MODELING FUTURE HYDROLOGICAL CHANGES IN THE AMAZON BASIN UNDER A DEFORESTATION SCENARIO

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ABSTRACT

The Amazon River Basin (ARB) has been losing forest cover, approximately 17% has been lost in the last 50 years, impacting the hydrological cycle, and altering the water flows of its main tributaries. This study aimed to model the hydrological trends in the main tributaries of the Amazon, considering the potential effects of projected deforestation. For this purpose, hydrological modeling was used to simulate the flows of the ARB by twin numerical experiments. It was observed that the changes in flows are significant, totaling a reduction of more than 10,000 m³/s in the main stretch of the Amazon River, with spatially heterogeneous impacts and distinct hydrological responses, ranging from increases in the northern basins to reductions in the southern basins.

Key words – *Forest changes, Amazon hydrology, remote sensing.*

1. INTRODUCTION

The Amazon River Basin (ARB) covers an area of more than 6 million km², approximately 40% of South America. It is the largest hydrological system in the world, playing a crucial role in the global water, energy and carbon cycles [1, 2]. The basin has some of the largest rivers on the planet, like Solimões, Madeira and Negro, that together with the Amazon River, contribute for an average annual flow of 206×10³ m³/s into the Atlantic, corresponding to around 20% of the Earth's liquid fresh water [3]. The basin also drains the largest tropical forest in the world with high rates of evapotranspiration, resulting in the recycling of 30% to 40% of local humidity through precipitation [2].

Precarious territorial planning has caused the ARB to lose part of its forest cover to activities such as agriculture, livestock farming and mining [4]. It is estimated that approximately 17% of its forest cover has been lost in the last 50 years [5]. This reduction has affected the hydrological cycle by decreasing evapotranspiration and altering the transport and recycling of moisture, aggravating the water vapor deficit and intensifying water stress in the forest [6, 7].

Changes in the flow rates of the basin's main tributaries are spatially heterogeneous, and as socioeconomic pressures continue to grow, more intense and frequent disturbances are expected [8]. Future scenarios indicate that, by 2050, around 40% of the Amazon forest cover could be deforested, reducing the current closed canopy area from 5.3 million km² to 3.2 million km² [9].

The study of hydrological trends in the main tributaries of the Amazon represents a significant scientific challenge since the potential effects of deforestation often overlap with natural variations in climate cycles, which are especially intense in the Amazon region [10]. In this context, hydrological modeling supported by remote sensing products has provided a deeper scientific understanding of hydrology and environmental changes in the Amazon, filling essential information gaps for the study of hydrological behavior in large regions.

Therefore, the objective of this work was to model the flows of the main tributaries of the ARB considering the potential effects of deforestatio, and to analyze hydrological trends to understand these future changes.

2. MATERIAL AND METHODS

The study area comprises the ARB and five of its sub-basins: The Solimões, Negro, Madeira, Tapajós and Xingu basins, and covers the regions 5°N to 20°S latitude and 50°W to 80°W longitude (Figure 1 A).

The Large Basin Hydrological Model (MGB), developed by the Institute of Hydraulic Research of the Federal University of Rio Grande do Sul [11], was used to simulate two flow scenarios. First, a control scenario with current land use and occupation data [12, 13]. The second simulation is a Business as Usual (BAU) scenario that considers the deforestation rate until 2050, assuming that current deforestation trends will continue [9] (Figure 1). The simulation parameters included the relief, soil types, vegetation and land use, climate data (temperature, relative humidity, wind speed, atmospheric pressure, radiation incident on the surface), precipitation and flow. The model subdivides each basin into hydrological response units (HRU) with similar hydrological behavior based on physical characteristics. This allows an accurate simulation of the transformation of precipitation into flow, and estimates of the volume of water drained and transformed into flow [11].

Flow rates were estimated for 12,466 HRU from 1990 to 2017, where the first two and the last year of the historical series were discarded from our analyses to avoid spin-up model time. The 5 most downstream HRUs of each basin were selected for the analysis.

The Mann-Kendall non-parametric test was used to verify whether there were any significant (p=0.05) trends in the simulated data. To assess the impact of deforestation on flows, percentage differences between the control and deforestation scenarios were calculated. To focus on long-term variations, a 12- month window moving average was applied to the monthly data to reduce the noise, and help

visualize flow changes over time.

The data processing and manipulations were done in a Python programming environment with the help of the pandas, matplotlib, numpy, and pymannkendall libraries. The maps and spatial analyses were performed in ArcGIS software version 10.8. More details of the model and data validation are available in the references [11, 14].

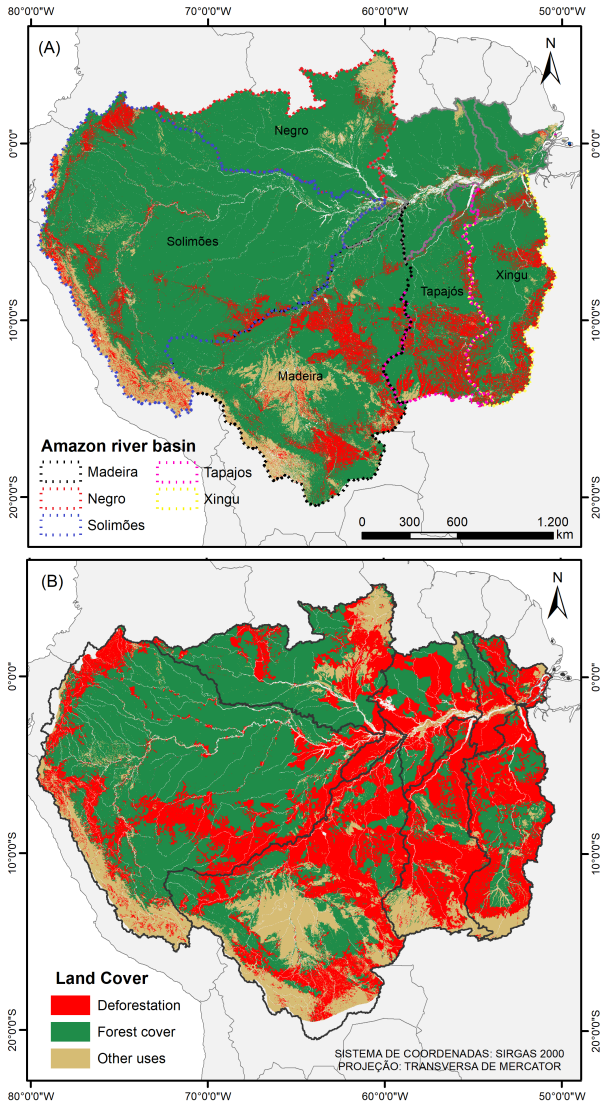

Figure 1: (A) Main sub-basins draining into the Amazon River and land cover in 2021 (B) land cover projected for 2050 in the Business As Usual (BAU) scenario.

3. RESULTS

From the 12,466 HRUs, only 870 showed a significant decreasing trend in flow and 2,925 showed an increasing trend over the 25-year historical series for 5% significance while 8,671 did not show any significant trend. The most increasing trend of HRU were found in the Solimões and Negro river basins, with 1,221 and 613 HRU each, while the majority of HRU with a decreasing trend were located in the Madeira and Solimões river basins with 313 and 289 HRU respectively (Figure 2 A).

Comparisons between the two scenarios (Figure 2 B) showed that 459 HRU (3.68%) had decrease in flow in the deforestation scenario when compared to the control scenario, with a reduction higher than 40%, with some points reaching a difference of 77.5%. 3221 (25.83%) showed a average percentage reduction in flow between 40 and 20%, 2913 (23.36%) a reduction between 20 and 10% and 3724 (29.87%) URH a reduction up to 10%. In addition, 1485 HRU (11.91%) had a increase in flow in the deforestation scenario up to 10%, while only 152 (1.21%) had an increase greater than that.

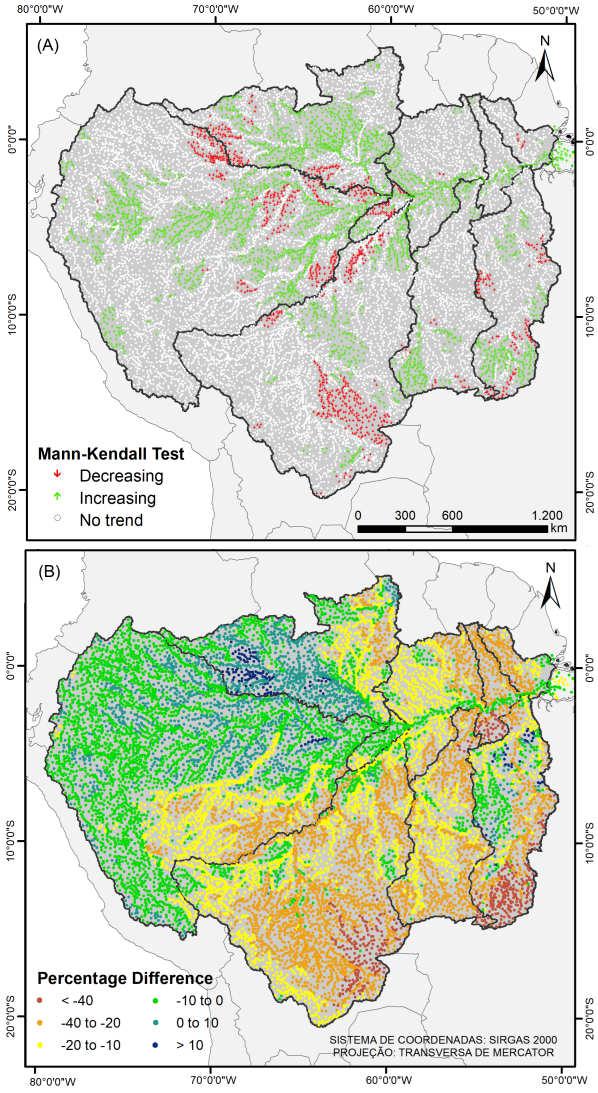

Figure 2: (A) Trends in time series by the Mann-Kendall test, (B) Average percentage difference between deforestation and control scenarios.

In the distribution of flows throughout the historical series (Figure 3), the Solimões and Negro river basins show little variation of the average flow between the control scenario and deforestation scenario, respectfully 92,719.07 m³/s and 91,348.01 m³/s for Solimões River basin and 36,296.00 m³/s

and 35,689.07 m³/s for Negro River basin.

The Madeira, Tapajós and Xingu river basins showed more pronounced flow reductions in the deforestation scenario, repectifully 30,211.98 m³/s and 25,766.65 m³/s for the Madeira river basin, 15,884.84 m³/s and 12,898.89 m³/s for the Tapajós river basin and 12,616.86 m³/s and 10,484.21 m³/s for the Xingu river basin.

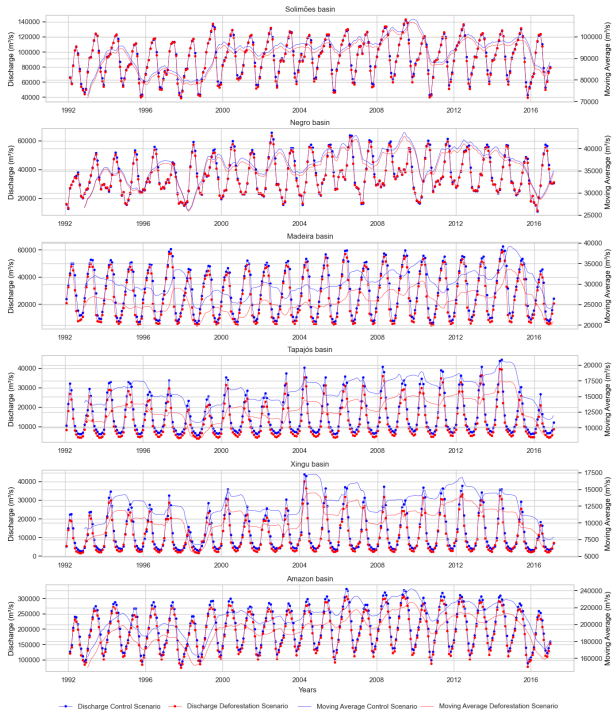

Figure 3: Time series for discharge (lines with points) and moving average 12 months (lines without points) in the Amazon basins (1992–2017). Deforestation scenario in red, control scenario in blue.

The Amazon basin, further downstream, integrates all the flow rates of the sub-basins and showed a reduction in the deforestation scenario, from 207,544.21 m³/s in the control scenario to 193,072.06 m³/s in the deforestation scenario. Details of the average flows are summarized in Table 1.

Basin	Scenario	Minimum	Mean	Maximum	Q1	Q2	Q3
Solimões	Control	40,649.44	92,719.07	142,113.05	72,487.03	94,725.76	113,223.08
	Deforestation	38,857.58	91,348.01	143,285.09	70,512.61	93,872.55	112,887.54
Negro	Control	10,953.42	36,296.00	65,662.60	26,203.76	33,760.39	46,812.96
	Deforestation	11,674.54	35,689.07	63,562.87	26,523.70	33,423.32	44,901.56
Madeira	Control	6,480.43	30,211.98	62,681.17	13,212.21	30,110.03	45,808.05
	Deforestation	4,662.71	25,766.65	59,167.54	9,534.79	22,708.80	41,459.69
Tapajós	Control	5,701.53	15,884.84	44,461.81	7,955.39	11,150.58	22,676.36
	Deforestation	4,005.36	12,898.89	39,799.21	6,016.75	8,691.24	18,558.87
Xingu	Control	2,767.86	12,616.86	43,928.01	4,527.63	7,769.63	19,471.60
	Deforestation	1,659.00	10,484.21	40,135.30	3,269.06	6,934.35	16,594.13
Amazonas	Control	83,992.11	207,544.21	331,603.05	148,099.60	209,520.96	266,342.54
	Deforestation	74,665.83	193,072.06	307,458.13	136,390.69	196,481.46	248,649.87

Table 1: Minimum, maximum and average flows (in m³/s) for each basin including the 1st, 2nd and 3rd quartiles.

The discharge differences (Figure 4 A) for the Amazon River Basin had a negative average (14,472 m³/s). The maximum difference observed was 32,093 m³/s (17.99%) and a minimum of 3,131 m³/s (7.32%). In the Tapajós basin, the average reduction is approximately 2,985 m³/s, while for the Xingu basin, the average is 2,132 m³/s, that represents an average percentage reduction of 21.42% and 18.87% respectively. For the Negro and Solimões river basins, the average difference in flow is much smaller compared to other basins, with a reduction of 606 m³/s (0.98%) and 1,371 m³/s (1.97%) respectively. Otherwise, the Madeira River basin has an average reduction of 4,445 m³/s (18.76%) but the extreme differences reach 21,050 m³/s (61.10%).

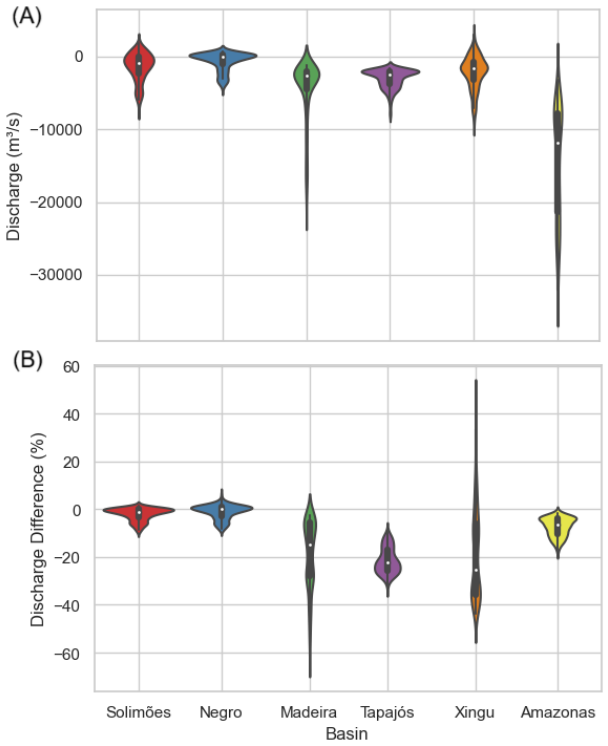

Figure 4: (A) Absolute difference and (B) Percentage difference between discharge in the deforestation and control scenarios for the Amazon basins.

4. DISCUSSION

The analysis of historical water flow patterns in the Amazon River basin reveals distinct behaviours among sub-basins. Those located in the south like Madeira, Tapajós and Xingu have shown a clear reduction in their flows of up to 21.42% in the Tapajós sub-basin. Otherwise, river flow from the sub-basins located to the north such as Negro and Solimões do not seem to have a significant reduction, showing almost no change between scenarios. These results are at odds with some previous studies that found an increase in river flow after deforestation [15].

Hydrological and climate modeling studies of deforestation effects on river flow have reached disparate results, in part, from approaches that include the effects of deforestation on precipitation and atmospheric feedback, such as the present study, in addition to the dependence on the spatial scale of deforestation [7, 16]. One approach is that deforestation increases river flow and surface runoff, mainly due to the reduction of “losses” through evapotranspiration,

and the other perspective suggests that the decrease in evapotranspiration after deforestation does not lead to increased flow, but rather reduces water volumes due to changes in precipitation [16].

There are indications that changes in precipitation occur after more than 40% of the basin is deforested [7, 17]. In this case, the Madeira, Tapajós and Xingu basins in the deforestation scenario have already reached this threshold, since these are located in the "arc of deforestation", an expanding agricultural frontier, marked by intense occupation, agricultural and livestock activities, concentrating around 75% of the deforestation rates in the Amazon [17]. The Negro and Solimões basins, which have a more preserved vegetation cover, saw an increase in flows at some points (see Fig. 4b).

Therefore, extensive deforestation alters the water balance, increasing runoff in river basins. This occurs because atmospheric feedback, caused by the replacement of natural vegetation by plantations and pastures, results in higher albedo and lower water demand [17]. These changes lead to reduced net surface radiation, decreased moisture convergence over the basin, lower water recycling, and reduced regional precipitation and river flow [18]

The significant trends observed in the results indicate the importance of accurate modeling of the Amazon basin considering the diversity of land cover and flow regimes.

5. CONCLUSIONS

The Amazon basin comprises hydrological regions with different flow regimes that vary in space and time. The reduction in forest cover between the control and deforestation scenarios has led to a decrease in river discharge volumes, especially in the southern basins where forest losses crossed the 40% threshold, highlighting the critical role of vegetation preservation in maintaining the region's water resources.

6. REFERENCES

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