Amazon River Basin: I – characterization and environmental impacts due to deforestation

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Abstract

The Amazon River basin is the largest basin of the planet and contributes about 15% of the total freshwater discharge in the world. Among the environmental concerns, habitat modification is considered the most relevant, since the integrity of the aquatic ecosystems and associated coastal/marine ecosystems are strongly dependent on the preservation of the terrestrial ecosystems. In the Amazon basin, deforestation has changed patterns during recent years; besides the "deforestation arc" embracing the south-eastern and eastern borders of the basin, new projects are now dissecting the heart of the basin. At the present deforestation rate, the main biomes - Amazon Rainforest and Cerrado - are expected to disappear in less than 100 years, leading to regional climate changes. Effective policies to preserve the integrity of terrestrial and aquatic ecosystems must focus on the root causes for the ongoing land conversion process.
Keywords: Amazon River basin, hydrological aspects, environmental impacts.

1 Introduction

The Amazon River basin, with a total area of 6,869,000 km^2 (table 1) is the largest basin of the planet and a major heat source in the general atmospheric circulation system [1]. It is totally situated in the tropics, between 5^{o}N and 17^{o}S and occupies more than one-third of the South America continent. Seven countries (Brazil, Bolivia, Peru, Colombia, Ecuador, Venezuela and Guyana) share the basin. The main headwaters are located in the Andes Cordillera, in Bolivian, Peruvian, Ecuadorian and Colombian territories. Headwaters of important tributaries are located in the Guyana and Brazilian Shields, an ancient

Precambrian crystalline basement along the north and south border of the basin. The headwaters of the north are shared by Venezuela, Guyana and Brazil, and the headwaters of the south are in the Brazilian territory.

Table 1: Areas by country that form the Amazon River basin.

	Amazon River Basin	Brazil	Peru	Bolivia
(km^2)	6,869,000	4,746,479	783,066	734,983
%	100	69.1	11.4	10.7
	Colombia	Ecuador	Guyana	Venezuela
(km^2)	405,271	137,380	6,869	54,952
%	5.9	2.0	0.1	0.8

The Amazon River arises in the oriental slope of the Mountain Andes and reaches the sedimentary lands of low declivity in the Peruvian lands, before crossing the frontier with Colombia and Brazil. Although the headwaters of the Amazon are approximately 100 km of the Pacific Ocean, the water runs 6,400-6,800 km towards the opposite direction to reach the Atlantic Ocean. The lack of precision in its length is due to: (i) the uncertainty as to where its main headwater is located and (ii) the difficulty in measuring the extension of long meandering rivers [2]. Most of the Amazon basin altitude is below 250 m and the main humid zones are identified below 100 m. The Amazon River flow (220,800 m^3/s) represents 15% of the total discharge of the rivers in the world [2]. Amazon transports annually 1.2 billion tons of sediments (less than Yangtze River in China and Ganges-Brahmaputra River in India-Bangladesh) [3]. The mouth of the Amazon River is in the Brazilian territory. The discharge of the Amazon River creates in the NE South America coast a large freshwater and salt-water mixture zone with 1,700-mile stretch of low-lying, muddy, and mangrove-fringed. This environment extends from the Orinoco Delta in Venezuela into the Brazilian State of Maranhão and hosts a large number of endemic species, genera and sub-families of fishes [4]. About 15 tributaries of Amazon River have more than 1,000 km and three have more than 3,000 km of extension [2]. Eight are formed by transboundary basins (basins shared by two or more countries) and six (five Brazilian and one Peruvian) are national rivers.

The main geological units of the Amazon basin include high mountains (Andes), old plateaus (Brazilian Central Shield and Guyana Shield) and the extensive lowlands (Central Amazonian Lowlands-Amazon Plain) (fig. 1). These geological structures are of high importance for the chemical characteristics of the water and the aquatic biodiversity. The Amazonian waters are classified as [5]: (i) white, (ii) clear and (iii) black (fig. 2). The high turbidity of the *white-water* rivers reflects a great amount of suspended matter, which lowers the visibility to around 20 cm depth. These rivers (Amazon, Napo, Marañón, Tiger, Juruá, Purus and Madeira) arise from the Andean slopes. The conductivity is high (above 60 micromho/cm), and the pH is 6.5 to 7.

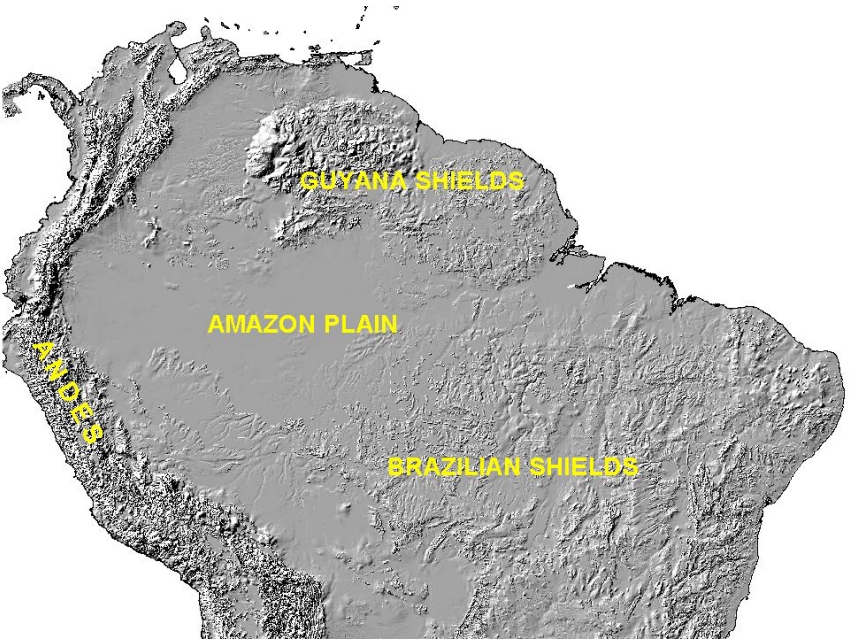

Figure 1: Geological landscapes of Amazon River basin.

Figure 2: Negro (black-waters) and Solimões rivers (white-waters) meet nearby Manaus city in Brazil. The waters flow side by side for 6 km before mixing.

Transparency is a characteristic of the *clear-water* tributaries. The visibility reaches almost 5 m depth for Tapajós, Xingú and Trombetas rivers. They are originated in the crystalline Shields of Guyana and Central Brazil that undergo erosion processes, with few suspended particles to be transported by the water. As a result, these waters are chemically poor, with low conductivity (6 to 5 micromho/cm) and pH 5-6 [5].

A great amount of humic acid in the colloidal form is a characteristic of *black water* rivers, such as Negro (fig. 2) and Urubu. The chemical properties of these waters originate from a sandy soil associated to a type of vegetation known as Campina and Campinarana. Soil porosity allows for high amounts of humic acid colloids to be carried by the river, acidifying the water (pH 4-5.5) and generating the dark appearance. Despite the elevated concentration of organic matter, these waters are chemically purer than white-waters. The conductivity is about 8 micromho/cm [6].

2 Climatic and hydrological characteristics

The Amazon River basin, in spite of its extension, is relatively homogeneous with regards to climatic parameters, such as temperature. This is probably due to small topographical variations, the abundance of the Tropical Rainforest as the main biome, and its position that occupies the north and centre of South America. However, important temporal/spatial variations are observed in relation to other climatic parameters. The area, according to the classification of Köeppen, is characterized by the several climate types: type *Afi* (relatively abundant rains throughout the year, total precipitation in the driest month exceeding 60 mm); type *Ami* (relatively dry season, elevated total annual pluviometric index); type *Awi* (relatively elevated annual pluviometric index, and clearly defined dry season) [7]. The annual rainfall presents great spatial variation (1,000-3,600 mm), exceeding 8,000 mm in the Andean coast [2]. In the Amazon River mouth, the annual rainfall exceeds 3,000 mm, while in the less rainy corridor (from Roraima state through Middle Amazon to Góias state in Brazil) with annual precipitation from 1,500 to 1,700 mm [8]. There are also different patterns of rainfall distribution along the year. As to the thermal regime, the climate is hot, with average temperature varying from 24-26ºC, practically for the entire basin. In the mountainous areas, the average temperatures are below 24ºC and along the Lower and Middle Amazon the averages surpass 26ºC [6]. Annual average evapotranspiration varies from 1,000 mm/yr, in the proximities of the Juruá and Purus rivers, to more than 2,600 mm/yr, close to Amazon River mouth, where the radiation is higher in relation to the lowest cloudiness (presence of winds) and to the lower latitude (line of Ecuador).

3 Main biomes in Amazon River basin

The limits of the Amazon Rainforest Biome extend far from the area of the Amazon River Basin and cover a great part of Suriname and French Guyana to the north. Beyond the limits of the Amazon Forest, the Amazon basin is covered

by an extensive area of *Cerrado* and Savannah in the headwaters of the Brazilian and Guyana Shields [9] (fig. 3). The biodiversity for the Cerrado Biome, including all its physiognomic forms, is estimated at 160,000 species of plants, animals, and fungi. Endemic higher plants have recently been estimated as 4,400 species, 1.5% of the world's total vascular plant species. Endemic vertebrates range from 3% (birds) to 28% (amphibians) of the species recorded [10].

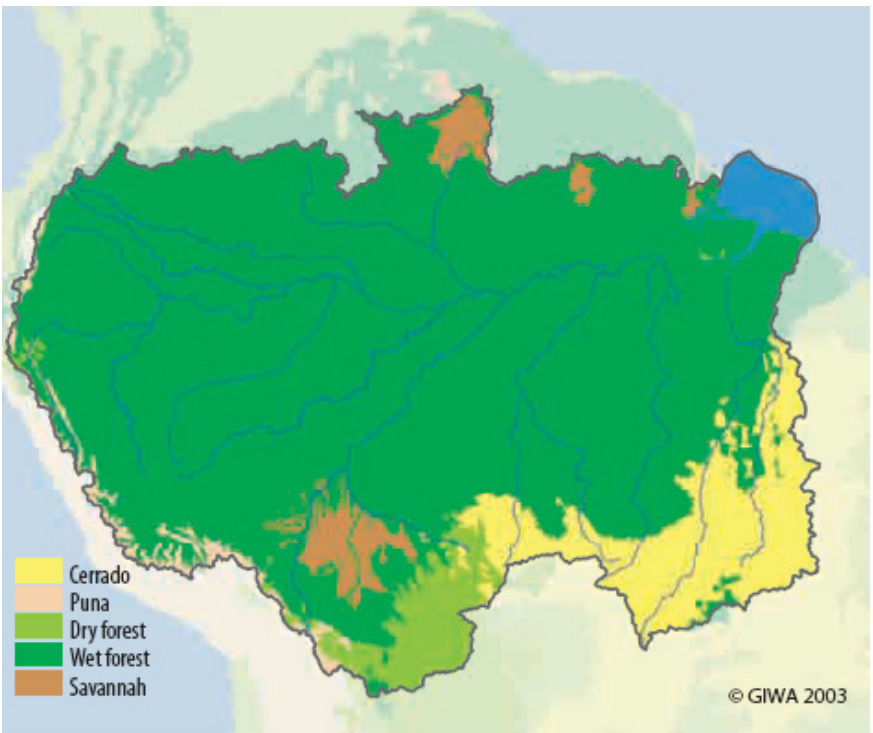

Figure 3: The main habitats of Amazon River basin [11].

The cloud forest is a special type of vegetation that grows between 1,500 m and 3,000 m on the slopes of the Andes and is exposed to constant moisture-laden winds. The vegetation changes abruptly at altitudes above 3,000 m, the climate becomes dry and cold with predomination of a vegetation type known as *Puna* composed mainly of grasses and bushes [2].

4 Main tributaries of Amazon basin and associated impacts

Amazon Plain (main rivers: Solimões, Purus, Tapajós, Xingú): One of the most important environments of Amazon Lowlands is the floodplains named *várzea* and *igapó)*. These areas extend along the rivers and are almost entirely flooded

during the rainy season. This environment shelters endemic species of several taxonomic groups and also maintains a great biomass of fish species [6, 11]. It is difficult to determine accurately the areas that are periodically flooded because of the complexity of the flooding regime, which is influenced by local rainfalls, river overflow and tides [2]. It is estimated that in Brazil, there are 70,000 to 100,000 km^2 of floodplains and more than 100,000 km^2 of lakes and swamps [2]. In Bolivia, flooded areas occupy 100,000 to 150,000 km^2 [12]. The floodplains of the *white-water* rivers are relatively preserved above Purus River mouth (Brazil), but the floodplains of Solimões and Amazon rivers are significantly altered, mainly in the area around Santarém, State of Pará (Brazil). In the area between the mouths of Tapajós and Xingú rivers (Brazil), and the mangrove ecosystem, *várzea* of tides are observed. In spite of the fact that mangrove has been intensely exploited by logging companies and small farmers [13, 14], this ecosystem is still preserved in the Breves channels as well as in the inner delta of Amazon River. Fields flooded by the rain are quite typical in the bigger islands of the Amazon mouth as well as in the coastal area of Amapá and Pará states, one of the most threatened areas of the entire Amazon plain due to human occupation, dams, channels, cattle and agriculture expansion [15].

Guyana Shields (main rivers: Negro, Branco, Trombetas, Jari and Araguari): The Negro River is the largest one that drains the Guyana Shields. Some important floodplains are the Anavilhanas Archipelago and the nameless archipelago between Padauari/Demini and Branco rivers. These areas are flooded by Negro River overflow. The forest periodically flooded by rainfall forms an environment with great contiguous areas close to the margins of the Negro and Branco rivers as well as in the headwaters of its tributaries. In the Branco River, the Savannah periodically flooded by rainfall favours cattle and rice cultivation, an area prone to fires during the dry periods. The falls and headwaters of the rivers suffer of severe environmental impacts due to mining.

Brazilian Shields (main rivers: Tocantins, Xingú, Tapajós, Madeira, Purus, Juruá): The Tocantins River has one of the most impacted sub-basins of the Amazon basin. It hosts two large hydroelectric dams, one in the Tucuruí city and the other in Lageado city. The ichthyofauna of the Xingu River upper the waterfall of Altamira dam is completely different from the lower. Although the fauna is not well-known, the main impacts are related to mining and agriculture in its headwaters. Tapajós River is the most impacted one by mining activities in its headwaters as well as by dredging but the ecology is not sufficiently known to evaluate the severity of the impacts. Madeira River (one of the most studied tributaries) has headwaters located in the Andean slopes but sub-basins that drain the Brazilian Shield. The impacts are due to: (i) mining, (ii) construction of Samuel's hydroelectric dam in the Jamari River, and (iii) agricultural activity in its headwaters. The impacts of mercury contamination and mining dredges on the migration of catfishes have not been properly assessed. The Purus and Juruá (state of Acre), are *white-water* rivers, with headwaters below 500 m of altitude. In the past they were connected with the Andes. The drainage changed in the geological past and now those rivers are draining a landscape formed by an older alluvium deposit. The rivers carry large loads of suspended solids and have one

of the largest floodplain areas of the Amazon, explored by professional fishermen in Manaus city [16]. Indians/local communities have been the main reason for creating protected areas for extractive activity and preservation of ethnic groups [2].

Andes (main rivers: Madeira, Marañón, Putumayo-Iça, Caqueta-Japura, Ucayali): The Madeira River is formed by Mamoré, Beni and Madre de Dios rivers and it is the main source of sediments of the Amazon basin. Madre de Dios River is one of the biggest alluvial gold sources in Amazon basin [17]. The foothills of the Andes are formed by a sequence of habitats, which change from the snowfall streams to the large rivers in the base of the mountains. The biodiversity increase downstream, but chemical processes and endemic species make the high portion an important area. The confluence of the rivers from the Andes and the Brazilian Shield is observed along a succession of rapids and falls located above the Porto Velho city. Below this point, the river is calm and navigable. The largest floodplain areas are located in the Bolivia territory, in the flooded Savannah. These areas are flooded by rivers and by local rainfall [2]. The Andean rivers Putumayo-Iça and Caqueta-Japura are the most preserved sub-basins of the entire Amazon basin having mainly indigenous inhabitants. However, the Andean zone has a similar history of the Madeira, Ucayali and Marañón rivers: the foothill region is an impacted area with the presence of colonization by the road. The area is a major coca-growing region, which has caused deforestation of large areas. Fishing is an important activity in the lower river. Gold exploitation occurs at the Colombian and Brazilian borders [2, 18].

5 The main cause of habitat modification: deforestation

Among others, (i) large extensions affected, (ii) the unknown degree of the severity of the impacts and (iii) the irreversibility nature of habitat destruction due to deforestation are the main reasons for considering this a priority concern in Amazon River basin. The economic pressures on the Amazon River basin [19] has been expressed by modifications of large extensions where terrestrial ecosystems, mainly the Amazon Rainforest and Cerrado have been substituted by agricultural and cattle grazing fields, which in turn, is likely to have a significant impacts on aquatic ecosystems. Unfortunately these impacts have not been fully-accessed. Since the 1960s, large-scale deforestation has been concentrated in the eastern and southern portions of the Amazon River basin inside Brazil, along the “arc of deforestation”, as well as along the main rivers. However, during recent years, the heart of the basin has been dissected by new highways and power lines that provide access to previously remote areas [20]. In the 1990s and 2000s, forest fires have ravished the Amazon. Many of these fires, which are set by land clearers to expand the agriculture frontier, spread accidentally into the virgin rainforest. Moreover, the severe drought provoked by the 1997-1998 El Niño threatened to increase the flammability of the forest adjacent to the agricultural areas of the eastern-southern regions of the basin, creating the potential for massive ecological losses through accidental fires.

During 20-year period (1978-1998) the mean rate of gross deforestation in the Brazilian portion of Amazon Rainforest was 0.66%/year, representing 13.2% of the Brazilian primary forest converted to agriculture and pasture [21]. Colombia, Venezuela, Ecuador and Bolivia have also registered high rates of deforestation [22]. In recent years (2001-2003), the Brazilian Rainforest experienced the highest annual rates of deforestation observed during a 15-year period (1988-2003), excluding the record of 1994-1995, when 29,059 km^2 of the original Rainforest were destroyed (fig. 4). At the present rate, the Rainforest is expected to disappear in less than 100 years [23]. Additionally, climate changes are foreseen as a result of deforestation.

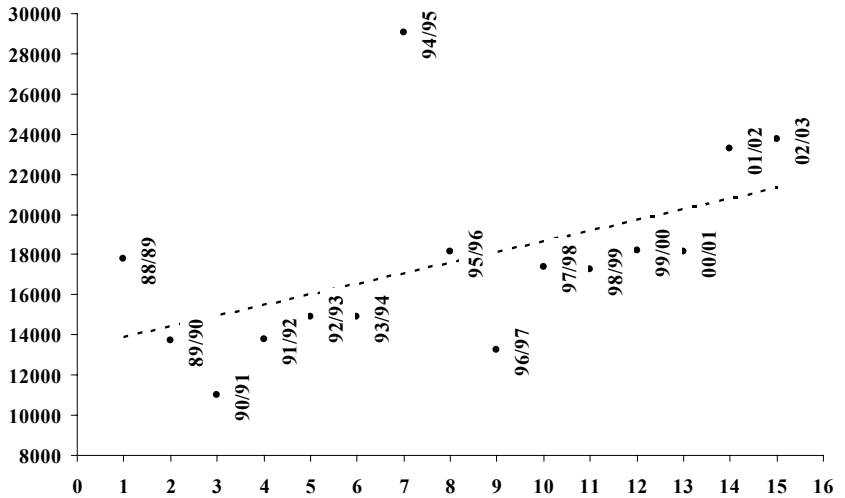

Figure 4: Mean rate gross deforestation in Amazon (km^2/yr) during a 16 year period obtained from satellite data [21].

Based on atmospheric general circulation model (AGCM) simulations, higher surface temperatures and lower evapotranspiration rates are two major effects of complete Amazon deforestation [22]. Cloud cover comparisons of deforested and forested areas suggest that a regional climate change is already underway in the most deforested part [1].

Differently from the Amazon Rainforest, very little international attention has been given to the Cerrado, despite the fact that it is the 2nd biome in importance for the Amazon River basin, one of the most threatened in South America that covers 22% of the Brazil's surface area (2 million km^2). The pressure over this biome is expressed by the fact that the Cerrado spatial distribution (fig. 3) is almost coincident with the "deforestation arc". Nearly 50% of the Cerrado is currently under direct human use, and about 35% of its total natural cover has already been converted into planted pastures and crops [10]. The average annual

rate of land clearing in the Cerrado during 1970-1975 was nearly twice the estimated rate for the Amazon Rainforest during 1978-1988 [10].

6 Conclusions

The Rainforest and the water cycle are known to be closely linked together. The conservation of terrestrial habitats is therefore indicated as a priority action in order to guarantee aquatic ecosystem integrity and control of the foreseen climate changes. Unless a significant reduction in the current deforestation rate in both Amazon Rainforest and Cerrado Biomes occurs, the Amazon River basin is likely to loose most of its original cover in less than 100 year period, representing large portion of the world biodiversity. The regional and global climate consequences are not fully addressed. Regardless all research initiatives carried out in the basin, the severity of the impacts is not clearly known. However, due to the basin extension and complexity, more important and urgent than conducting a comprehensive assessment of the environmental impacts due to deforestation - a necessary but time and resource-consuming effort - is the identification of the main socio-economic factors and driving forces that have increased deforestation during recent years [18], regardless all efforts to promote environmental laws compliance. A clear understanding of these factors must precede the decision-making process to be carried out by those countries sharing the basin, in order to achieve an alternative and less-destructive model for the economic development of the region.

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