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Future Projections of Sediments in the Tapajós River and its possible Relationship with Mining Areas

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Authors' notes'

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Abstract

Objective: The objective of the article is to analyze the possible relationship between illegal mining activities and sediment flow in the Tapajós river basin, in Pará.

Methodology: It is quantitative research, which uses simulation and modeling to project the data in different future scenarios, and descriptive analysis to evaluate two results.

Originality/Relevance: It is observed that the Amazon is vital in maintaining the global ecosystem and mitigating the impact of climate change. In this sense, rivers are of great importance in assessing environmental, social and economic impacts. Therefore, this research is relevant due to the fact that there is a lack in the literature about the impact of prospecting activities on Amazonian rivers, with emphasis on the impact of climate change on future projections, mainly in the Tapajós River Basin, which has been suffering a noticeable impact from transport of sediments.

Results: The results will allow us to identify the potential anthropic impact where we have the sediment measurements, which have much more short-term impacts than global climate changes, more robust and long-term.

Social contributions/ to Management: From this research, it is possible to affirm that the changes in the sediments of the Tapajós river can act as a catalyst for the environmental impacts that have already occurred in the region. Logo, the results become a tool for decision-making in environmental, social, and economic questions.

Keywords: hydrology, climatic changes, WBMsed, Amazon

Projeções Futuras de Sedimentos no Rio Tapajós e sua possível relação com Áreas de Garimpo

Resumo

Objetivos: O objetivo do artigo é analisar a possível relação entre atividades de mineração ilegal e fluxo de sedimentos na bacia do rio Tapajós, no Pará.

Metodologia: Trata-se de uma pesquisa quantitativa, que utiliza simulação e modelagem para projetar os dados em diferentes cenários futuros, e análise descritiva para avaliação dos resultados.

Originalidade/Relevância: Observa-se que a Amazônia é vital na manutenção do ecossistema global e mitigação do impacto das mudanças climáticas. Neste sentido, os rios possuem grande importância na avaliação dos impactos ambientais, sociais e econômicos. Logo, esta pesquisa é relevante pelo fato de haver carência na literatura acerca do impacto de atividades garimpeiras em rios amazônicos, com ênfase no impacto das mudanças climáticas em projeções futuras, principalmente na Bacia Hidrográfica do Rio Tapajós, que vem sofrendo um perceptível impacto de transporte de sedimentos.

Resultados: Os resultados permitiram identificar que o impacto antrópico pontual nos locais onde houve as medições de sedimentos tem muito mais impactos a curto prazo do que as mudanças climáticas globais, mais robustas e a longo prazo.

Contribuições sociais/para a gestão: A partir desta pesquisa, é possível afirmar que as mudanças nos sedimentos do rio Tapajós podem agir como um catalisador para os impactos ambientais que já ocorrem na região. Logo, os resultados tornam-se uma ferramenta para tomada de decisão em questões ambientais, sociais e econômicas.

Palavras-chave: hidrologia; mudanças climáticas; WBMsed; Amazônia

Proyecciones Futuras de Sedimentos en el Río Tapajós y su Posible Relación con Áreas Mineras

Resumen

Objetivo: El objetivo del artículo es analizar la posible relación entre las actividades de minería ilegal y el flujo de sedimentos en la cuenca del río Tapajós, en Pará.

Metodología: Esta es una investigación cuantitativa, que utiliza simulación y modelado para proyectar datos en diferentes escenarios futuros, y análisis descriptivo para evaluar los resultados.

Originalidad/Relevancia: Se observa que la Amazonía es vital para mantener el ecosistema global y mitigar el impacto del cambio climático. En este sentido, los ríos son de gran importancia a la hora de evaluar los impactos ambientales, sociales y económicos. Por lo tanto, esta investigación es relevante debido a que existe una falta de literatura sobre el impacto de las actividades de prospección en los ríos amazónicos, con énfasis en el impacto del cambio climático en las proyecciones futuras, principalmente en la cuenca del río Tapajós, que ha sido sufriendo un notable impacto por el transporte de sedimentos.

Resultados: Los resultados permitieron identificar que el impacto antrópico puntual en los lugares donde se tomaron las mediciones de sedimentos tiene mucho más impactos de corto plazo que los cambios climáticos globales, que son más robustos y de largo plazo.

Contribuciones sociales/a la gestión: A partir de esta investigación, es posible afirmar que los cambios en los sedimentos en el río Tapajós pueden actuar como un catalizador de los impactos ambientales que ya ocurren en la región. Por lo tanto, los resultados se convierten en una herramienta para la toma de decisiones en temas ambientales, sociales y económicos.

Palabras clave: hidrología, cambios climáticos, WBMsed, Amazonas

Introduction

The river and its drainage basin constitute a functional unit for the water cycle and a privileged integrative space for establishing balances or validating models of change and erosion. Thus, rivers are at the heart of the elements' cycle, transporting matter lifted from the continents to the oceans (Filizola & Guyot, 2011).

The knowledge of the characteristics of a watershed is fundamental for conserving its natural resources and guiding the application of techniques that favor sustainable development.

To determine this knowledge, it is important to monitor the physical variables of the hydrological cycle, such as infiltration, surface runoff, elevations and flows (Pereira et al., 2016).

According to Mapani, Shikangalah and Mwetulundila (2023), cities located near watercourses suffer directly from the consequences of river levels, both positively and negatively, associated with extreme floods and droughts and other factors. In their study, Sousa, Santos and Costa (2022) mention the influence of seasonality in the Tapajós River basin's flows, whose seasonal periods alternate between high water (floods) and low water (droughts), as well as the action of climatic phenomena. These changes in the level of the river, combined with the movement of sediment, cause problems for the municipalities and beaches in areas that are directly affected by the seasonal periods.

The Tapajós River basin is a tributary of the right bank of the Amazon River. It is a federal basin (as it drains more than one state) and makes an important contribution to the maintenance of Amazonian ecosystems, as well as being an area of different potential for the exploitation of natural resources. With approximately 1,260,000 inhabitants (IBGE, 2010), it holds 6% of the Brazilian territory and has 25% of the Amazon's hydroelectric potential, which accounts for 70% of the national potential (BRASIL, 2005). Villela and Bueno (2016) infer that the southwest of Pará is currently considered an agricultural frontier, where soybean cultivation is becoming increasingly important.

Soybean monoculture has a major economic, social and environmental impact, as it requires infrastructure such as roads, railroads and waterways to transport production and at the same time to receive the inputs used in farming (Branco et al., 2021). These factors increase the concentration of people living in the region with the exodus from other states in search of services and job opportunities (Cardoso & Smith, 2018). It should be also noted that this region is a hub for logging and gold mining in the Tapajós Province, which consequently contributes to the need to transport production in roads and the river, thus leading to increased deforestation of the forest (Sauer, 2018; Neves et al., 2021).

An important point that should be mentioned is the issue of erosion and siltation in adjacent watercourses, aspects caused by mining activities, which generate environmental damage and above all contribute to the degradation, water resources contamination and all human life affected there (Souza et al., 2008). Among the main environmental impacts caused by mining are the degradation of vegetation due to the opening of roads for the transportation of ores, the silting up of waters owing to sediment's discharge from riverbanks and contamination by mercury used in the amalgamation process to separate the gold (Gonçalves et al., 2018).

Over the course of a decade, the number of mining sites in Brazil doubled, while industrial mining took two decades to achieve the same result. This is the third consecutive year in which more land is occupied by mining than by industrial mining (Costa & Rios, 2022). However, mining does not correspond to mining in the technical sense, but rather to an archaic process of extracting mineral resources, characterized by a lack of knowledge of the deposit and a lack of planning, technical resources, as well as poor environmental practices, safety, health and finally operating illegally, without a license and knowledge of the environmental agencies (Massaro et al., 2022).

The Amazon Biome concentrates 91.6% of the area mined in 2021, and Pará and Mato Grosso states account for 71.6% of the country's mined areas, that is, when we add industrial mining and prospecting. Four of the five Brazilian municipalities with the largest mining areas are in Pará: Itaituba (57,215 hectares), Jacareacanga (15,265 hectares), São Félix do Xingu (8,126 hectares) and Ourilândia do Norte (7,642 hectares) (MapBiomas, 2022).

This research sought to analyze part of these impacts (present and future) in a region in the central part of the Amazon basin (west-east direction), the so-called Tapajós River Basin (TRB), which has extensive aquatic-forest ecosystems, from the high reliefs of the Mato Grosso savannah to the low latitudes and altitudes. Using simulated sediment flow data from the WBMsed global model, provided by the University of Alabama (USA), readings were taken for six points on the Tapajós River under future climate scenarios. Subsequently, descriptive statistics were carried out for the data obtained with a brief analysis of the mining areas in the TRB and their possible interference in these reading points.

Methodology

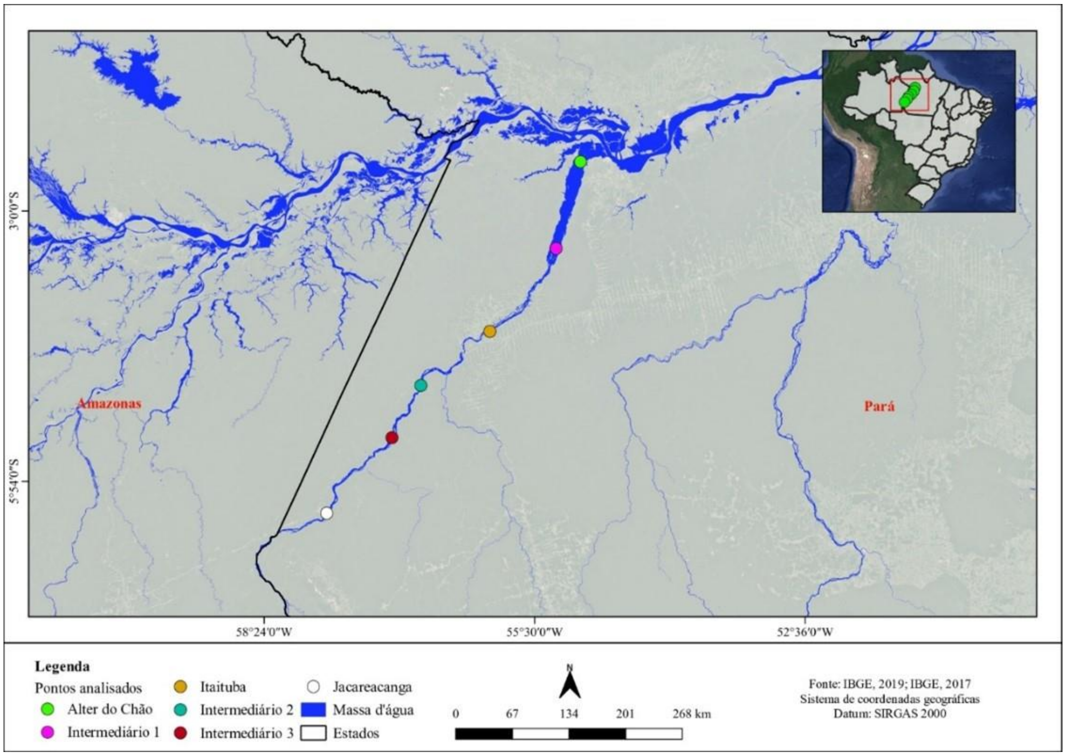
Study area

The Tapajós River basin is one of the basins with the greatest potential for generating electricity in Brazil, with an area of 764,183 km², almost the size of Sweden and Norway combined (Fearnside, 2015). The study area comprises the Tapajós River, formed from the confluence of the Teles Pires River with the Juruena River, which drains the states of Pará, Amazonas and Mato Grosso. According to Alvares et al. (2013), the Tapajós river basin has three climatic typologies within the Köppen-Geiger climate classification. In the upper Tapajós, its climate is classified as Am, characterized by a tropical monsoon climate, with a brief dry season and intense rainfall during the rest of the year, the coldest month having an average temperature of over 18°C and annual rainfall oscillating around 2000 mm. In the middle of Tapajós, the climate is classified as Af, tropical humid or super-humid, without a dry season, and the average temperature of the hottest month is over 18ºC. The total rainfall in the driest month is over 60 mm, with the highest rainfall from March to August, exceeding 1,500 mm per year. However, the lower Tapajós is classified by climatology as being Aw, with summer rainfall, a climatic characteristic of savannah regions, which can reach 1,800 mm/year.

The Tapajós River is approximately 146 kilometers long and drains an area of approximately 131,000 square kilometers, spread between the states of Amazonas and Pará. The points were chosen strategically, due to their great economic potential, and are distributed as follows (Figure 1) Alter do Chão - Point 1, intermediate 1 - Point 2, Itaituba - Point 3, intermediate 2 - Point 4, intermediate 3 - Point 5 and Jacareacanga - Point 6.

Figure 1

Location of reading and analysis points on the Tapajós River



In the Tapajós basin, there are plans to build a significant number of dams; by 2022 there will be more than 40 projects, including Small Hydroelectric Plants (SHPs) and Hydroelectric Plants (HPPs), the latter of which will generate more than 30 MW each (Lees et al., 2016). The Tapajós River and its tributaries are the focus of plans by the Ministry of Transport, which intends to convert it into a waterway for transporting soy from Mato Grosso to ports on the Amazon River (Costa et al., 2020). Other large-scale projects are planned, such as the construction of river ports to transport grain, causing the population to increase or explode in the coming years (Melo et al., 2017).

The Tapajós basin is a mosaic of preservation areas, including conservation units and indigenous lands. According to Cavalcante et al. (2021) this basin has nine full protection conservation units, twenty sustainable use conservation units and thirty indigenous lands, i.e. 40% of its area corresponds to conservation units and indigenous lands.

Obtaining and reading data from the WBMsed model

Readings were taken for six specific points on the Tapajós River under future climate scenarios. Simulated sediment flow data from the WBMsed global scale hydrogeomorphic model for Amazonia, provided by the Surface Dynamics Modelling Laboratory at the University of Alabama (https://sdml.ua.edu/datasets-2/), was used. This uses data forced with General Circulation Models (GCMs) projections into the future.

WBMsed is robust and simulates the entire global river system, predicting suspended and bottom sediment fluxes based on the water balance and transport model (Cohen et al., 2013). It is also important to highlight that the Amazon sediment flux may be much higher than predicted in some areas, due to the current configuration of WBMsed. This model also allows predictions on the variation in the flow of suspended material in the main continental rivers in response to climate change (Maragoda & Cohen, 2020). We chose to use simulated data in the study, given the scarcity of public data from direct measurements, available on online platforms (such as Hidroweb-ANA).

The future climate scenarios used in the simulations provided were the RCP's (Representative Concentration Pathway) defined by the IPCC (Intergovernmental Panel on Climate Change) from 2006 to 2100. For this work, two of the four climate scenarios defined by the IPCC were selected, namely RCP 4.5 and RCP 8.5. When determining the scenarios for the Pontos analysis, it was taken into account that RCP 2.6 is the least likely to occur, while RCP 4.5 and 6.0 are intermediate and desired scenarios, i.e. those in which countries manage to control emission levels and the level of CO2 in the atmosphere stabilizes soon after 2100. However, the RCP 8.5 scenario is recognized as the most likely to occur (Schardong et al., 2014).

As the model data is in global grid format (NetCDF), the FERRET grid data analysis tool (http://www.ferret.noaagov/ferret) was used and installed on the Linux Ubuntu 16.04 LTS operating system. The software was developed by the Thermal Modeling and Analysis Program (TMAP) of the Pacific Marine Environment Laboratory (PMEL/NOAA) in Seattle, USA, to analyze the results of its global numerical models and compare them with observational grid data (Ohunakin et al., 2015).

Analysis of mining areas

In the Amazon context, mining activities have increased dramatically, and with them the negative impacts on the Brazilian Amazon basin, by influencing deforestation, health risks, violence, loss of cultures and identities, irregularity and illegality of the products extracted (Risso et al., 2021), as well as other negative aspects that cause serious problems for the peoples who live there in all their specificities.

Territorial conflicts experienced by the Munduruku and Sai Cinza people located in the cities of Itaituba and Jacareacanga in the Tapajós river basin, especially related to mining, are important examples of how activities related to the development and neo-extractivist model disrupt indigenous daily life in the territories where they operate (Porto & Rocha, 2022; Veja et al., 2022).

Observing the intense mining activities within the TRB, it was necessary to analyze these areas, both spatially and quantitatively, to see if mining was possibly contributing to the demand for sediment in the river. Data for the study was obtained from the MapBiomas platform, the National Indian Foundation (FUNAI) and the National Mining Agency (ANM). A map was drawn up showing the spatialization of these areas to evaluate and compare their possible correlation with the sediment reading points.

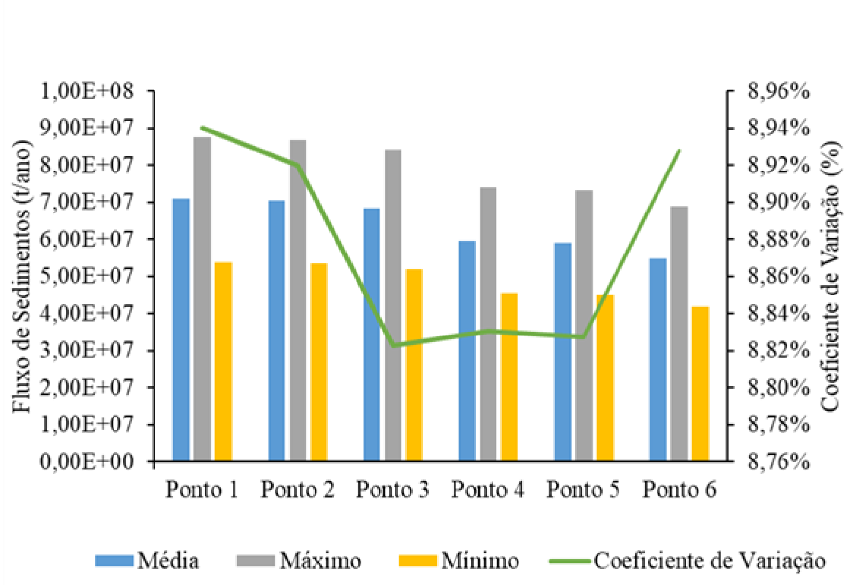
Results and Discussion

Statistical analysis

Figure 2 shows a slight variation between the maximum and minimum values at the points presented, with Point 1 having the highest maximum and Point 6 the lowest sediment flow.

Figure 2

Statistical results for RCP's 4.5 scenario



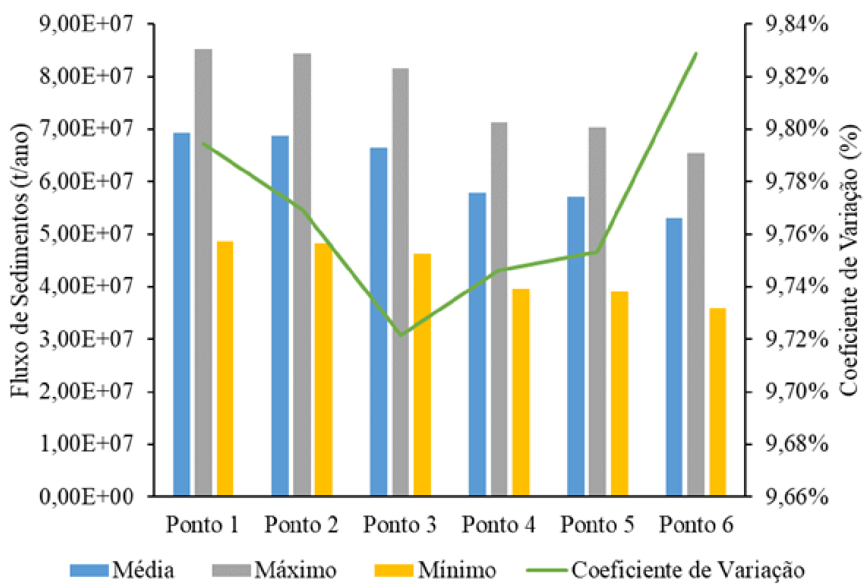
When analyzing the sediment flows for scenario 4.5, shown in Figure 2, the averages observed were at Point 1 ($7.10x10^7$t/year), Point 2 ($7.04x10^7$t/year), Point 3 ($6.82x10^7$t/year), Point 4 ($5.96x10^7$t/year), Point 5 ($5.89x10^7$t/year) and Point 6 ($5.47x10^7$t/year). Point 1 had the highest average, while Point 6 had the lowest average. The highest maximum was calculated at Point 1, which is furthest from the mouth, and was $8.75x10^7$t/year, while Point 2 was around $8.69x10^7$t/year, Point 3 was $8.41x10^7$t/year, Points 4 and 5 were very close ($7.39x10^7$t/year), ($7.32x10^7$t/year) respectively, and Point 6 was around $6.89x10^7$t/year.

Regarding to the minimum values, Point 1 ($5.39x10^7$t/year), Point 2 ($5.35x10^7$t/year) and Point 3 ($5.20x10^7$t/year), have closer values and from Point 4 onwards this value decreases, highlighting Point 6 which has the lowest minimum among all the points analyzed, around $4.19x10^7$t/year. Points 1, 2 and 3 showed higher sediment concentrations, which is linked to the fact that they are located close to the Amazon River, corroborating the result found by Fassoni-Andrade and Paiva (2019) in their study on sediment flow along the Solimões-Amazonas River, since when its confluences with the Tapajós River shows an increase in sediment flow.

Considering the coefficient of variation, the points with the least variability between the data were 4 and 5, which had a coefficient of 8.83% respectively. Point 1 had the greatest dispersion between values, with a coefficient of variation of 8.94%. The study by Fagundes et al. (2023) mentions that sediment flow in the Amazon region will decrease by 16% and this is directly related to the reduction in rainfall, which according to Brêda et al. (2020) will decrease by 27%. Figure 3 shows the time series data for the RCP's 8.5 scenario.

Figure 3

Statistical results for RCP's 8.5 scenario



It can be seen in Figure 3 that the averages obtained for scenario 8.5 were lower than for scenario 4.5: Point 1 had the highest average of $6.93x10^7$t/year, Points 2 and 3 had ($6.87x10^7$t/year and $6.65x10^7$t/year), for Points 4, 5 and 6 there was a change, with values lower than the others, such as $5.79x10^7$t/year, $5.71x10^7$t/year and $5.30x10^7$t/year. However, the highest maximum was established at Point 1 with $8.52x10^7$t/year, while Point 6 had the lowest maximum estimated at ($6.54x10^7$t/year), Points 2 and 3 ($8.44x10^7$t/year, $8.15x10^7$t/year) had approximate values, as did Points 4 and 5 ($7.13x10^7$t/year, $7.03x10^7$t/year).

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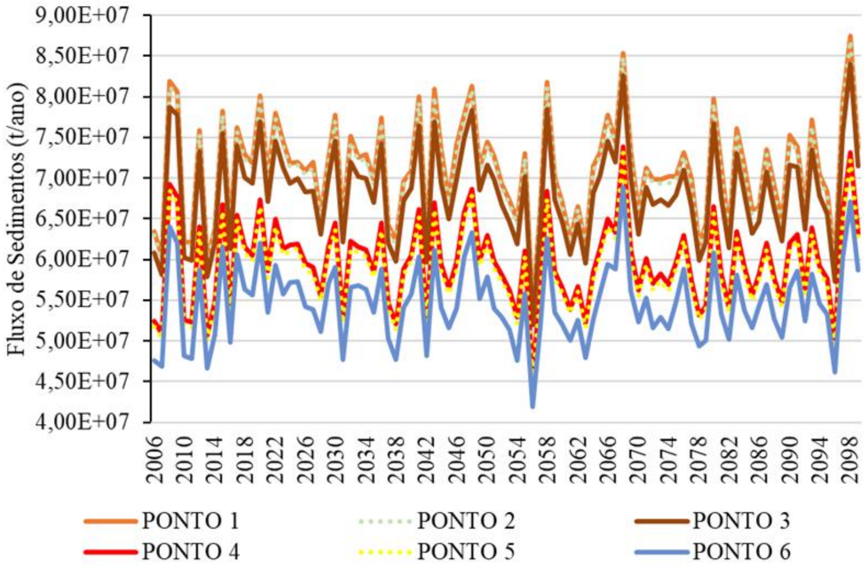
The point with the lowest variability in the data was Point 3 with 9.72% and the point with the highest variation was Point 6, which showed approximately 9.83%. Based on the values obtained, it is understood that the coefficient of variation is within the normal range, since based on Oliveira and Camelo (2019) when it is less than or equal to 15% considered low dispersion, so the data is considered homogeneous.

Figures 4 and 5 show the variation in sediment in the Tapajós River over the course of the century may be linked to climate change, which is increasingly intensifying due to the negative impacts of anthropogenic action. Therefore, it is necessary to study these impacts, together with the projection of this sediment flow, which can help in mitigating actions so that there is no severe damage to the community and the ecosystem present in this region (Montanher et al., 2018).

Figure 4

Variation of sediment flows for RCPs 4.5



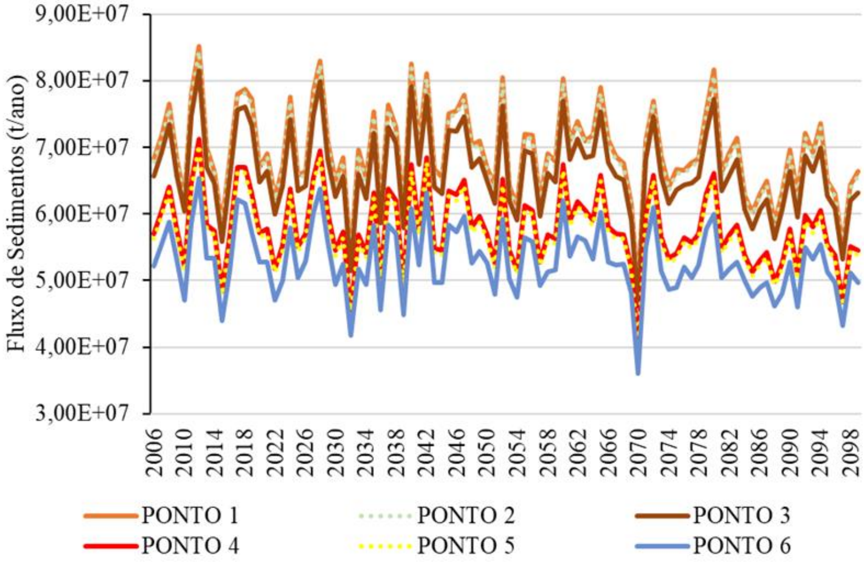
Based on the 94-year historical series, for the Tapajós River basin the variation in the average annual sediment flow for scenarios 4.5 and 8.5 (Figures 4 and 5) was $3.83x10^8$ t/year and $3.72\ x10^8$, respectively. When comparing the flow averages for the two scenarios, the differences were small, approximately 2.96%.

When analyzing the results by decade, the following results are presented: between 2006 and 2013, the maximum values remained constant at all points during the 2008 period, while the minimum values also remained constant at all points in 2013. When comparing this same period for scenario 8.5, the highs occurred at all points in 2012 and the lows in 2015.

In the periods from 2036 to 2045 there was a variation in the series, where the minimums were presented in two different periods, in Point 1, 2 and 3 they were maintained in the year 2038, while in Points 4, 5 and 6 they occurred in 2042. The same was repeated between the period from 2066 to 2075, however, the series only alternated in Point 6 where it occurred in the year 2074, the other years presented the minimums in 2070, in this same period in scenario 8.5 the lowest minimums of the entire historical series occurred, as shown in Figure 5.

Figure 5

Variation of sediment flows for RCP's 8.5



When analyzing the series, points 1, 2 and 3 had their highest maximums in the year 2098, while points 4, 5 and 6 had their highest maximums in the year 2068, point 1 had the highest maximum ($8.75x10^7$t/year) in scenario 4.5, however, for scenario 8.5 the highest maximums all occurred in the year 2012, with emphasis on point 1 which had the highest maximum among the points ($6.93x10^7$t/year). Between 2054 and 2056, all the points had the lowest sediment flow, as shown in Figure 5, thus obtaining a total minimum of $6.36x10^8$t/year, the same occurs in scenario 8.5, but in different years, the variation occurred in 2070 with a total minimum of $2.88x10^8$t/year.

There is an increase in the river's average sediment content, from further upstream to the mouth, where the highest concentration of sediment is observed. According to Silva et al. (2021), in their hydrodynamic modeling study of the Tapajós River, it was found that in the stretch between points 4 and 3 there was an abrupt reduction in the levels of the water depths, which is justified by the slope of the bottom of the channel averaging 0.00021 m/m. The other stretches (points 5 and 6) had an average slope of 0.00013 m/m, i.e. around 161.53 % less than the other stretches mentioned. As a result of the high slope, the speed was also high, reaching an average of 1.49 m/s near point 4, while the average speed at point 3 was 1.44 m/s, while at point 6 the speed was approximately 1.19 m/s.

The Tapajós River's significant sediment-laden flows in its mouth regions are sustained by its hydrodynamic features, complemented by the frequent rainfall characteristic of the Amazon region. In this region Alter do Chão is located, which in 2009 was voted the most beautiful freshwater beach in the world, becoming popularly known as the "Brazilian Caribbean" (Barreto and Tavares, 2017). This raises concerns about the large accumulation of sediment, especially considering its tourist potential, as it attracts a floating population during high seasons and is possibly vulnerable to possible negative effects and environmental liabilities.

When analyzing the projections of the graphs, presented in Figures 4 and 5, for the two scenarios, it was noted that because of the inconsistency between them, it was expected that there would be an increase in sediments for the pessimistic scenario (8.5), however, this increase occurred in the optimistic scenario (4.5). The values between the scenarios were relatively close and the main difference occurred between the points on the Tapajós River and not necessarily between the scenarios.

Yang et al. (2003) showed global estimates of erosion rates considering climate change. They estimated that the erosion rate in South America would increase from 1980 (8.5 t/ha.year) to 2090 (10.3 t/ha.year). For the Amazon basin, the authors estimated, for the same period, a 24% increase in the erosion rate, however, this study uses very old data and only evaluates changes in soil erosion and not in the other components of water flows. sediments. Nevertheless, in more recent work using the WBMsed global model, Dunn et al. (2019) considered four climate change projections, with the most up-to-date data (CMIP5) and estimated that in the Amazon basin there would be a 10% reduction in sediment discharges comparing the period 1990-2019 with the period 2070-2099.

The Dunn's conclusions are closer to those found by Brêda et al. (2020), which indicate a reduction in precipitation in most of the Amazon basin, showing that with the decrease in precipitation for future scenarios, there will also be a reduction in sediments, both studies indicate that the impact will be greater than 29%. Furthermore, changes in sediment transport are associated with changes that may occur in nutrient transport, which has been a source of great importance in Amazonian rivers for the maintenance of aquatic biodiversity and the sustenance of traditional communities (Heilpern et al., 2021).

Mining areas

In the country, mining areas were detected in 232 municipalities, among the ten municipalities with the largest mining area in Brazil, nine are in the state of Pará and two of these municipalities are within the Tapajós River basin. Again, Itaituba with around 44,890 ha leads the ranking and Jacareacanga in second with 9,450 ha (MapBiomas 2022). In these municipalities, the practice of illegal mining is common, and informally, their largest source of income, which directly impacts the environment and socioeconomic problems (Monte et al., 2021).

According to a survey carried out by Cavalcante et al. (2021), the Tapajós River basin has a high number of hydroelectric plants (UHEs) to be implemented in the region. These HPPs combined with mining cause negative impacts on the waters of this basin, since the mercury used by these mining activities when combined with the damming of rivers can cause the accumulation of mercury in the water body, promoting methylation (Arrifano et al., 2018). The aforementioned cities also have indigenous reserves within their limits, as shown in Figure 6.

Figure 6

Map of mining areas located in the TRB

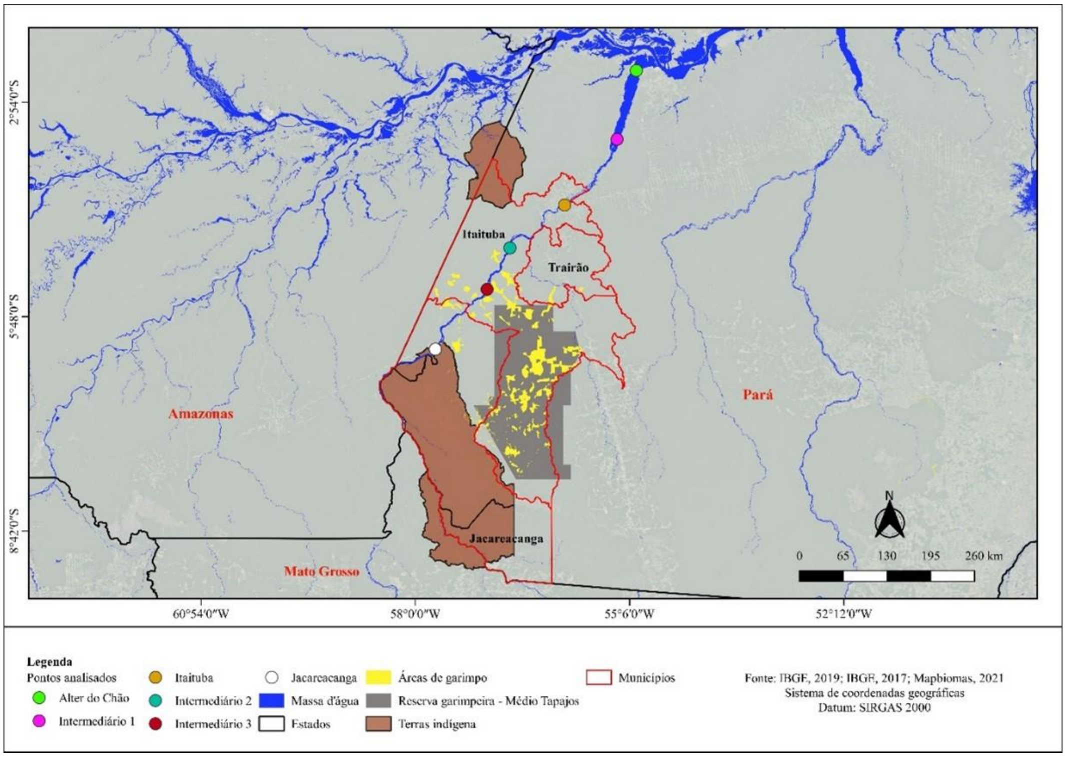


Figure 6 shows the municipalities that are located in the Tapajós river basin, and their mining areas. The municipality with the largest mining area is Itaituba, where the Points (intermediate 2, intermediate 3) are located, suffering direct influence from mining activity, so the sediment flow in these Points tends to be greater. According to the National Mining Agency (ANM), mining is considered an illegal economic activity when it is carried out in areas exceeding 50 hectares or on Indigenous Lands. Illegal mining both in Montanha and Mangabal and in the Munduruku territories proceeds in an uncontrolled manner with the use of industrial machinery (Cunha & Earp, 2022).

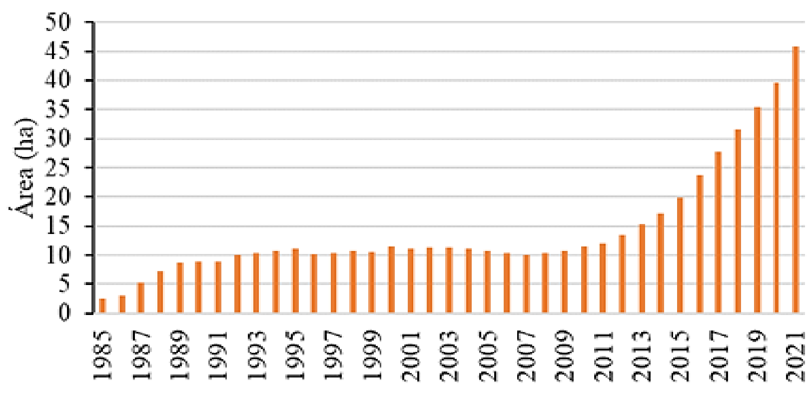
Changing the riverbed directly impacts its microbiota, phenomena that drastically modify the flow or cause turbulence at the bottom of the river can cause stress to aquatic fauna and alter the physical conditions of the watercourse (Siddha & Sahu, 2022). Correct handling of the cleaning process in mining, the organic soil should first be removed for subsequent restoration of the degraded area, however, this is often not carried out and this type of mining can cause sediment transport to rivers, altering the physical-chemical conditions. of water resources.

The Tapajós river basin has numerous mining areas, for example in the municipalities of Jacareacanga and Itaituba which have mining sites in their territory, the waste produced in these activities will possibly be carried into the water body, causing negative impacts, such as silting of the rivers and water pollution, in addition to mercury contamination in both species and water in this basin (Lobo et al., 2015; Lino et al., 2019). As demonstrated in Figures 3 and 4, it is observed that as the river progresses the sediment flow gains volume between the analyzed Points, this difference becomes evident when the maximum at Point 6 is much lower than at Point 1, and may have a direct relationship with the practice of mining in these locations.

According to MapBiomas (collection 7), the mining areas in the Tapajós River basin (Figure 7) jumped from 11,403 ha in 2010 to 45,893 ha in 2021, an expansion of 34.9 hectares. The 37-year series (1985-2021) shows interrupted growth, however, the survey also showed that the expansion was more intense in indigenous territories and conservation units.

Figure 7

Mining areas in TRB



Source: MapBiomas (2022).

In Figure 7, from 2012 onwards there was accelerated growth in mining areas, according to data observed by MapBiomas, this may be linked to the publication of the new forestry code and its flexibility in terms of preservation and recovery of areas. deforested and the construction of new roads (Pereira et al., 2021; Oliveira, 2015). Mining activities are known for having a high production of waste and sediments that are discarded in inappropriate areas, causing various impacts on the environment.

Rosa and Weihs (2021) highlight in their study that the methods used in these activities affect the quality of water for consumption and that the factors linked to this problem are the sediments produced in high quantities, such as fine sand, which end up being transported to bodies of water, leading to poor water quality and silting of rivers. Mining in Yanomami indigenous territory may be the biggest contributor to the increase in sediments in the riverbed, according to the work of Queiroz et al. (2022), small-scale mining is directly related to the increase in the concentration of suspended solids in the water, in addition to the increase in the concentration of chemicals such as mercury and nickel.

The survey carried out by InfoAmazonia (2021) reveals that pollution from gold mines in the Tapajós basin already extends for hundreds of kilometers. Upstream of Jacareacanga the waters are very turbid. From this point onwards, successive tributaries take the bright yellow sediments from the mines to the Tapajós River. The study also portrays an event that occurred in January 2022, when the clear waters of Alter do Chão gave way to a muddy tone, therefore, the hypothesis was raised that the change was related to mining activity.

Although there are no in-depth studies that prove the current link between the river's change in color and mining, the hypothesis raised by the traditional populations living on the banks of the Tapajós is valid. That the color of the river has changed is a fact, the cause of this change remains to be proven. The practice of mining and deforestation play an important role, as they are two potential polluters of the environment. This scenario demonstrates the need to look back at the Amazon region, which is rich in biodiversity. It is also understood that the importance of not only replicating studies like this, analyzing simulations, but analyzing direct measurements, for correct data validation is necessary. This would certainly contribute not only to important areas of the environment, but to parallel areas in the region, but of great relevance to the economy (such as tourism).

Conclusions

The results obtained through the simulations carried out by the WBMsed model, based on the analysis of the six Points used in two climate scenarios (RCP's 4.5 and RCP's 8.5), in general caused us a certain impact, as it was expected that there would be a sediment growth for the pessimistic scenario (8.5), however, this increase occurred in the optimistic scenario (4.5), which demonstrates that the specific anthropogenic impact in these locations has much more short-term impacts than global climate change (more robust and long term).

An important point that draws attention throughout this research is the mining activity, which was evident in the TRB region, causing significant damage to the environment and consequently to the population. Therefore, it can be inferred that these changes can act as a catalyst for the environmental impacts that already occur in the region, whether due to sediment accumulation, but mainly, social and economic issues.

It is expected that the data and information from this study can support projects and sizing of works, avoiding possible environmental disasters, contributing to the adaptation and mitigation policy. This will support public managers, technicians and decision makers in the region, in addition to encouraging other similar studies in the Amazon and Brazil. Finally, possible changes caused by climate variability are often more sensitive in a specific way, which requires an on-site analysis, with measurements, to be able to perceive any changes.

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