for each parameter "*j*".

By modeling the allocations of estimated loads for each scenario within the sectors of the reservoir, it was possible to understand how loads variations can potentially impact water quality (Agência Nacional de Águas e Saneamento Básico, 2022). The necessary reduction results were presented for each sector of the reservoir, considering the two scenarios and the resulting classification of water quality classes (Equation 3).

$$Percentage\ of\ load\ reduction\ required = 100\ .\left(1 - \frac{F_{j,limix,k}}{F_{j,k}}\right) \quad (3)$$

where $F_{j,limix,k}$ is the admissible load for the critic parameter *"j"* for each water class *"k"* and $F_{j,k}$ is a calculated annual load of the critical parameter *"j"* for each water class *"k"*.

Web-GIS: translating information for decision makers

For the development of the Web-GIS, the ArcGIS online portal was used, which is a geographic information system software (Esri's web-based) used to create and use maps, compile geographic data, analyze mapped information, as well as manage geographic information in cloud databases (Figure 3.1). The information and results considered most relevant for decision-making were compiled. A link between the need to understand the substances that are emitted in the basin and how they behave in rivers and reservoirs when they reach the water bodies was established (Figure 3.2). The Web-GIS was designed to explore the potential for reducing pollutant loads in the sub-basins and the necessary reductions in river sections to achieve water quality compatible with classes 2 and 3 in different scenarios (Figure 3.3).

Results are presented in an interactive and user-friendly manner to facilitate public and stakeholder participation in decision-making processes (Figure 3.4). Facilitating the decision to define resource use priorities and the definition of goals and intervention strategies in the basin, that guarantee the maintenance of water quality according to the most restrictive use (Figure 3.5). Additionally, the analysis can be used to prioritize and determine the locations and parameters that should be monitored to ensure the attainment of the defined framing goals (Figure 3.6).

Narrative interface development

The narrative interface was developed using the Story Maps web application from the ArcGIS online portal. The definition of the structure was a participative process, through weekly meetings (from September 2020 to February 2021) between the modeling and geoprocessing teams, project coordinators and ANA agents. In the meetings, the concept and purpose of the system were discussed, the type of information it should have and the main objectives it should achieve to contribute to the needs of decision makers.

The structure of the narrative interface was defined based on the essential information and steps required to define the Water Quality Standards goals (Figure 4).

Interactive panels development

To present data and results in the WebGIS plataform, a series of three interactive panels were constructed. The first panel provides a comprehensive overview of current situation and serves as a general diagnosis of the basin. The second panel shows the results obtained from the estimation of polluting loads for the base year (2012). Finally, the third panel outlines the priorities for reducing polluting loads and the corresponding reductions required to meet the classification categories.

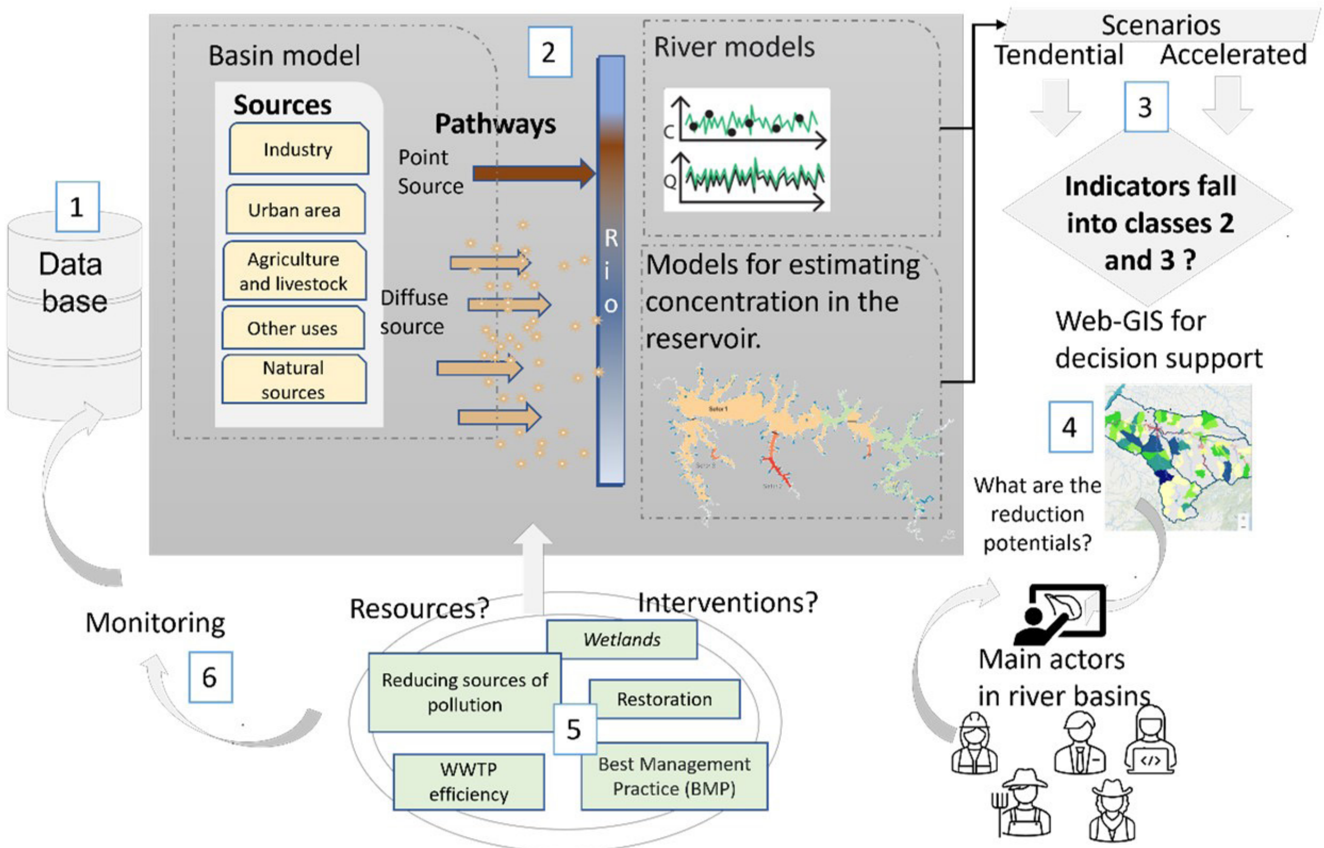

Figure 3. Processes to develop a decision support system for defining water quality goals in the basin.

First, the data was prepared and organized to be individually uploaded in .zip format to the online ArcGIS cloud. A total of 10 web maps were prepared, such as: four with general characteristics of the Water Management Units (UGH), map of land use and coverage, map of restricted areas, map of water concessions, tree maps of load estimation and tree synthesis maps, one for each of the selected parameters (total phosphorus, total nitrogen and BOD). Finally, the three panels with the respectively combination of maps was loaded to the platform according to the Figure 4.

Context dashboard

The first set of maps namely "context panel" was structured using the ArcGIS dashboard application. In order, to display all the information, a series of tabs were incorporated to show the four web maps with general information on the Paranapanema River basin. Dynamic dialog boxes with information that changes according to the selection of the Water Management Unit (UGH) to be analyzed were placed on the panel. The breakdown of information included the area in kilometers, the total population, the urban and rural population, as well as the demographic density. For aggregation of information, 3 levels of aggregation were used: municipal, by UGH, and by sub-basins. The necessary bases for the elaboration were loaded in shapefile format, and the attributes were integrated in a comma-separated values files (.csv) table with a unique identifier that allowed linking the shapefiles and attributes (Table 1) .

Links were added between data tables and web maps to establish functions such as selection, filters, zoom and dynamic text changes. For this panel, capabilities for selecting Water Management Units were added in the side panel to display information, for each of the UGHs, both about general characteristics, such as the display of percentage and area of use and land cover by UGH and display of information related to the number of water concessions.

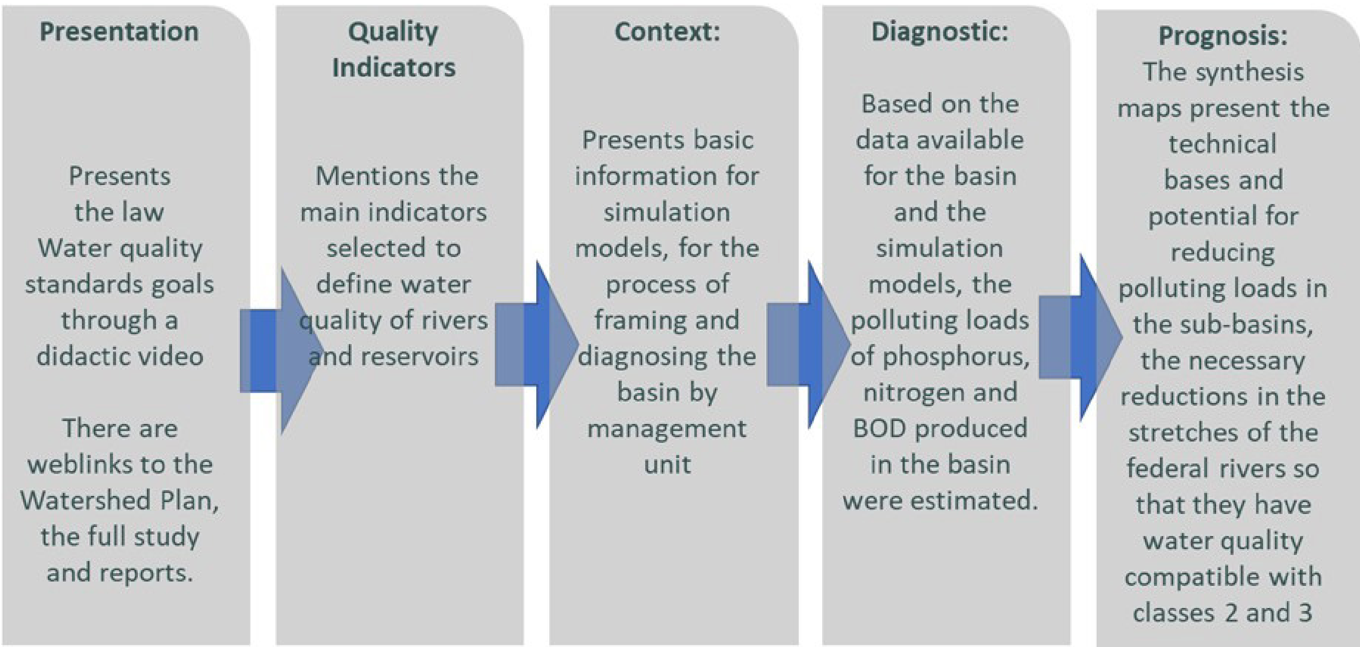

Figure 4. Structure of the narrative interface for the WE-GIS.

Table 1. Input data for building the panel on the Basin Context.

Input data	*Format type*	*Source*
Water Management Units	*Shapefile*	*ANA*
Reservoirs	*Shapefile*	*ANA*
Main Hydrography	*Shapefile*	*ANA*
City Hall	*Shapefile*	*IBGE*
Land Use Land Cover	*Shapefile*	*ANA*
Table with social and territory attributes	*.csv*	*IBGE*
Priority areas for conservation	*Shapefile*	*GIA*
Conservation Units	*Shapefile*	*GIA / IAT / MMA /ICMBio*
Devonian Escarpment	*Shapefile*	
Protection Areas	*Shapefile*	
Water Concessions	*Shapefile*	*ANA / DAEE/*
Attributes table of water concessions grouped by UGH containing type and concession purpose	*.csv*	*Project results UFPR/ANA*

Diagnostic dashboard

The diagnosis interactive panel presents the results of the pollutant load estimates for the base year scenario that was elaborated in the basin modeling. The results were grouped into sub-basins and organized as demonstrated in Table 2. The web maps used to create the panel show the total load in kg/day estimated for the water quality indicators showing the areas with highest emission in darker tones. The function of filtering by UGH was added to the estimation panel, making it possible to visualize the priority basins for each parameter. Graphs were also generated showing the ranking of the basins with the highest loads and the characterization of the main sources of each type of pollutant.

Synthesis maps dashboard

In the summary map panel, the required reductions to achieve the water quality classification of water bodies (class 2 and class 3) as well the magnitude of the reduction in the basins are presented. The panel functionalities also provided filters to show the results by UGH, for each scenario (trend and accelerated) and for the desired Water Quality Standard. The input data was prepared as demonstrated in Table 3.

RESULTS

The Web-GIS for Water Quality Standard definition is an innovative and user-friendly tool designed specifically for management stakeholders seeking for effective solutions. It provides an intuitive visualization of the study area and the models results, enabling managers to explore several scenarios and simulate the potential outcomes of different actions. By utilizing this tool, managers can conduct objective analyses to ensure that their actions align with environmental objectives and regulations and to identify viable alternatives to define goals for maintaining the water quality.

Collaborative modeling estimation basin – river - reservoir

Basin pollutant load modeling

The spatial distribution of the results related to the estimation of pollutant loads for the baseline and for each parameter a) Total Phosphorus; b) Total Nitrogen and c) Biochemical Oxygen Demand can be found on Figure 5. Additionally, the graphs show the estimative grouped by load sources. The diffuse loads are produced especially from areas with crops, natural areas including forest, countryside, and pasture areas. In addition, the point sources include the estimation of untreated sewage and drainage from urban areas, as well as effluents discharged by industries and effluent treatment stations (WWTP). In the provided example, the results are grouped by UGH, but they can also be presented by municipality or by sub-basin. The Paranapanema River basin has a high percentage of occupation by agriculture with a percentage exceeding the 70%. This agriculture influence is clearly depicted in the emissions presented in the graphs. The basins with the highest loads are related to high urban and industrial occupation in addition to agricultural activities, such as UGH 4, where 2 large cities with a population greater than 100,000 inhabitants are located (Instituto Brasileiro de Geografia e Estatística, 2019).

Figure 6a provides insights about the influence of land use land cover to the phosphorus loads. It demonstrates that agriculture, pasture, or/and urban development, can have a substantial effect on the phosphorus levels in the basin. This suggests that the practices associated with these land uses, such as fertilizer application or stormwater runoff from urban areas, significantly contribute to the phosphorus load in the river basin.

By analyzing Figure 6b it is possible identify the presence of industries and treatment plants located near areas where the basin has high phosphorus loads. This indicates that point sources are still a major contribution to the overall phosphorus levels to the river.

Figure 7 present the results by sub-basin for UGH 4, showing the respective assessment of polluting sources in percentage of contribution by source (left axis). In total, 80 sub-basins were evaluated, and ranked based on the basin with the highest pollutant load (right axis).

Figure 8 showcases the outcomes presented through the Web-GIS, where it is possible to compile the most relevant information within a single platform. This functionality allows users to explore various features including location proximity, information filtering, map comparison, and ranking the basins with the highest loads. Moreover, users can visualize the primary sources for all UGH and the sub-basins. In this way, the filters used are passed on to the tabs of the other substances showing the results for each indicator.

Table 2. Input data for building interactive panels.

Input data	Format type	Source
Water Management Units	*Shapefile*	*ANA*
Basins with handle from Ottobacia	*Shapefile*	*ANA*
Attribute table of basin modeling results (current condition) containing in the columns: Ottobacia Identifier, UGH, results for each Parameter in kg/day, both total and by type of source.	*.csv*	*Project results UFPR/ANA*

Table 3. Input data for building interactive panels.

Input data	Format type	Source
Table containing the required reduction for rivers and reservoirs grouped by sector of the reservoir and river section. Containing UGH information, results per scenario and reduction for each parameter and for each class.	*.csv*	*Project results UFPR/ANA*
Reduction potential for each sub-basin with table of attributes containing the following information for each Otto: UGH, reduction for each parameter, for each scenario and according to the class that needs to be achieved.	*Shapefile and attribute table*	*Project results UFPR/ANA*

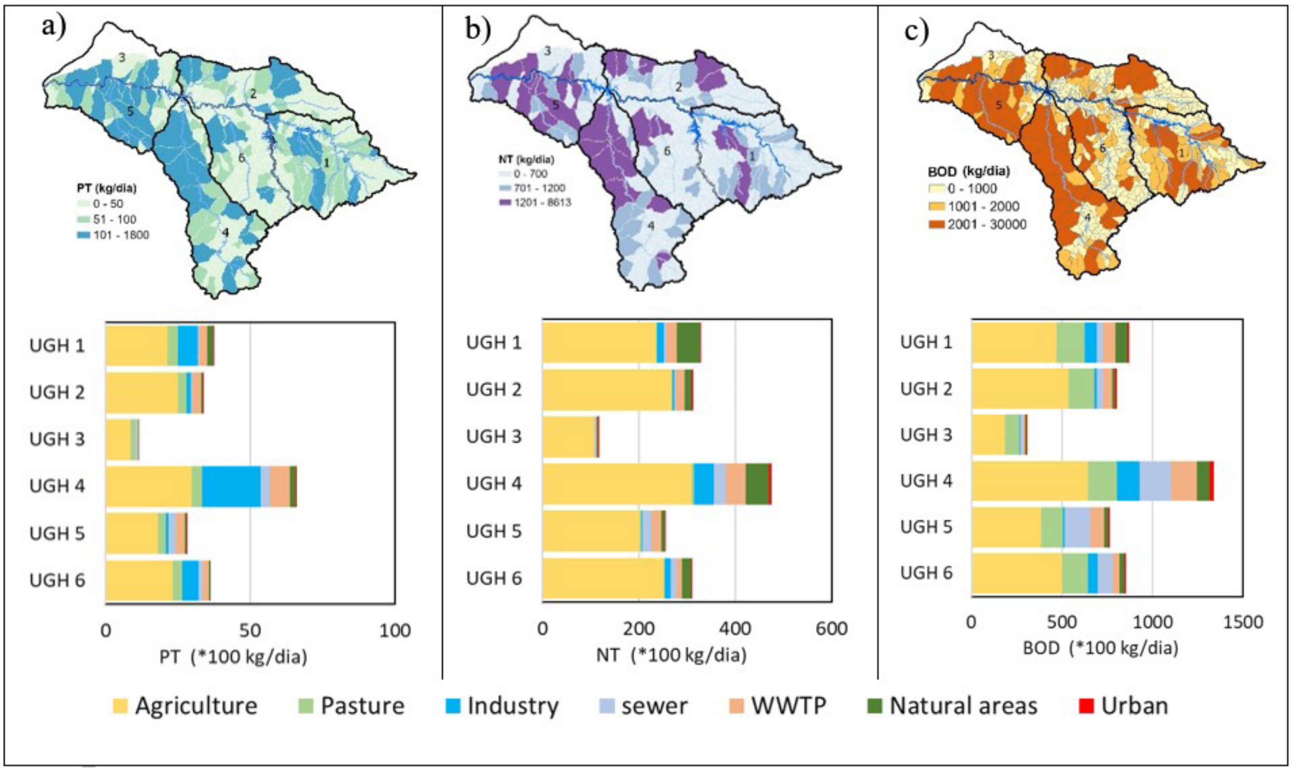

Figure 5. Spatial distribution of the results from the pollutant load modeling. Daily average in kilograms by day for total phosphorus (a); for total nitrogen (b) and for BOD (c). The graphs show the results for the Paranapanema watershed aggreged by source and by UGH.

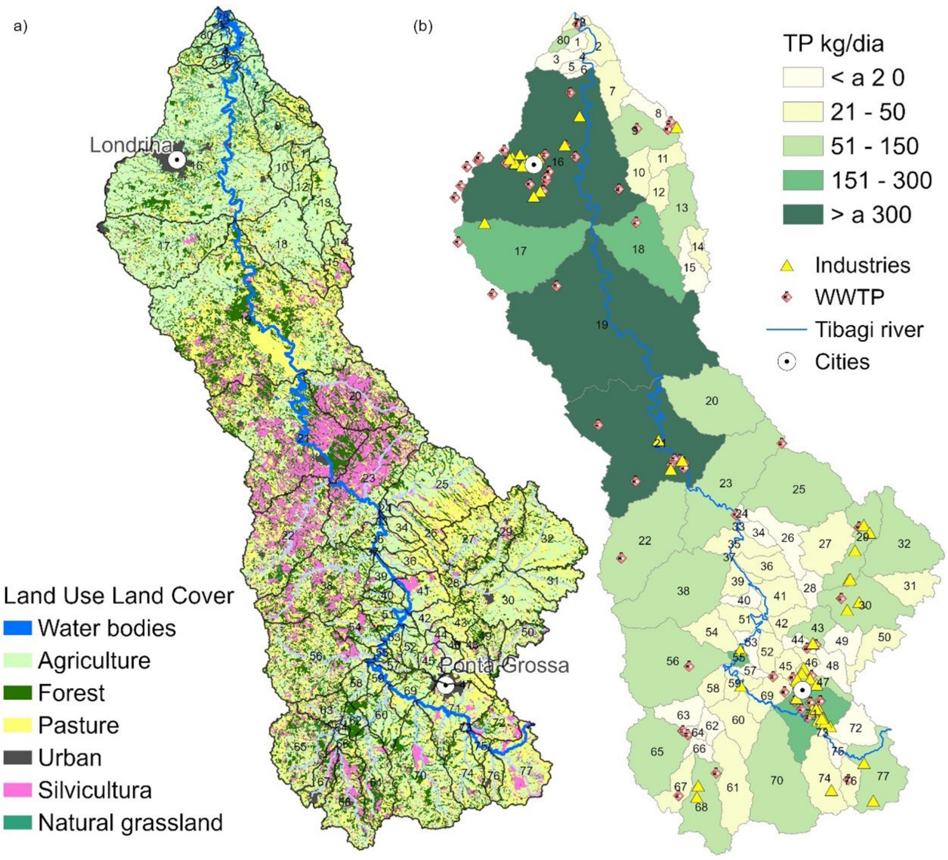

Figure 6. (a) Shows the Land use and land cover and localization of most populated cities; (b) Results of the pollutant loads estimative for total phosphorus in daily average (kg/day) aggregated by sub-basin in UGH Tibagí.

Additionally, the chart data changes interactively as the UGH or basin to be analyzed is selected.

This tool helps to obtain a clearer discussion about where it is possible to act and what kind of action may be necessary to modify the current and/or future scenario. For example, in Figure 9a. a ranking of the basins with the highest phosphorus load is observed. When selecting the second basin with identification (id) 864231, it is possible to observe the main polluting sources (Figure 9b) related to loads coming diffusely from agricultural areas (43%) and from sewage treatment plants (33%), the first due to the use of fertilizers and soil erosion and the second possibly where the treatment has low total phosphorus removal efficiency. This knowledge provides tools for decision makers pointing out where interventions can be carried out as a priority to achieve the framework goals.

Hydrodynamic models rivers and reservoir

To evaluate the temporal and spatial concentration of pollutants in the rivers, the flows and concentrations of the parameters in different sections of the rivers were simulated. First, the model was calibrated with observed data for the base year of 2012 and then modeled based on the selected future scenarios.

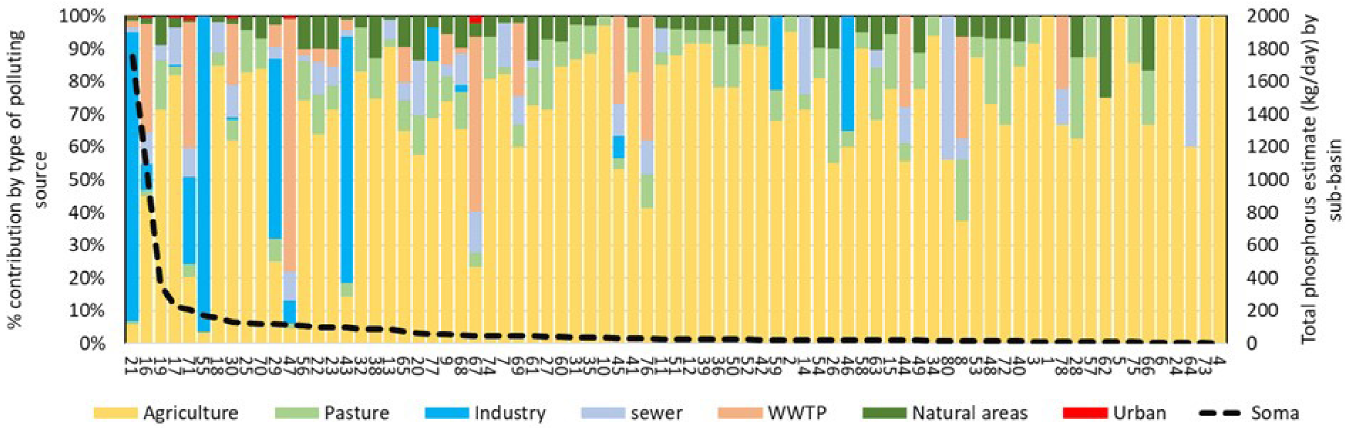

Figure 7. Pollutant loads estimative: average phosphorus daily loads in kg/day and summarized by sub-basin (right axis), and the percentage contribution by type of pollutant source in relation a total contribution of pollutants (left axis).

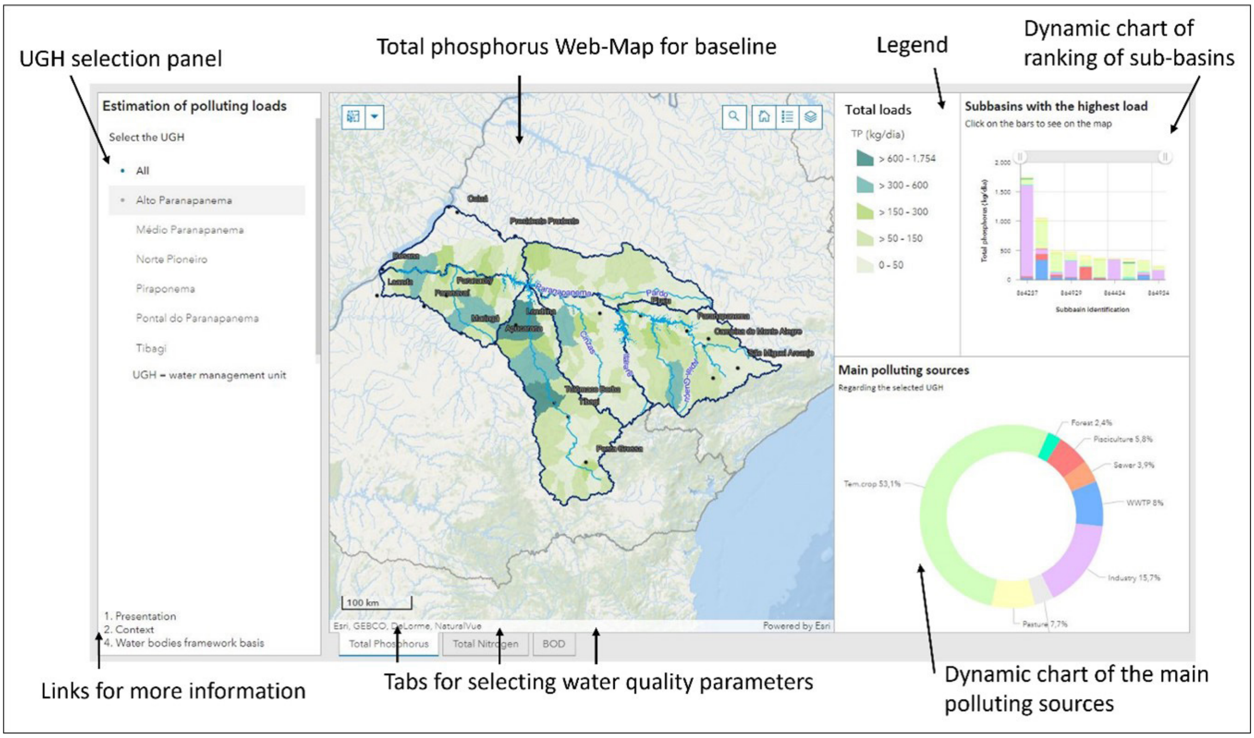

Figure 8. Screenshot of the pollutant loads estimative panel showing: the maps whit the average phosphorus daily loads in kg/day; The selection panel; the bar chart with the ranking and the pie chart showing the contribution percentual by sources.

A subset of the results is presented on Figure 10, highlighting the comparisons between simulated and observed for the calibration period. The modeling results are expressed in hydrographic curves (Figure 10a) and duration curves (Figure 10b). The Figure 10c demonstrate the comparison of the quality data with the water classification ranges defined in CONAMA resolution nº 357/2005 (Brasil, 2005). The probability of exceeding the limit value for class 1 (below 0.05 mg/L) is 65%, while the probability of exceeding class 2 (exceeding the limit of 0.10 mg/L) is about 3%. Finally, the Figure 10d. shows the spatial distribution by sections of the simulation of total phosphorus concentrations and their classification into water quality classes.

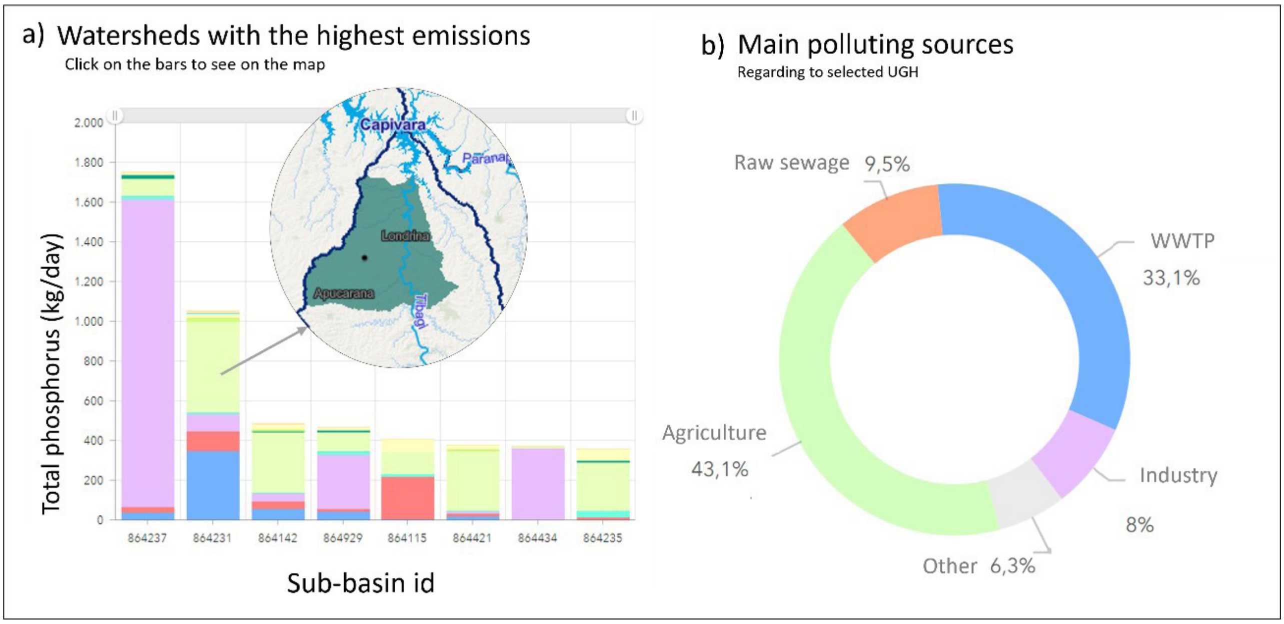

Figure 9. Screenshot of the graphics (a) Ranking of sub-basins with the highest load and their respective sources and; (b) The distribution of the main polluting sources in the selected sub-basin.

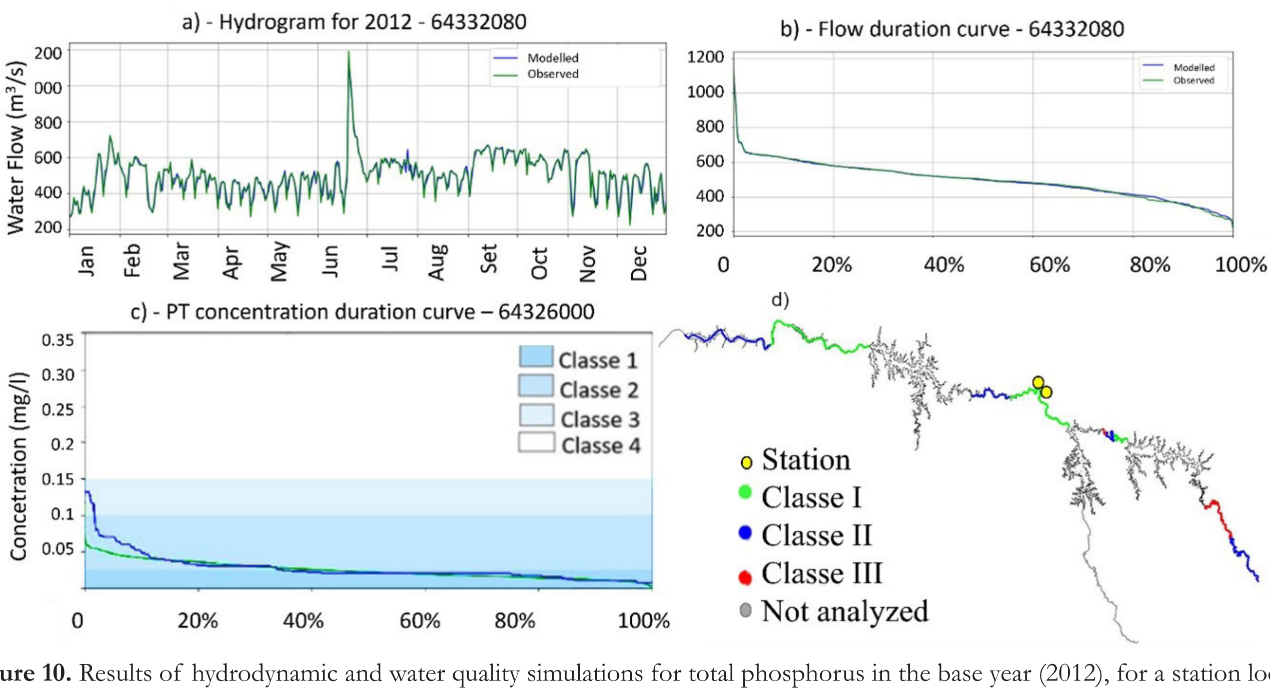

Figure 10. Results of hydrodynamic and water quality simulations for total phosphorus in the base year (2012), for a station located in the middle of the Paranapanema River (quality nº 64326000 and flow nº 64332080). (a) Modeled versus observed comparative hydrographs; (b) Presentation of the same result in the form of a duration curve; (c) comparison of observed total phosphorus duration curves versus modeled for the base year; and (d) Total phosphorus concentrations in the year 2012 in the simulation stretches on the Paranapanema River. Source: Ferreira et al. (2021); Universidade Federal do Paraná (2020b).

The hydrodynamic results for the base years are the basis for the diagnosis of the current condition of the water quality in the river. Evaluations conducted using the future scenarios illustrate the expected behavior in the water quality classes. Both simulations are needed to understand and to define the goals for Water Quality Standards. Full results are available on studies (Ferreira et al., 2021; Universidade Federal do Paraná, 2020b), for the scenarios (trend and accelerated), analyzed parameters (total phosphorus, total nitrogen and BOD) and for each of the reference stations used for calibration.

The evaluations conducted using reservoir modeling have revealed that the need for complex simulation processes is not justified, because the interannual and extreme events do not interfere in the definition of goals to frame the water quality. However, in the case of evaluations that include long-term modifications such as changes in land cover and climate change, it is important to perform hydrodynamic modeling that allows to analyze the seasonal behavior of the reservoirs (Universidade Federal do Paraná, 2020b). Additionally, the evaluation conducted using hydrodynamic and water quality models identified the need of implementing a zoning approach to determine the water quality framework. The zoning exhibits distinct water quality characteristics and behaviors. Figure 11 shows the results of the different sectors obtained after applying temporal and spatial evaluation of the behavior of substances in the reservoirs (Universidade Federal do Paraná, 2020a, 2020b).

Load reduction in rivers and reservoirs

To understand the necessary reduction of loads in rivers and reservoirs, an analysis was conducted on 7 sections of the Paranapanema and Itararé rivers and 11 sectors of the reservoirs. The analysis revealed the required reductions to reach classes 2 and 3 in the trend and accelerated scenarios for the projection of 2035 (Table 4). Negative values indicate that no reduction is necessary, while positive values indicate the percentage of reduction required for each section.

In the summary map panel (Figure 12), the compiled information showcases the necessary reductions to achieve the classification of water bodies into class 2 and class 3.

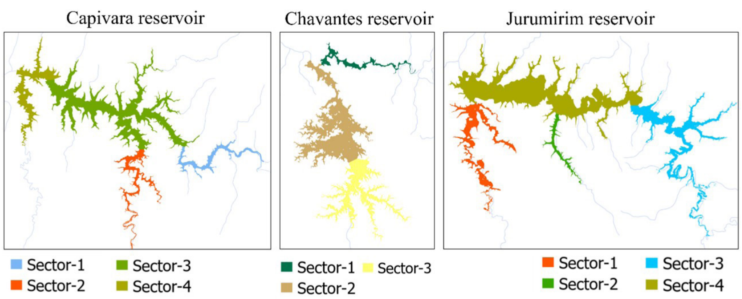

Figure 11. Zoning of the Paranapanema River storage reservoirs. Source: Universidade Federal do Paraná (2020a).

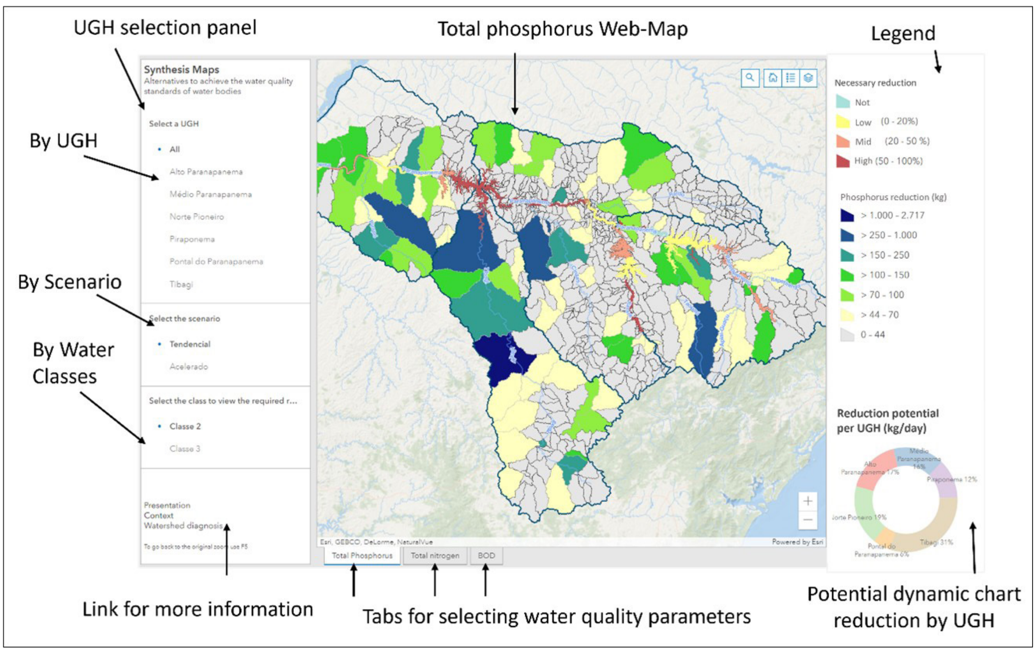

Figure 12. Screenshot whit the summary map panel. The panel shows the total phosphorus load reductions required for the Paranapanema Basin, the rivers and reservoirs.

Table 4. Assessment of load reduction for Water Quality classes 2 and 3 for the accelerated and trend scenarios of 2035.

Scenario	River-Reservoir section	Water Class 2			Water Class 3		
		TP	TN	BOD	TP	TP	BOD
TENDENTIAL 2 2035 - LOAD REDUCTION	Capivara-1	75%	0%	n/a	58%	0%	n/a
	Capivara-2	81%	0%	n/a	68%	0%	n/a
	Capivara-3	57%	0%	n/a	28%	0%	n/a
	Capivara-4	37%	0%	n/a	0%	0%	n/a
	Chavantes-1	64%	0%	n/a	41%	0%	n/a
	Chavantes-2	49%	0%	n/a	15%	0%	n/a
	Chavantes-3	11%	0%	n/a	0%	0%	n/a
	Jurumirim-1	6%	0%	n/a	0%	0%	n/a
	Jurumirim-2	95%	0%	n/a	92%	0%	n/a
	Jurumirim-3	54%	0%	n/a	0%	0%	n/a
	Jurumirim-4	6%	0%	n/a	0%	0%	n/a
	River section 1	55%	27%	0%	32%	0%	0%
	River section 2	0%	0%	0%	0%	0%	0%
	River section 3	2%	63%	18%	0%	45%	0%
	River section 4	68%	13%	12%	52%	7%	0%
	River section 5	1%	0%	3%	0%	0%	0%
	River section 6	47%	0%	11%	21%	0%	0%
	River section 7	11%	0%	0%	7%	0%	0%
	River section 8	89%	85%	0%	83%	77%	0%
ACCELERATED 2035 - LOAD REDUCTION	Capivara-1	84%	0%	n/a	73%	0%	n/a
	Capivara-2	89%	0%	n/a	82%	0%	n/a
	Capivara-3	74%	0%	n/a	56%	0%	n/a
	Capivara-4	62%	0%	n/a	36%	0%	n/a
	Chavantes-1	74%	0%	n/a	57%	0%	n/a
	Chavantes-2	70%	0%	n/a	50%	0%	n/a
	Chavantes-3	39%	0%	n/a	0%	0%	n/a
	Jurumirim-1	32%	0%	n/a	0%	0%	n/a
	Jurumirim-2	96%	12%	n/a	94%	0%	n/a
	Jurumirim-3	67%	0%	n/a	45%	0%	n/a
	Jurumirim-4	34%	0%	n/a	-10%	0%	n/a
	River section 1	67%	59%	23%	51%	38%	0%
	River section 2	0%	0%	0%	0%	0%	0%
	River section 3	31%	64%	41%	0%	46%	0%
	River section 4	80%	19%	33%	70%	14%	0%
	River section 5	29%	16%	25%	5%	0%	0%
	River section 6	55%	16%	29%	48%	0%	0%
	River section 7	35%	14%	23%	14%	0%	0%
	River section 8	93%	94%	40%	90%	91%	0%
High reduction (50 - 100%)					Low Reduction (0 - 20%)		
Medium Reduction (20 - 50%)					Reduction not necessary (< 0%)		

n/a - not analyzed. Source: Modified from Agência Nacional de Águas e Saneamento Básico (2022).

The panel highlights the basins that require prioritization for reducing pollutant loads, and the corresponding value of loads that could be reduced for each scenario. Furthermore, the maps provide detailed information on the percentage reductions necessary for each river section and reservoir sector under each scenario.

The left selection panel allows the user to visualize the UGH of interest, in addition to being able to perform combinations between future scenarios and the desired classes.

CONCLUDING REMARKS

In the current study, it was demonstrated how it is possible to integrate basin-river-reservoir models within a decision support system, creating an easy-to-operate and flexible tool that effectively presents complex processes to the basin actors from different sectors.

In order to understand the pollutant load in the system, deep knowledge about geographic information systems is not necessary, which provides the user with the opportunity to interact with the information without extensive training.

The information used for water quality framing is currently presented through reports and geographic databases, which prove to be effective in generating valuable data and supporting the overall process. Nevertheless, to empower decision-makers with actionable insights, there is a requirement for synthesizing the available documentation and working with the technicians to gather information into a more accessible system.

The platform can be used as a tool for the basin stakeholders who still do not have GIS knowledge to interact with the information presented in the Web-GIS.

The Web-GIS provide vital information to evaluate the best actions within the basin. Even though it was not tested during this project, it is relatively simple to update the panels with new information. Additionally, it's possible to create new ways of better represent the changes in the basin set by land use, land cover changes or by implementation of the interventions.

There exists an opportunity to implement platforms like these to integrate information from institutions involved in data generation, enabling automatic feed processes that provide real-time updates every time new information is generated. One of the author's suggestions is the incorporation of a water concessions showing the allocated water quantity per basin, being fed by the responsible institution in real-time. Given the easy to use and capability to adapt the modelling part of the framework, this could also be seen as a first step to the creation of a digital twins of a large water resources system in Brazil. A digital twin is a virtual replica that reflects the physical system's behavior, allowing for real-time monitoring, analysis, and decision-making.

The Web-GIS represents the initial version of a proposed solutions to create a comprehensive data set to be utilized for water quality framework. By understanding the dynamics of both upstream and downstream basin, it can be an alternative to avoid conflicts. By finding the necessary information for the decision-making process only within one platform, it is possible to communicate the modeling results more quickly to define the prioritization of actions that can make adequate use of resources to really be able to assess the river's framework.

ArcGIS platform costs can vary significantly depending on several factors, including the size and complexity of the project, the number of users, the required features and functionalities, and the hosting options. For the platform to work we need to have an ArcGIS License, and the cost of licenses can vary based on the number of users and the specific ArcGIS products you need. Also, it's necessary a hosting Infrastructure like the ArcGIS Online and Esri's cloud-based solution, which is generally more straightforward to set up and has a subscription-based pricing model. In our case, we have an enterprise license and cloud form that the ANA already has installed. To develop and customize, we have our expertise in ArcGIS and web development. Overall, utilizing the existing infrastructure and knowledge allowed us to develop the platform more cost-effectively, but in other cases, implementation could be more expensive.

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Gabriel Henrique de Almeida Pereira: Revision and editions.

Tobias Bernward Bleninger: Conceptualization; Revision and editions, Project coordination and funds acquisitions

Cristóvão Vicente Scapulatempo Fernandes: Conceptualization; Revision and editions, Project coordination and funds acquisitions.

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João Marcos Carvalho: Revision and editions and Reservoir modeling.

Bruna Arcie Polli: Revision and editions and Reservoir modeling.

Danieli Mara Ferreira: Revision and editions and River's modeling.

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