

CONNECTING LOCAL ENVIRONMENTAL ISSUES AND EDUCATION THROUGH DATA-DRIVEN TOOLS: A HIGH SCHOOL ENVIRONMENTAL EDUCATION PROJECT IN MINAS GERAIS, BRAZIL

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Resumo: A integração da Educação Ambiental (EA) à educação formal é exigida pela legislação brasileira, porém sua implementação ainda é limitada. Com vistas a essa integração, foi desenvolvido um projeto com estudantes do ensino médio, tendo como eixo a investigação da qualidade da água do córrego Ribeirão das Neves. A metodologia envolveu o uso de um protocolo de avaliação rápida em campo, análise dos dados, desenvolvimento de um painel interativo e aplicação de redes neurais artificiais. Os resultados demonstram o potencial de estratégias contextualizadas e baseadas em dados para fortalecer a EA, contribuindo para a alfabetização ambiental, o pensamento crítico e a compreensão integrada dos desafios relacionados à conservação da água.

Palavras-chave: Educação ambiental; Qualidade da água; Análise estatística; Redes neurais artificiais; Pensamento computacional.

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Abstract: The integration of Environmental Education (EE) into formal education is required by Brazilian legislation; however, its implementation remains limited. To promote this integration, this project was developed with high school students, focusing on investigating the water quality of the Ribeirão das Neves stream. The methodology involved a rapid field assessment protocol, data analysis, the development of an interactive dashboard, and the application of artificial neural networks. The results demonstrate the potential of contextualized, data-driven strategies to strengthen Environmental Education, contributing to environmental literacy, critical thinking, and a more integrated understanding of the challenges related to water conservation.

Keywords: Environmental education; Water quality; Statistical analysis; Artificial neural networks; Computational thinking.

Introduction

In Brazil, the National Environmental Education Policy (Law No. 9,795/1999) recognizes environmental education as essential for raising awareness and encouraging citizen participation in environmental preservation, integrating it into formal education at all levels (Brasil, 1999). According to the same law, Environmental Education (EE) is understood as the processes through which individuals and society build social values, knowledge, skills, and competencies directed toward the conservation of the environment. The fundamental principles of EE include a holistic view of the environment, ongoing critical assessment, and a strong connection to local realities. Furthermore, the defense of environmental quality is considered an inseparable value of citizenship, promoted through individual and collective participation in maintaining environmental balance, including within educational institutions at all levels.

Similarly, the National Common Curricular Base (NCCB) establishes environmental issues, scientific inquiry, interdisciplinarity, and the use of digital technologies as important components of basic education (Brasil, 2018). Among the essential competencies outlined in the NCCB are the recognition of environmental quality indicators, identification of sources of water pollution, and the ability to communicate scientific analyses in an accessible and engaging manner through the use of digital technologies (Brasil, 2018). However, the inclusion of EE in formal curricula does not necessarily ensure that environmental issues are approached through critical, contextualized, and participatory educational processes.

A critical perspective of EE goes beyond the transmission of information about environmental conservation or the promotion of individual behavioral changes. It considers environmental problems as complex phenomena arising from the historical, social, political, economic, and ecological relationships established between society and nature. From this perspective, EE seeks to

develop subjects capable of critically interpreting their realities and participating in processes of transformation (Loureiro, 2004; Layrargues and Lima, 2014). This understanding is closely related to Freirean problem-posing education, in which learning begins with the concrete reality experienced by students and involves dialogue, questioning, and collective construction of knowledge (Freire, 2005; Costa and Loureiro, 2017). Thus, environmental problems can become pedagogical opportunities through which students investigate their surroundings, question the processes underlying environmental degradation, and develop more critical ways of understanding their relationship with the environment.

This perspective also converges with place-based education (PBE), which emphasizes learning through direct engagement with the ecological, social, cultural, and historical characteristics of students' local environments (Cincera et al., 2019; Yemini et al., 2023). More specifically, the concept of critical pedagogy of place combines place-based approaches with critical pedagogy, encouraging students not only to learn about their surroundings but also to examine the social and historical processes that shape them (Gruenewald, 2003; Stevenson, 2008; Dimick, 2016). From this standpoint, the local environment is not merely a setting in which educational activities take place; rather, it becomes a source of knowledge and a starting point for questioning environmental conditions and the relationships that produce them (Rêgo, 2018; Freitas et al., 2024).

Thus, water resources provide a particularly relevant context for this approach. Urban growth in Brazil has frequently been characterized by the expansion of peripheral areas without adequate planning and infrastructure, contributing to the occupation and degradation of water-source areas and urban watercourses (Tucci, 2002). Sewage collection and treatment deficits remain a major challenge in Brazilian cities, leading to significant pollutant discharges into water bodies. Nationwide, 45% of sewage produced by urban populations is not treated. In Minas Gerais, the state where the study was conducted, the scenario is similar: while 86% of the urban population is served by sewage collection systems, only 44% of the collected sewage is actually treated (ANA, 2017). Although a range of technologies is available for wastewater treatment, a substantial organic load still reaches aquatic ecosystems (Queiroz et al., 2024). This underscores the importance of monitoring water quality and evaluating its suitability for multiple uses.

Ribeirão das Neves, a municipality in the metropolitan region of Belo Horizonte, the capital of Minas Gerais, faces critical challenges related to basic sanitation and the environmental impacts of unplanned urban growth. Over the past decades, its rapid population increase, driven by proximity to the state capital, has occurred in a disorganized manner, leading to significant degradation of local aquatic ecosystems.

The main watercourse in the area, the Ribeirão das Neves stream, from which the city takes its name, is a tributary of the Rio das Velhas watershed, one of the most important river basins in Minas Gerais (Ferreira, 2019). Given the

documented environmental degradation in the region, this stream was selected as the focus of an interdisciplinary project involving high school students from a local public institution. Moreover, the watercourse under study is located near the educational institution and runs through the city where the students live, providing opportunities for closer engagement and on-site technical visits.

In this context, the present project was designed from a critical and place-based Environmental Education perspective, using the Ribeirão das Neves stream as a starting point for investigation and problematization. Rather than treating water quality as an abstract scientific topic, the project engaged high school students in examining an environmental problem present in their own territory. Field visits allowed students to directly observe different sections of the stream and apply a rapid environmental assessment protocol, while publicly available monitoring data were used to investigate water quality over time. These activities provided opportunities for students to confront their perceptions of the local environment with empirical evidence and to construct interpretations based on observations and data.

The integration of statistical and computational tools in this project further expanded the possibilities for environmental inquiry, moving beyond the typical computer education offered in schools, which is often limited to training students in basic tasks such as editing documents, creating slides, or conducting internet searches. Rather, the project approached the integration of Computing into basic education as an opportunity to foster computational thinking, algorithmic organization, and, above all, the understanding that problems can be solved with students as active agents and direct protagonists in the process (Resnick, 2017). Students organized and analyzed water-quality data and developed an interactive dashboard using the R statistical environment as a means of visualizing and communicating scientific information. Artificial neural networks (ANNs) were also employed to calculate a Water Quality Index (WQI). Therefore, the present project enabled students to develop computational thinking skills, allowing them to solve problems through computational strategies and to approach environmental issues from a data-driven and analytical perspective (Pires et al., 2019). By integrating these elements, the study investigated how environmental data and digital technologies can function as pedagogical mediators for the critical interpretation of a local socio-environmental problem while simultaneously supporting scientific, investigative, and computational learning.

Materials and methods

The project was conducted in four stages: i) site visits to three distinct locations along the watercourse to perform a preliminary environmental assessment and establish initial contact with the local context; ii) analysis of publicly available water monitoring data from Ribeirão das Neves stream to allow a more detailed evaluation of water quality and potential environmental impacts; iii) development of an interactive dashboard to disseminate results, making the

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information accessible to both the academic institution and the local community; iv) application of artificial neural network algorithms to calculate a water quality index.

Study area

The study was conducted in the municipality of Ribeirão das Neves, located in the Metropolitan Region of Belo Horizonte, the capital of the state of Minas Gerais, Brazil (Figure 1). The city has a population of 329,794 inhabitants and a population density of 2,126.26 inhabitants per square kilometer (IBGE, 2022). It presents a Human Development Index (HDI) of 0.684 (IBGE, 2010) and a school enrollment rate of 96.5% for children aged 6 to 14 years.

The local economy is diversified, with prominent sectors including services, commerce, and industry. In terms of basic sanitation, 74.3% of households have access to an adequate sewage system. Additionally, 69.2% of urban streets are tree-lined, while only 8.5% are considered adequately urbanized, taking into account the presence of drainage systems, sidewalks, pavement, and curbs. The average infant mortality rate is 11.95 deaths per 1,000 live births, and the rate of hospital admissions due to diarrhea is 2.4 per 1,000 inhabitants (IBGE, 2022).

Ribeirão das Neves is also home to a campus of the Federal Institute of Education, Science and Technology of Minas Gerais (IFMG), a federal public institution dedicated to offering high-quality education in technical, undergraduate, and continuing education programs. IFMG focuses on integrating teaching, research, and community outreach, with an emphasis on professional and technological development. However, EE is scarcely or not at all included in the standard curriculum, often depending on research or outreach projects to be implemented (Lutkenhaus et al., 2022). The watercourse studied in this project is located near the IFMG campus and is part of the students' daily reality, as many of them live in the city and are directly affected by the environmental conditions of the local streams.

The first stage of the project involved student visits to three sites with distinct characteristics along the Ribeirão das Neves stream. The sampling points were selected to represent different environmental contexts within the municipality: one point located in a less urbanized area (Point 1), another in a region within the city boundaries but still featuring preserved vegetation (Point 2), and a third situated in a fully urbanized and impervious area of the city (Point 3), as shown in Figure 1. In addition, there was also a state-level monitoring point at the end of the watercourse.

For the analysis of the stream sections, the Rapid Assessment Protocol proposed and adapted by Callisto et al. (2002) and previously applied by França et al. (2019) was used. This protocol serves as a tool to evaluate alteration indices and levels of environmental impact. It assesses a set of categorized parameters, each scored from 0 to 5 or from 0 to 4. Scores are assigned to each parameter

based on observations of habitat conditions, including characteristics such as nearby and/or riverbank erosion and sedimentation in the streambed. The final score is obtained by summing the values of all evaluated parameters, with the resulting score reflecting the current condition of the river section: 0–40 points indicate impacted sections; 41–60 points indicate altered sections; and 61 points or more indicate natural sections (see Supplementary Material).

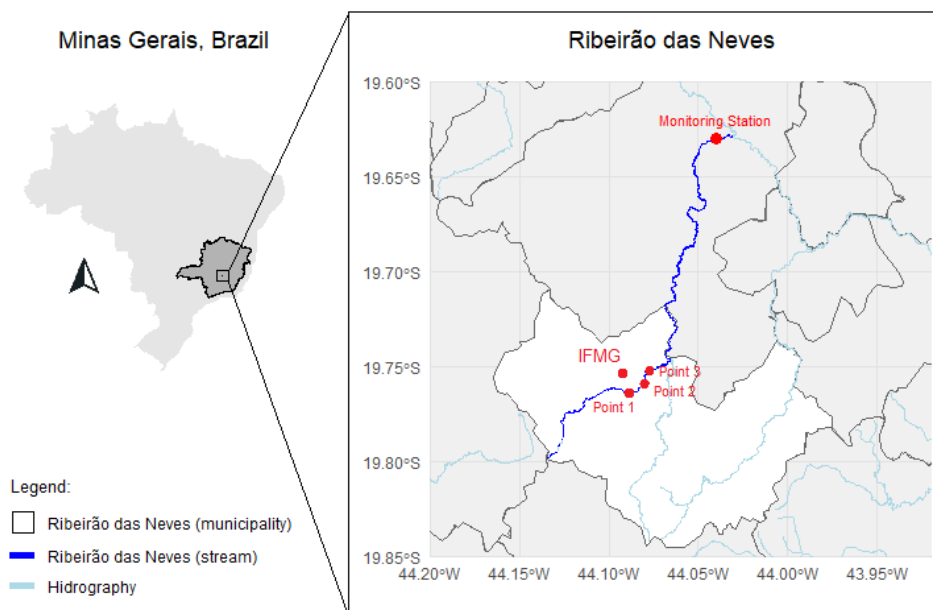


Figure 1: Location of the city of Ribeirão das Neves, Minas Gerais, Brazil and sampling points.
Source: Own authorship.

Environmental databases and statistical analyses

In the state of Minas Gerais, where the municipality of Ribeirão das Neves is located, the monitoring of water bodies is carried out by the Minas Gerais Water Management Institute (IGAM), the governmental agency responsible for the management and regulation of the state's water resources. IGAM conducts systematic monitoring of both water quality and quantity through its surface water quality monitoring network, which gathers and analyzes data from multiple strategically selected sites. Among these monitoring sites is station BV160, located downstream from the municipal center, and known to receive a significant portion of the pollution load originating from the municipality. The available dataset comprises 92 observations collected over the period from 2000 to 2023 (IGAM, 2024).

The water quality data for Ribeirão das Neves are publicly available. For the analysis of surface water quality, parameters commonly included in water quality indices were selected from the database, including phosphorus, biochemical oxygen demand (BOD), dissolved oxygen (DO), turbidity, pH,

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temperature, total solids, nitrate, total phosphorus, and *E. coli*. Students performed descriptive analyses, calculating measures of central tendency, dispersion, and other relevant statistics for each parameter evaluated. Boxplot graphs were created to visualize data distribution and identify potential outliers, with parameters separated according to dry and rainy seasons.

In Minas Gerais, the State Council for Environmental Policy (COPAM) and the State Water Resources Council (CERH) established the Joint Normative Resolution COPAM/CERH-MG No. 08/2022, which defines the classification of water bodies and sets environmental guidelines, including effluent discharge standards (Minas Gerais, 2022). The resolution categorizes water bodies into Special, Class 1, Class 2, Class 3, and Class 4, ensuring appropriate water quality standards for various uses. Special Class waters are designated for the most stringent uses, such as human consumption with minimal treatment and protection of aquatic ecosystems. Class 1 waters allow simplified treatment, while Class 2 requires conventional treatment for human consumption. Class 3 waters are suitable for advanced treatment, irrigation of certain crops, and fishing, whereas Class 4 waters are designated for activities such as navigation and landscape preservation. Ribeirão das Neves is classified as Class 2. Based on the legal limits for Class 2 parameters, the percentages of exceedances of water quality standards were calculated for all the selected parameters.

Dashboard development

To disseminate the results to the community, the flexdashboard package in the R software was used. This tool facilitates the creation of dashboards that combine static and dynamic features, presenting data in a visually appealing manner. Flexdashboard builds interactive panels using the rmarkdown package, which publishes interactive JavaScript visualizations based on htmlwidgets (and is also compatible with base, lattice, and grid graphics), allowing for flexible and easily specified layouts. The charts automatically adjust to fit screen sizes on both browsers and mobile devices, without requiring advanced programming skills.

Additionally, the shiny package was employed to provide dynamic interactivity within the visualizations. The tabbed structure of the dashboard enables navigation between different sections, facilitating the exploration of data and analyses on each topic. This tool serves as an efficient means of scientific outreach, making the results accessible to the general public and promoting the dissemination of scientific knowledge.

Application of Artificial Neural Networks for the calculation of a Water Quality Index (WQI)

The calculation of the WQI was also employed as an educational tool, enabling students to synthesize the results obtained from both the rapid assessment protocol and the measured water quality parameters into a single, comprehensive index. The calculation of the WQI used by IGAM requires, in

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addition to the use of specific weights, the application of various equations and access to individual curves for each parameter (IGAM, 2025). To simplify this process and eliminate the need for direct manipulation of graphs and equations, the students were challenged to develop an artificial neural network (ANN) model to calculate the index using data provided by IGAM. These models are capable of learning the relationships between parameters and the WQI based on a training dataset, making the calculation more efficient and accessible.

ANNs have a basic structure composed of three types of layers: an input layer, one or more hidden layers, and an output layer. Each layer consists of neurons connected to a defined number of neurons in the subsequent layer. The models tested in this study adopted a feedforward structure with the backpropagation algorithm (Goodfellow et al., 2016). The optimal number of hidden layers and neurons was determined experimentally. Models with 1 to 3 hidden layers and 1 to 9 neurons per layer were tested. Model performance was also evaluated using different activation functions, including rectifier, tanh, and maxout. The number of epochs tested were 200, 500, and 1000. The best-performing model, considering the established criteria, was selected for further analysis and validation.

A total of 185 WQI values, collected from multiple monitoring stations across Brazil, were provided by IGAM. As input variables, the nine parameters employed by IGAM in the index calculation were considered. For the training phase, 70% of the dataset was used, while the remaining 30% was reserved for testing. The dataset was previously standardized to minimize the impact of significant scale differences among parameters on model performance. The model with the best performance indicators — coefficient of determination (R^2), root mean square error (RMSE), and mean absolute error (MAE) — was selected for subsequent analyses. All modeling was performed by the students using the R software, and at the end of the study, the simulated results from the ANNs were compared with the values provided by IGAM for the BV160 monitoring station in Ribeirão das Neves.

Nowadays, the calculation of the WQI is straightforward, with various websites and online tools available that perform the computation directly. Therefore, the use of ANNs for this calculation served primarily as an educational tool, enabling students to understand the theoretical foundations behind the WQI and gain practical experience in programming and modeling.

Results and Discussion

Technical visit and protocol application

The field assessment took place on March 15, 2024, during clear and sunny weather, with no rainfall in the days prior (Figure 2). The three surveyed sections exhibited markedly different characteristics, chosen strategically to enable students to observe how changes in each segment affected the watercourse.

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Figure 2: Visit to the Ribeirão das Neves stream at (a) Point 1, (b) Point 2, and (c) Point 3.
Source: Authors' archives.

Sections 1 and 2 are situated in areas with dense tree cover (Figures 2a and 2b), contributing to higher evaluation scores. Conversely, Section 3 corresponds to a channelized portion of the river located in the municipality's central area, which receives direct sewage discharge, thereby justifying its lower score (Figure 3c).

The final score for each evaluated section is presented in Table 1. The applied protocol is provided in Tables S1 and S2 in the Supplementary Material.

Table 1: Final scores of the evaluated sections.

SECTION	SCORE	CONDITION
Point 1	52	Altered
Point 2	49	Altered
Point 3	21	Impacted

Source: Own authorship.

The results of the field assessment also revealed important dimensions of EE. Rather than limiting the activity to the identification of physical and ecological conditions, the comparison among the three sections enabled students to recognize environmental degradation as a process associated with different forms of land use and human intervention. The lower score observed at Point 3, where channelization and direct sewage discharge were evident, provided a concrete basis for discussing the social and environmental factors underlying the degradation of the stream. This local immersion allowed them to connect

theoretical knowledge to real-world conditions, fostering a deeper understanding of environmental processes and human impacts.

In this sense, the activity contributed to a critical understanding of the local environmental reality, an important foundation of EE. The students were not merely observing environmental conditions, but interpreting differences among sites and relating them to human actions and their consequences. This process can contribute to the development of environmental awareness and a sense of collective responsibility, particularly because the environmental problem investigated is part of the students' own community. The experience also demonstrates how PBE can provide a concrete context through which broader objectives of EE, such as critical reflection, environmental responsibility, and active engagement with local issues, can be developed.

Statistical analyses of the data from BV160 monitoring station

Beyond the rapid assessment protocol, students were also given access to data collected by IGAM at the BV160 monitoring station, situated along the Ribeirão das Neves stream, downstream from the urban area. The final database from the monitoring site at station BV160 contained 92 observations collected from 2000 to 2023. All parameters included in the Water Quality Index (WQI) were analyzed, with biochemical oxygen demand (BOD) and *E. coli* standing out negatively, indicating the possibility of fecal contamination in this water body. Figure 3 presents boxplots of these two parameters during the dry and rainy seasons. The dashed line indicates the legal limit established by the legislation of Minas Gerais for a Class 2 water body, corresponding to 5 mg/L for BOD and 1,000 MPN/100 mL for *E. coli*. These are some examples of graphs produced by the students during the course of their analyses.

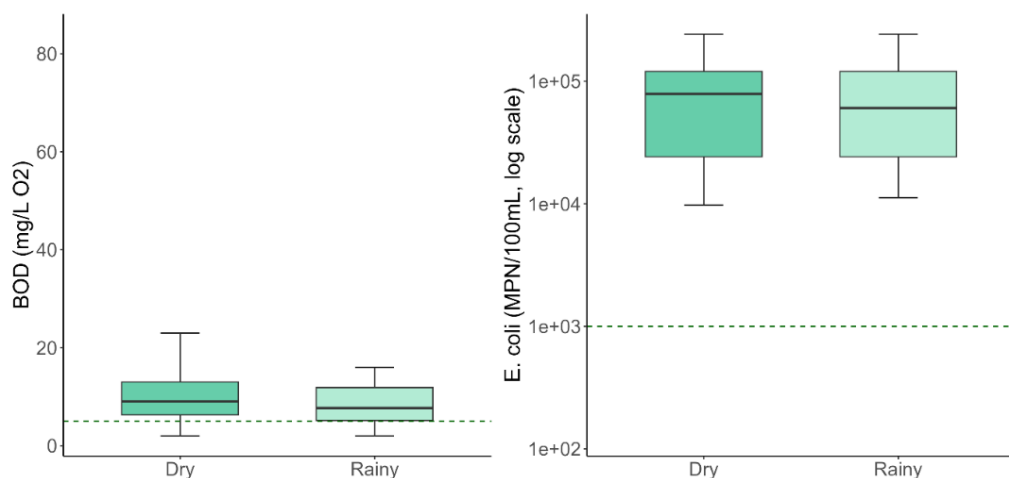


Figure 3: Boxplots of BOD and *E. coli* during the dry and rainy seasons.

Source: Own authorship.

The graphical analysis shows that the observed concentrations for both parameters are higher during the dry season compared to the rainy season. In addition to this, all other water quality parameters were analyzed, and the percentage of violations relative to the quality standards was calculated and presented in Table 2, according to the legal limits established by Minas Gerais legislation. A total of 93 observations were recorded for the parameters listed in Table 2.

Table 2. Percentage of parameter violations according to DN COPAM/CERH-MG 08/2022.

PARAMETER	LEGAL LIMIT	VIOLATION (%)
Biochemical Oxygen Demand (BOD)	5.0 mg/L	81.5
<i>E. coli</i>	1,000 MPN/100 mL	95.6
Dissolved Oxygen (DO)	5.0 mg/L	30.4
pH	6.0 a 9.0	1.1
Total Solids (TS)	100 mg/L	100.0
Turbidity	100 NTU	73.9
Total Phosphorus (TP)	0.050 mg/L	93.5

Source: Own authorship.

The results presented in Table 2 reveal a high rate of violation of water quality standards for several parameters analyzed in the Ribeirão das Neves stream. BOD exhibited a violation rate of 81.5%, indicating a concerning level of decomposing organic matter that compromises the self-purification capacity of the water body. This situation can be attributed to the discharge of untreated domestic and industrial sewage.

The violation rate for *E. coli* was even more alarming, with 95.6% of the samples exceeding the legal limit, suggesting significant fecal contamination in the stream's waters. This finding reinforces the hypothesis that sewage directly discharged into the river is a major factor contributing to water quality degradation, posing serious public health risks.

Total solids showed a violation rate of 100%, indicating that all samples exceeded the established limits. This excess of suspended particles may result from both intensified erosive processes due to loss of vegetation cover and improper discharges. Total phosphorus also showed a high violation rate, with 93.5% of the samples exceeding the established limits.

Dashboard

All analyses were compiled into an interactive dashboard, allowing students to correlate numerical data with real-world impacts on the ecosystem and public health by illustrating the water quality conditions of the Ribeirão das

Neves stream. The dashboard, available in Portuguese at (<https://ifmgneves.shinyapps.io/dashboardRibeiraoDasNeves>), serves as an accessible tool for exploring the results and supporting EE.

The main interface is organized into four tabs: “Introduction,” “Ribeirão das Neves,” “Water Quality Index,” and “Other Parameters.” The “Ribeirão das Neves” tab is further divided into the sub-tabs “City History,” “Stream Description,” “Water Body Classification,” “Technical Visit and Protocol,” and “Visit Day Photos”. The “Water Quality Index” tab includes sub-tabs such as “What is the WQI?,” “Dissolved Oxygen,” “pH,” “*Escherichia coli*,” “BOD,” “Total Phosphorus,” “Nitrogen,” “Turbidity,” “Temperature,” “Total Solids,” and “WQI Calculation”. Finally, the “Other Parameters” tab features sub-tabs for “Arsenic,” “True Color,” “Nitrate,” “Nitrite,” and “Ammoniacal Nitrogen.” This tabbed structure facilitates navigation through the dashboard’s different sections, enabling a detailed exploration of topics such as the characteristics of Ribeirão das Neves, WQI parameters, and other relevant environmental indicators.

The development of the interactive dashboard expanded the educational potential of the activity by transforming the environmental data collected and compiled in the study into an accessible learning resource. The dashboard enabled students to explore environmental conditions through evidence rather than relying solely on descriptive information. This approach aligns with the need for active methodologies that empower youth to address socio-environmental problems in their own territories, promoting the appropriation of technological knowledge as an instrument for understanding and intervening in reality, as highlighted by Freitas et al. (2024). The interactive visualization of water quality parameters encouraged students to examine relationships among environmental indicators and to reflect on the possible implications of changes in water quality for ecosystem conditions and human well-being. In this sense, the dashboard supported an inquiry-based approach in which students could interact with environmental information and construct interpretations from the available evidence.

Moreover, making the results available through an accessible digital platform extends EE beyond the classroom. The dashboard can facilitate access to locally relevant environmental information and encourage students and other community members to engage with issues affecting their own territory. This aspect is particularly relevant to the participatory and citizenship-oriented dimension of EE, in which access to knowledge can contribute to a more informed understanding of environmental problems and support individual and collective engagement.

The dashboard therefore complemented the field assessment by connecting direct observation of the Ribeirão das Neves stream with the analysis and interpretation of environmental data. While the field activity provided students with firsthand experience of the local environmental reality, the dashboard provided a means to investigate that reality through multiple indicators and over time. Together, these resources created a learning process that moved from

observation to data interpretation and critical reflection, strengthening the connection between local environmental knowledge and EE.

Water Quality Index (WQI) calculation using Artificial Neural Networks (ANNs)

The calculation of the Water Quality Index (WQI) provided another opportunity to operationalize the principles of EE discussed above. By integrating multiple water quality parameters into a single indicator, the WQI allowed students to move beyond the interpretation of isolated measurements and develop a more comprehensive understanding of the environmental condition of the Ribeirão das Neves stream. This integrated perspective is particularly relevant to EE, as it encourages students to recognize the interconnected nature of environmental processes and to interpret environmental problems through multiple dimensions rather than through individual indicators.

From an educational perspective, the WQI also helped translate complex environmental information into a form that could be more readily interpreted and communicated. By comparing the index with the results of the rapid assessment protocol and examining the parameters contributing to the final classification, students could relate quantitative measurements to the broader environmental condition observed during the field activity. Thus, the WQI served not only as a means of summarizing water quality, but also as a bridge between scientific data, environmental interpretation, and communication of a local environmental issue.

The best-performing model for WQI calculation was obtained using a neural network architecture comprising three hidden layers, each with five neurons (Figure 4). Among the activation functions tested, the hyperbolic tangent (tanh) function yielded the best results. The optimal performance was achieved after 200 training epochs, indicating that the model was able to learn the underlying patterns in the data effectively without signs of overfitting.

The model with the best configuration achieved a coefficient of determination (R^2) of 90.1%, indicating that it was able to explain most of the variability in the WQI based on the nine input parameters. The error metrics were also low (RMSE = 5.1 and MAE = 3.8), demonstrating good predictive accuracy. A high R^2 indicates that the model can account for a substantial portion of the variation in WQI using the selected parameters. The low RMSE and MAE values further support the model's ability to generate consistent and accurate predictions of water quality (Ye et al., 2020). In the case of WQI, this means the predictions made by the model are reliable and precise.

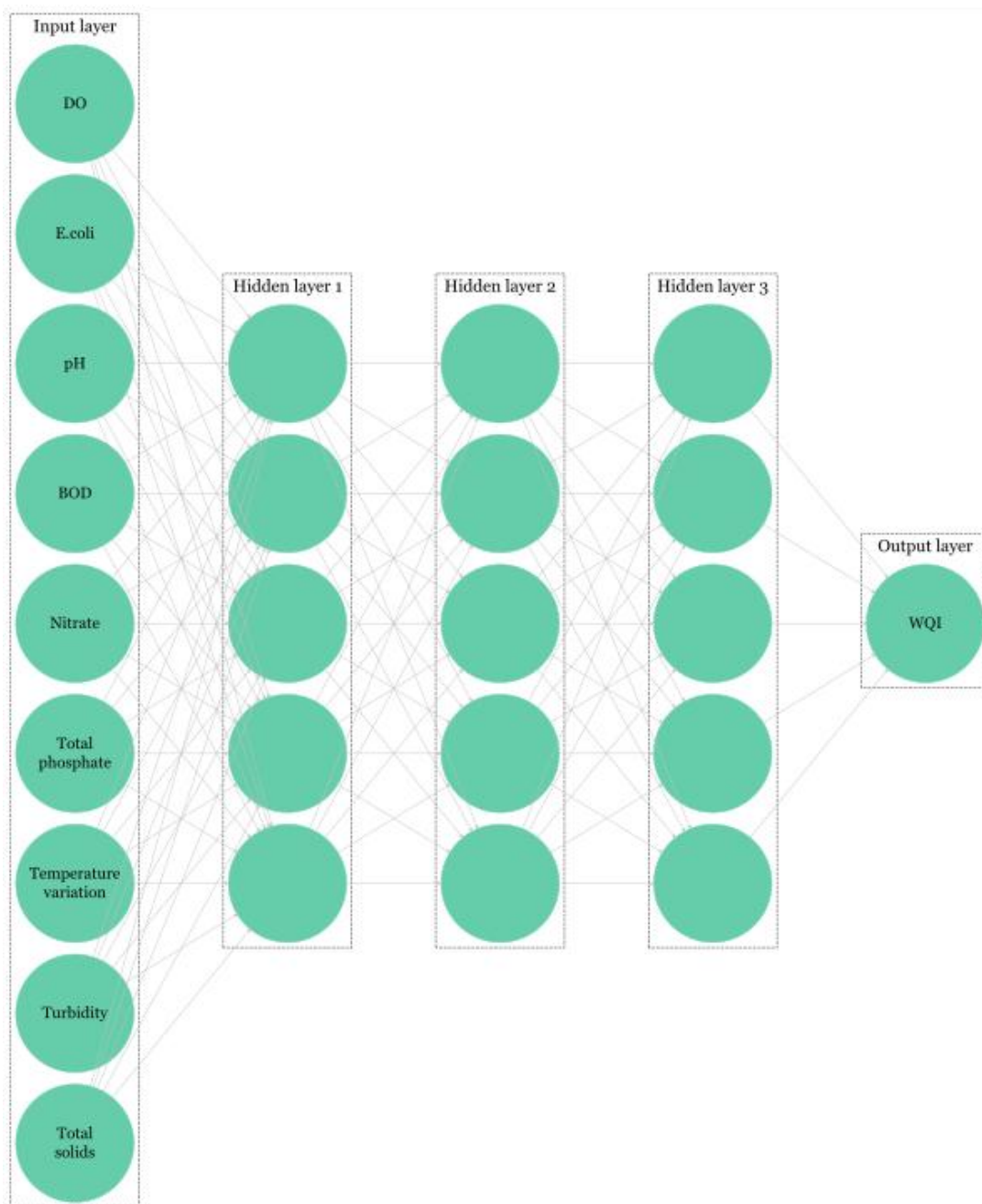


Figure 4: Neural network architecture for WQI prediction, with one input layer, three hidden layers, and one output layer.

Source: Own authorship.

When comparing the values simulated by the model with the results provided by IGAM for the Ribeirão das Neves monitoring site (station BV160), a strong agreement between the values was observed, demonstrating the neural network's ability to efficiently replicate the traditional WQI calculations, as shown in Figure 5. This indicates that the model can be used for WQI calculation with low prediction errors.

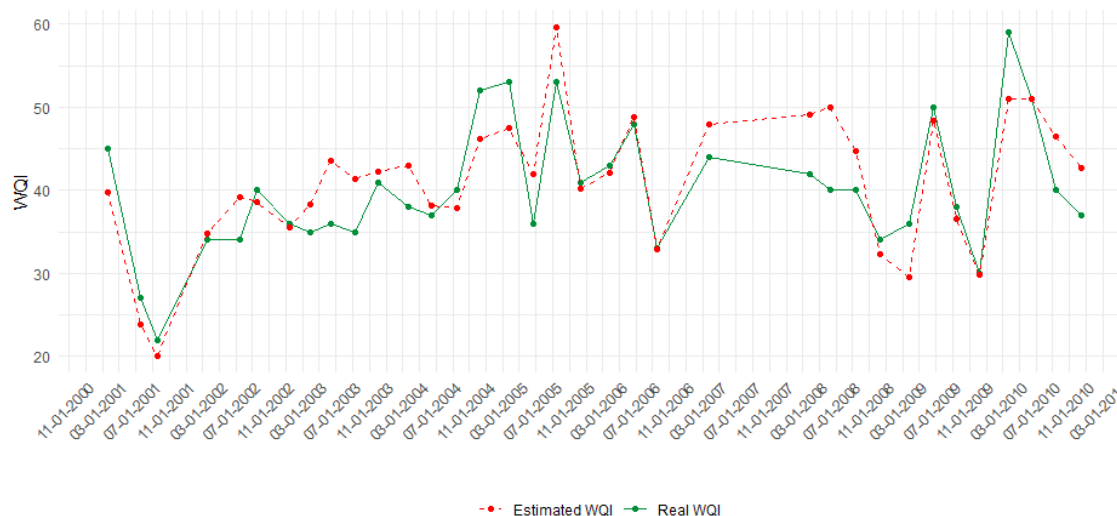


Figure 5: Real and estimated WQI values for station BV160 between 2000 and 2011.

Source: Own authorship.

By carrying out this modeling, the students not only understood the theoretical foundations of the WQI but also acquired practical experience in programming and model development. They learned how to analyze environmental data, fine-tune models, and validate their results. This practical training played an important role in their technical development as well as their civic awareness.

Conclusion

Environmental Education provides an important framework for connecting scientific knowledge, lived experiences, and the social dimensions of environmental problems. In this study, the assessment of water quality in the Ribeirão das Neves stream created a contextualized learning experience in which students could investigate an environmental issue directly connected to their own community. By combining field observations, rapid assessment protocols, water quality data, WQI calculation, interactive data visualization, and ANN-based modeling, the project enabled students to move from observing environmental conditions to analyzing, interpreting, and communicating evidence about the watercourse.

This integration of experiential and data-driven learning is particularly relevant to a critical approach to EE. Rather than presenting water pollution as an exclusively technical or ecological problem, the activities provided opportunities to discuss the relationships between urbanization, inadequate sanitation, environmental degradation, public health, and the social organization of the territory. The identification of contrasting conditions along the stream also encouraged students to reflect on how environmental impacts are produced and

experienced differently across urban spaces, broadening the discussion beyond individual behaviors to include the social and structural factors underlying environmental problems.

The practical analysis of environmental parameters made otherwise abstract concepts related to ecosystem health tangible and meaningful, while the interactive dashboard and computational modeling expanded students' opportunities to engage with scientific information. In this context, environmental data were not treated merely as technical outputs, but as resources for inquiry, critical reflection, and environmental communication. The widespread evidence of impaired water quality therefore served as a concrete case through which students could develop environmental literacy and a deeper understanding of the connections between environmental quality, human health, and community well-being.

Within the educational context, the use of R software enabled a comprehensive and applied investigation of the water quality in Ribeirão das Neves, employing statistical techniques and highlighting the potential of digital technologies to expand the reach and impact of Environmental Education initiatives. By learning to use R, students were introduced to one of the most relevant and widely used tools for statistical analysis and data science, developing skills aligned with scientific and technological competencies emphasized by the National Common Curricular Base.

From data preprocessing to descriptive analysis and results visualization, the process brought students closer to the real challenges of water resource management and preservation. The development of a dynamic and intuitive dashboard enabled not only technical analysis but also the dissemination of environmental data in an engaging and accessible way, fostering meaningful and contextualized learning. The use of R software further encouraged logical reasoning, problem-solving, and computational thinking, while providing students with practical experience in working with data related to a real environmental issue.

The application of artificial neural networks to model the WQI proved to be effective both in terms of technical performance and as an educational resource. The developed model showed strong agreement with the results provided by IGAM, while simplifying the calculation of the index and reducing the need for complex equations and graphical procedures. More importantly, the modeling process enabled students to integrate computational theory and practice with statistical analysis and environmental knowledge, strengthening the interdisciplinary character of the learning experience.

Although the development of the dashboard and the application of neural networks serve as indicators of the development of students' analytical skills, the present study presents a methodological limitation by not utilizing formal empirical instruments to assess this learning. The absence of tools such as pre- and post-intervention pedagogical surveys precludes the exact quantitative measurement of the degree of change in students' environmental awareness. Future research

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should incorporate pedagogical evaluations to map this evolution more accurately.

Taken together, these activities demonstrate how data-driven and computational approaches can be incorporated into EE without reducing environmental issues to technical problems alone. By working with real data from a watercourse in their own community, students were able to connect computational and scientific knowledge with the interpretation of a concrete environmental reality. The combination of data analysis, visualization, and modeling therefore created opportunities for critical reflection on water quality and its broader environmental and social implications, reinforcing the role of EE in developing contextualized competencies and informed engagement with local environmental challenges.

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References

- ANA – Agência Nacional de Águas e Saneamento Básico. **Atlas esgotos: despoluição de bacias hidrográficas**. 2017. Disponível em: https://arquivos.ana.gov.br/imprensa/publicacoes/ATLASESGOTOSDespoluicaoodeBaciasHidrograficas-ResumoExecutivo_livro.pdf. Acesso em: 12 jun. 2023.
- BRASIL. **Lei nº 9.795, de 27 de abril de 1999**. Dispõe sobre a educação ambiental, institui a Política Nacional de Educação Ambiental e dá outras providências. Diário Oficial da União: seção 1, Brasília, DF, 28 abr. 1999.
- BRASIL. **Base Nacional Comum Curricular**. Brasília, DF: Ministério da Educação, 2018.
- CALLISTO, M.; FERREIRA, W.; MORENO, P.; GOULART, M. D. C.; PETRUCIO, M. Aplicação de um protocolo de avaliação rápida da diversidade de habitats em atividades de ensino e pesquisa (MG–RJ). **Acta Limnologica Brasiliensia**, v. 14, n. 1, p. 91–98, 2002.
- CINCERA, J.; VALESOVA, B.; KREPELKOVA, S.; SIMONOVA, P.; KROUFEK, R. Place-based education from three perspectives. **Environmental Education Research**, v. 25, n. 10, p. 1510–1523, 2019. DOI: <https://doi.org/10.1080/13504622.2019.1651826>.
- COSTA, C. A.; LOUREIRO, C. F. A interdisciplinaridade em Paulo Freire: aproximações político-pedagógicas para a educação ambiental crítica. **Revista Katálisis**, v. 20, n. 1, p. 111–121, 2017. DOI: <https://doi.org/10.1590/1414-49802017.00100013>.

FERREIRA, A. P. V. **Panorama atual do monitoramento da qualidade das águas no Brasil: Estudo de caso: Ribeirão da Mata – Aplicação do IQA-CCME**. 2019. Dissertação (Mestrado em Gestão e Regulação de Recursos Hídricos) – Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2019.

FRANÇA, J. S.; SOLAR, R.; HUGHES, R. M.; CALLISTO M. Student monitoring of the ecological quality of neotropical urban streams. **Ambio**, v. 48, p. 867–878, 2019. DOI: <https://doi.org/10.1007/s13280-018-1122-z>.

FREIRE, P. **Pedagogia do oprimido**. 42. ed. Rio de Janeiro: Paz e Terra, 2005. 213 p.

FREITAS, N. C. S.; FIGUEIREDO, D. M.; NUNES, S. S.; MORINI, A. A. E. T. Diagnóstico ambiental de uma microbacia urbana como instrumento de Educação Ambiental. **Revista Brasileira de Educação Ambiental (RevBEA)**, v. 19, n. 2, p. 163–180, 2024. DOI: <https://doi.org/10.34024/revbea.2024.v9.15496>.

GOODFELLOW, I.; BENGIO, Y.; COURVILLE, A. **Deep learning**. Cambridge: The MIT Press, 2016.

IBGE – Instituto Brasileiro de Geografia e Estatística. **Ribeirão das Neves – MG**. 2010. Disponível em: <https://www.ibge.gov.br/cidades-e-estados/mg/ribeirao-das-neves.html>. Acesso em: 16 out. 2024.

IBGE – Instituto Brasileiro de Geografia e Estatística. **Ribeirão das Neves – Panorama**. 2022. Disponível em: <https://cidades.ibge.gov.br/brasil/mg/ribeirao-das-neves/panorama>. Acesso em: 16 out. 2024.

IGAM – Instituto Mineiro de Gestão das Águas. **Índice de qualidade das águas (IQA)**. 2025. Disponível em: <https://igam.mg.gov.br/w/indice-de-qualidade-das-aguas-iqa>. Acesso em: 10 maio 2025.

IGAM – Instituto Mineiro de Gestão das Águas. **Portal InfoHidro – Águas Superficiais**. 2024. Disponível em: <https://portalinfohidro.igam.mg.gov.br/index.php>. Acesso em: 10 maio 2025.

LAYRARGUES, P. P.; LIMA, G. F. C. As macrotendências político-pedagógicas da educação ambiental brasileira. **Ambiente & Sociedade**, v. 17, n. 1, p. 23–40, 2014. DOI: <https://doi.org/10.1590/S1414-753X2014000100003>.

LOUREIRO, C. F. B. **Trajetória e fundamentos da educação ambiental**. 2. ed. São Paulo: Cortez, 2004. 150 p.

LUTKENHAUS, P. H. M.; PESSOA, G. P.; PEIXOTO, M. A. N. Educação Ambiental: análise comparativa dos projetos pedagógicos dos cursos do ensino médio do Instituto Federal de Minas Gerais considerando as diretrizes educacionais. **Revista Brasileira de Educação Ambiental (RevBEA)**, v. 17, n. 2, p. 329–348, 2022. DOI: <https://doi.org/10.34024/revbea.2022.v17.12920>.

MINAS GERAIS. Deliberação Normativa Conjunta COPAM-CERH/MG nº 8, de 21 de novembro de 2022. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as

Revbea, São Paulo, V. 21, Nº 4: 97-115, 2026.

condições e padrões de lançamento de efluentes, e dá outras providências. **Diário do Executivo: Minas Gerais**, Belo Horizonte, 2 dez. 2022.

PIRES, F.; HONDA, F.; SILVA, G.; FERREIRA, R.; FREITAS, R.; PICANÇO PESSOA, M. S. A game proposal to develop computational thinking and environmental awareness. **Journal on Computational Thinking (JCThink)**, v. 3, n. 1, p. 111, 2020. DOI: <https://doi.org/10.14210/jcthink.v3.n1.p111>.

QUEIROZ, M. M.; DANTAS, M. S.; OLIVEIRA, S. M. A. C. An overview of wastewater treatment technologies in Minas Gerais, Brazil: Predominance of anaerobic reactors. **Journal of Water, Sanitation and Hygiene for Development**, v. 14, n. 3, p. 209–219, 2024. DOI: <https://doi.org/10.2166/washdev.2024.184>.

RÊGO, J. R. S. Educação Ambiental: análise da percepção dos alunos do ensino fundamental sobre a qualidade da água consumida no município de Belém (PA). **Revista Brasileira de Educação Ambiental (RevBEA)**, v. 13, n. 4, p. 87–110, 2018. DOI: <https://doi.org/10.34024/revbea.2018.v13.2542>.

RESNICK, M. **Lifelong kindergarten: cultivating creativity through projects, passion, peers, and play**. Cambridge: The MIT Press, 2017.

TUCCI, C. E. M. Gerenciamento da drenagem urbana. **Revista Brasileira de Recursos Hídricos**, v. 7, n. 1, p. 5–27, 2002. DOI: <https://doi.org/10.21168/rbrh.v7n1.p5-27>.

YE, Z.; YANG, J.; ZHONG, N.; TU, X.; JIA, J.; WANG, J. Tackling environmental challenges in pollution controls using artificial intelligence: A review. **Science of the Total Environment**, v. 699, 134279, 2020. DOI: <https://doi.org/10.1016/j.scitotenv.2019.134279>.

YEMINI, M.; ENGEL, L.; BEN SIMON, A. Place-based education – A systematic review of literature. **Educational Review**, v. 77, n. 2, p. 640–660, 2023. DOI: <https://doi.org/10.1080/00131911.2023.2177260>.