Hydrological Response Assessment of Land Cover Change in a Peruvian Amazonian Basin Impacted by Deforestation using the SWAT Model

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Madre de Dios River, 2020

RIVER MINING

Project 2020-2023

“Impacts of alluvial mining in the Madre de Dios river basin: physical effects and mitigation planning”

PARTNERSHIPS FOR ENHANCED ENGAGEMENT IN RESEARCH (PEER)
Cycle 8 (2019 Deadline)

Impacts of alluvial mining in the Madre de Dios Basin: physical effects and mitigation planning

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U.S. Partner: Eddy Langendoen, United States Department of Agriculture/ Agricultural Research Service
Project Dates: January 2020 - June 2022

Project Website: https://sites.google.com/utec.edu.pe/rivermining/ (includes links to research briefs under the Publications tab)

Project Overview:

Despite many efforts in the Madre de Dios Basin to estimate the impacts of alluvial gold mining with regard to mercury concentration, deforestation, and socioeconomic implications (e.g., human trafficking, tax evasion), very few investigations have been conducted to understand the effects of extensive alluvial mining operations on the rates of sediment supply and morphodynamics of the rivers in southeastern Peru and on the spatiotemporal distribution of mercury concentrations. This is a time-sensitive project because mining activities advancing rapidly, producing drastic physical alterations to river systems, and the Peruvian National Government lacks adequate impact assessment methodologies of alluvial mining concessions, many of them already operating. Currently, basic analyses with satellite imagery feature these assessments, rather than analyses with multi-temporal and historical data to elaborate predictive models to determine principal sources and sinks of mercury across the watershed and gold deposits that indicate potential areas to be targeted for mining. The location and topography of the Madre de Dios headwaters, where alluvial gold mining occurs, create a high potential for escalating this environmental and public health problem, putting large portions of the basin at risk. There is a critical need to provide both a baseline of river morphodynamics and linkages between aquatic ecosystems and landscapes to develop not only decision-relevant indicators for environmental quality but also methods for identifying trends to determine environmental quality in the future.

This PEER-supported project will involve an integrated assessment of a coupled natural-human system in southeastern Peru where there is an urgent need to develop science-based sustainable practices and conservation of natural resources. By combining state-of-the-art techniques in field measurement, remote sensing, and mathematical modeling of riverine processes, this project will explore the interactions between flow, sediment transport, and channel change in rivers in association with the distribution of mercury along the food chain. The outcomes will provide useful insights for land managers and decision makers on river morphodynamics and function, a crucial gap in the understanding of rivers, currently a critical national priority for Peru. Local authorities and partners working in the region will be encouraged to share their knowledge about sediments in rivers in the area, as well as gaps that can be fulfilled with this research. They will also be encouraged to incorporate best practices and environmental standards in their management efforts and to include river morphodynamics as a component of natural resource management. Developing a more sustainable approach for the use and monitoring of the environment will promote and support responsible economic activity in the Amazon region through viable economic alternatives to illegal exploitation of natural resources and the development of alternative processes for extracting gold with the least possible negative impact on the surrounding ecosystems.

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Main objectives of River Mining

1. Estimate and analyze suspended and bedload sediment concentration before and after mining activities.

2. Assess the impact of the land cover change due to deforestation in the hydrology of the watershed.

3. Assess potential environmental impacts from extractive industries based on the spatiotemporal dynamics of rivers.

4. Develop methodologies and tools to measure, monitor, and predict future environmental impacts and degradation.

5. Transfer of knowledge to decision makers and the establishment of local capacities with the use of methodologies and tools to improve the assessment and monitoring of Amazon headwaters rivers.

Madre de Dios : Biodiversity hotspot


National Reserve of Tambopata

Source: Actualidad Ambiental


Bahuaja Sonene National Park

Source: Mongabay


Manu National Park

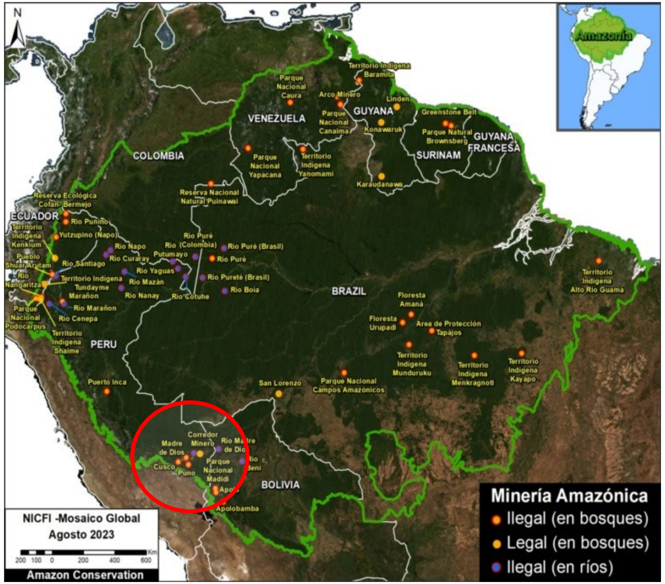

Amarakaeri Community Reserve

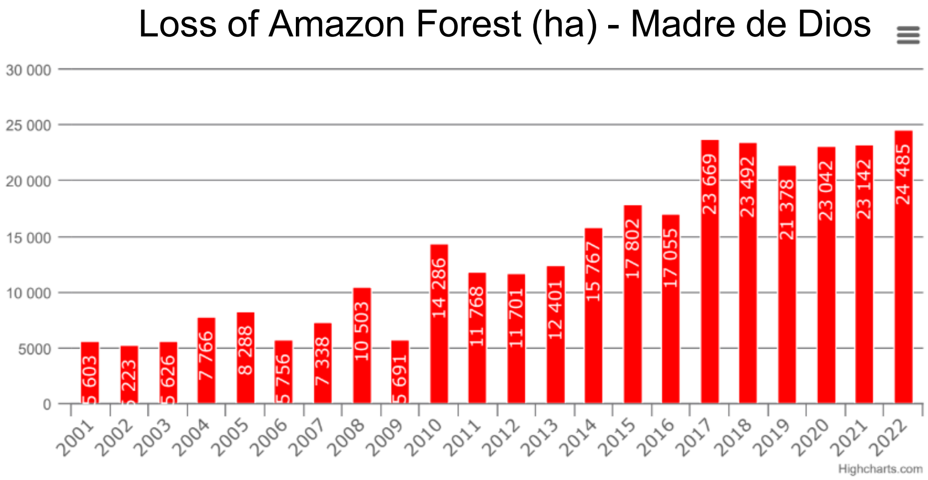
Foto: IIRSA SUR

Madre de Dios : Biodiversity hotspot

Madre de Dios region

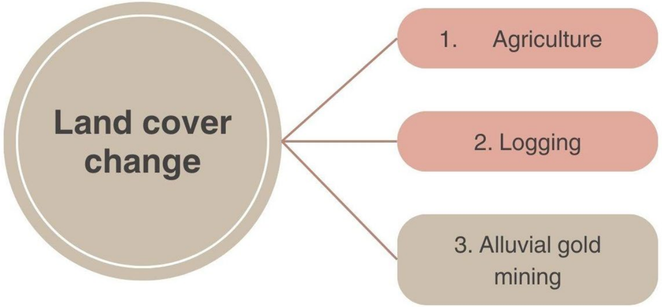
- **The main causes of deforestation are agriculture, logging and alluvial mining.** From 2002 to 2023, Madre de Dios lost 278 kha of humid primary forest. Total area of humid primary forest in Madre de Dios decreased by 3.5% in this time period.
- Mining and deforestation have coexisted in Madre de Dios for **more than 40 years.**





What are the hydrological impacts of deforestation ?

- The intense rainfall typical of the humid tropics and the deforested or bare soil results in an intensification of soil erosion processes, which causes an increase in sediment transport to water bodies. The presence of excess sediment in rivers causes **siltation, overflow and flooding, as well as affecting aquatic life.**



Land cover change

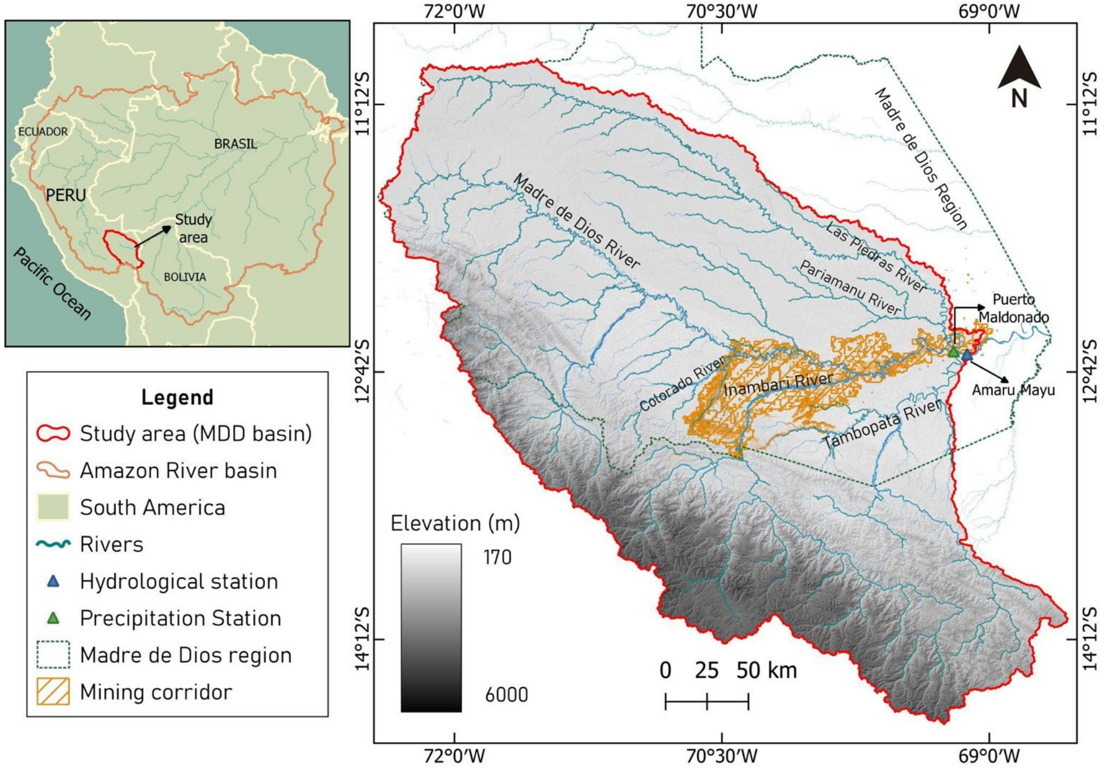
1. Agriculture
2. Logging
3. Alluvial gold mining

Source: Calloquispe Flores 1,130 hectares of crops affected by floods, El Comercio March 13, 2024.

Methodology

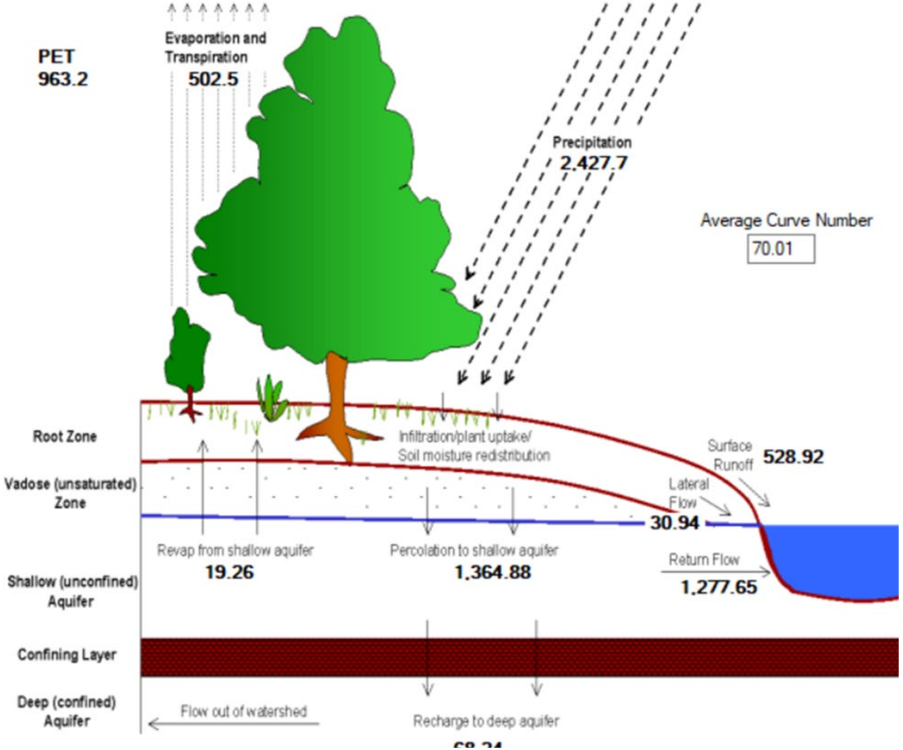
Study Area

- The study area covers 90 7350 km^2.
- The altitude of the study area varies from 170 to 6000 meters above sea level.
- The delimitation of this basin was made taking the “Amaru Mayu” hydrometric station as the oulet point.



Methodology

SWAT Model - Soil and Water Assessment Tool (2012 version)



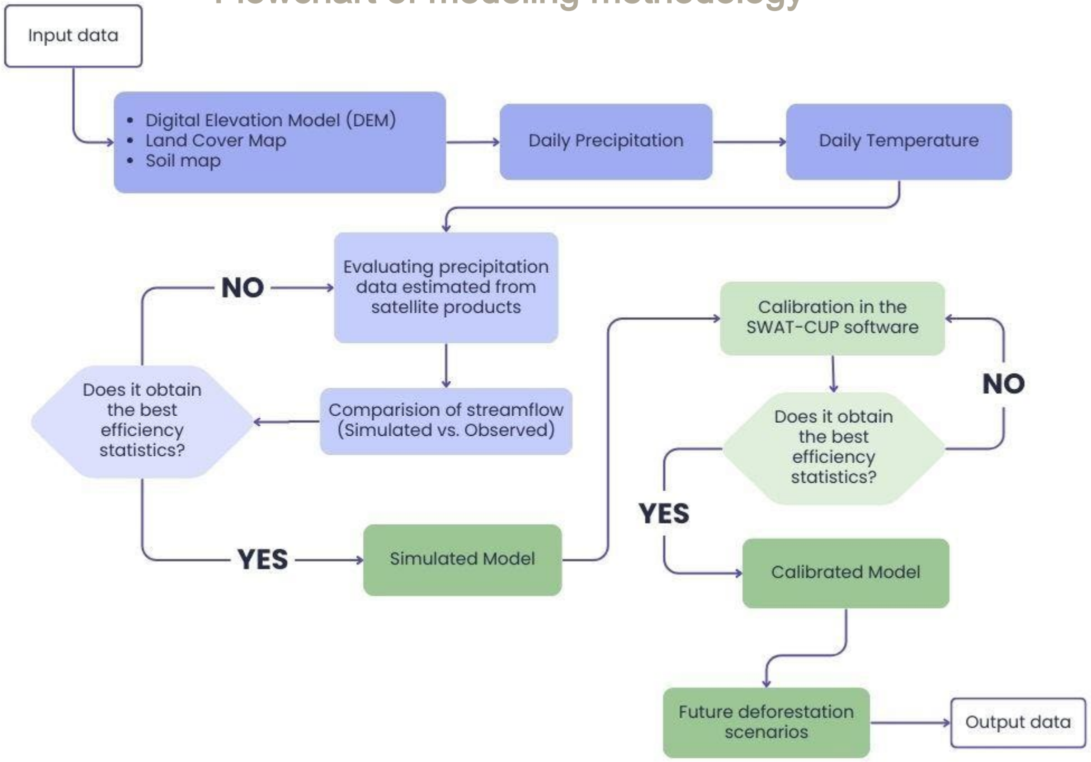
Water balance

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw})$$

- **SWt** is the final soil water content (mm H_2O).
- **SW**$_0$ is the initial water content of the soil on day i (mm H_2O).
- **Rday** is the amount of precipitation on day i (mm H_2O),
- **Qsurf** is the amount of surface runoff on day i (mm H_2O)
- **Ea** is the amount of evapotranspiration on day i (mm H_2O),
- **Wseep** is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O).
- **Qgw** is the amount of return flow on day i (mm H_2O).

03. Methodology

Flowchart of modeling methodology



Input data

- Digital Elevation Model (DEM)
- Land Cover Map
- Soil map

Daily Precipitation

Daily Temperature

Evaluating precipitation data estimated from satellite products

Comparision of streamflow (Simulated vs. Observed)

Does it obtain the best efficiency statistics?

NO

YES

Simulated Model

Calibration in the SWAT-CUP software

Does it obtain the best efficiency statistics?

NO

YES

Calibrated Model

Future deforestation scenarios

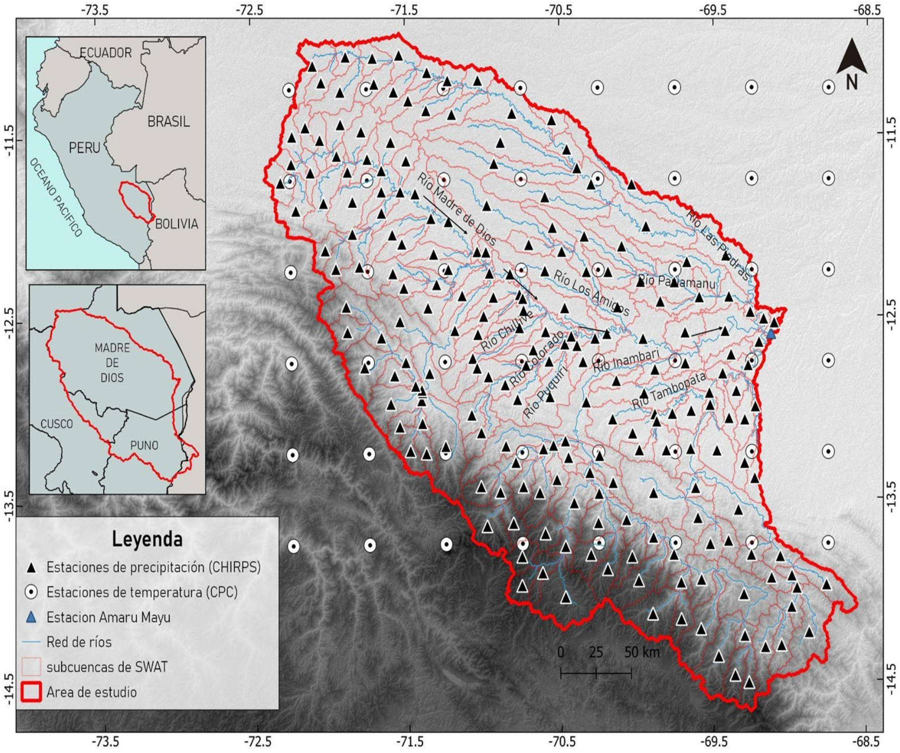
Output data

Summary of model input data

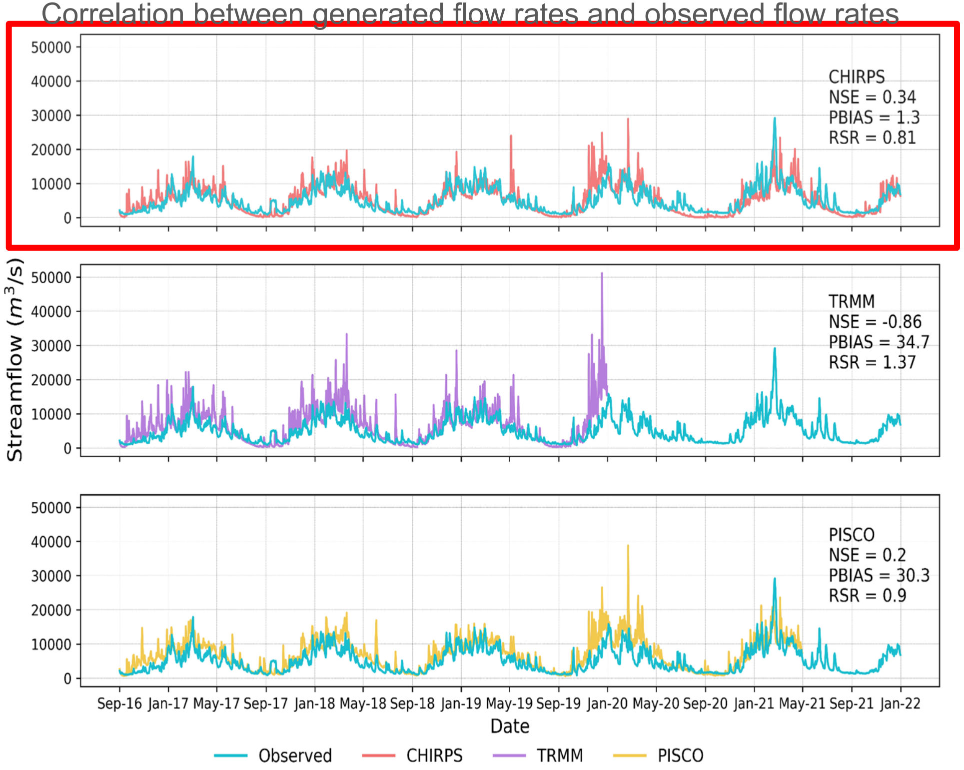
Input data	Spatial resolution	Source
Precipitación	0.05° (∼5 km)	CHIRPS v2.0
Temperatura	0.05° (∼55 km)	CPC Global Unified Temperature
DEM	30 m	SRTM
Soil type	1: 5,000,000	FAO v3.6
Land cover map	∼0.5 km	GLCC-USGS v2

03. Methodology

Precipitation datasets

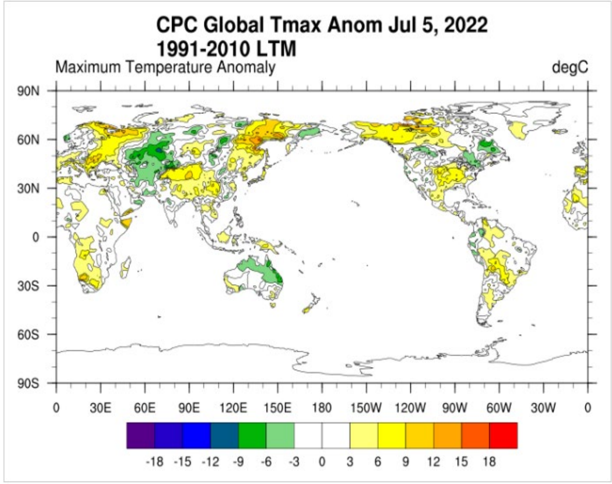


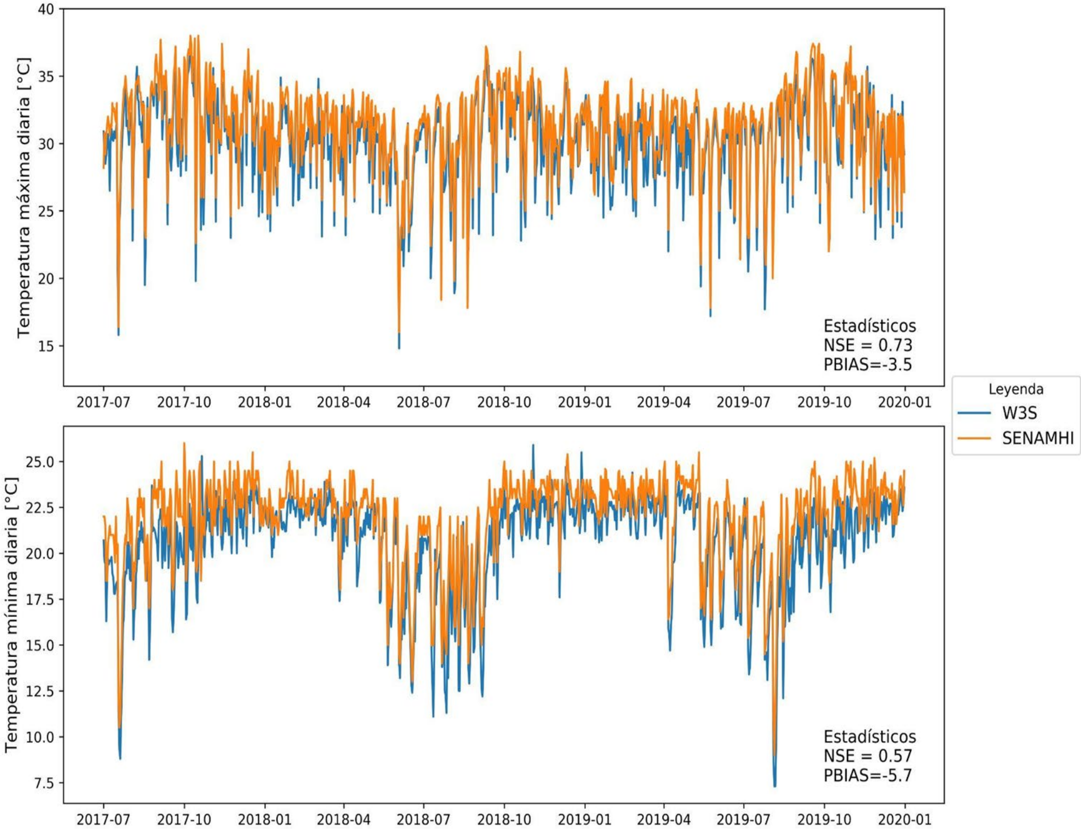
Correlation between generated flow rates and observed flow rates



03. Methodology

Temperature Dataset - CPC Global Unified Temperature data provided by the NOAA



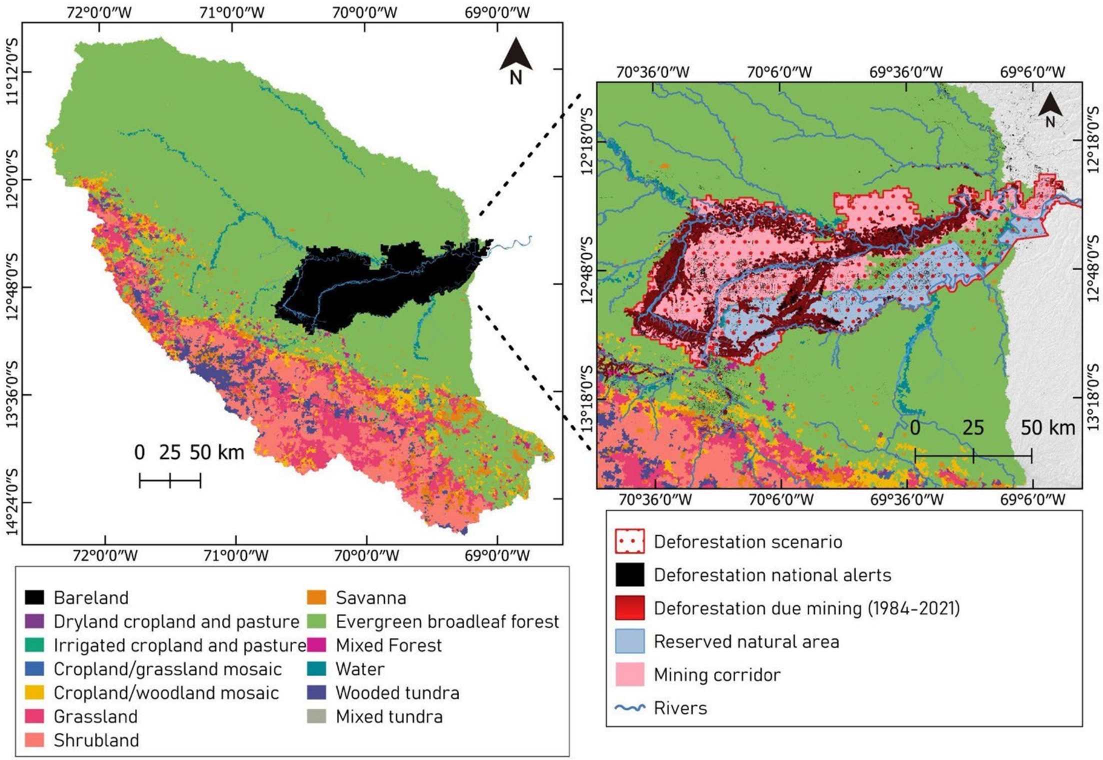


- Time coverage
  Daily from 1979/01 to 2022/12
- Spatial coverage
  0.50 - degree latitude x 0.50 - degree longitude grid (720x360) 89.75N-89.75SN, 0.25E-359.75E

03. Methodology

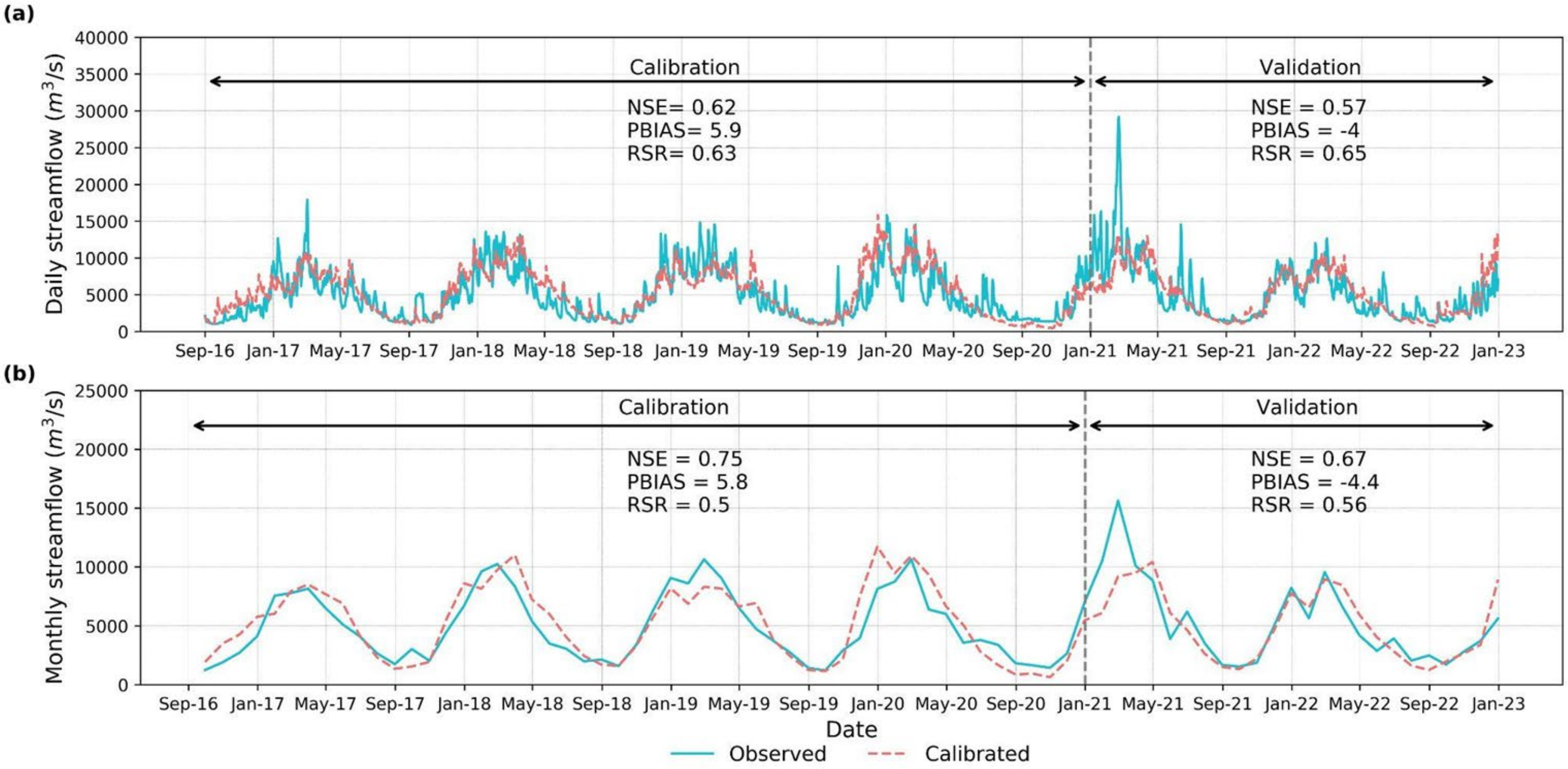
Deforestation scenario

- Replacement of **forest to bare soil**
- The total area covers 8109 km² equivalent to **12% of the total study area.**
- This area includes **the highest density of deforestation alerts** issued by the Geobosques project.
- There were 3,171,743 deforestation alerts reported in Madre de Dios between 1st of January 2021 and 1st of January 2022, covering a total of 38.2 kha.



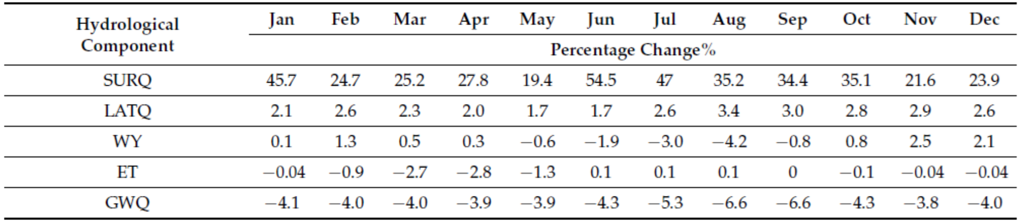
04. Results

Comparison of simulated and observed flow rates

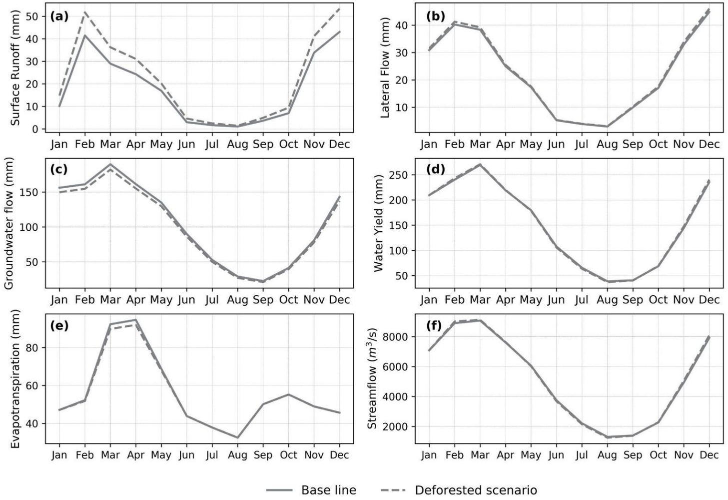


04. Results

Response of hydrological variables - Monthly averages



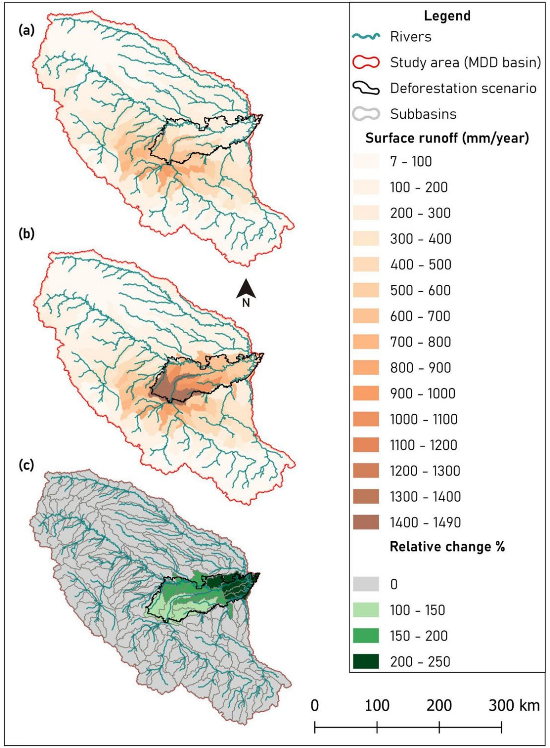
Hydrological Component	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Percentage Change%											
SURQ	45.7	24.7	25.2	27.8	19.4	54.5	47	35.2	34.4	35.1	21.6	23.9
LATQ	2.1	2.6	2.3	2.0	1.7	1.7	2.6	3.4	3.0	2.8	2.9	2.6
WY	0.1	1.3	0.5	0.3	−0.6	−1.9	−3.0	−4.2	−0.8	0.8	2.5	2.1
ET	−0.04	−0.9	−2.7	−2.8	−1.3	0.1	0.1	0.1	0	−0.1	−0.04	−0.04
GWQ	−4.1	−4.0	−4.0	−3.9	−3.9	−4.3	−5.3	−6.6	−6.6	−4.3	−3.8	−4.0

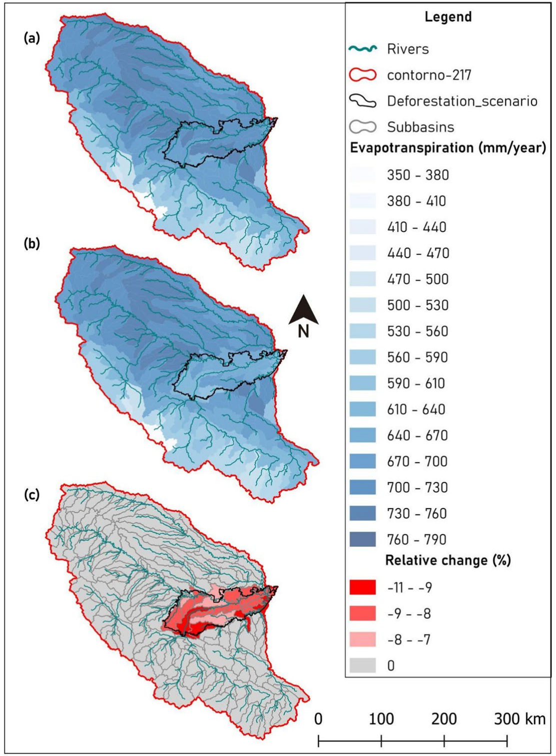


- Surface runoff **increased by 33% with the highest peaks during the dry season (May to September)**
- Evapotranspiration **decreased notably during February to May, with a reduction of 2% in average.**
- Lateral flow **has experienced a slight increase of 3%, primarily during the period from July to December.**

04. Results

Average Annual Means at Subbasin Scale





- **An average annual increase of 164% in surface runoff** was observed within this area. Among these, the subbasin of the Inambari River demonstrated a notable increase of 187%.
- The subbasins that encountered alterations experienced a **decrease of 7% in their annual average evapotranspiration**

05. Conclusions

- SWAT proved to be a feasible tool to successfully simulate river flow in the Madre de Dios basin, a "good" calibrated model was obtained at the daily level and "very good" at the monthly level (NSE = 0.75, PBIAS = 5.8%, RSR = 0.6).

What are the hydrological impacts of deforestation ?

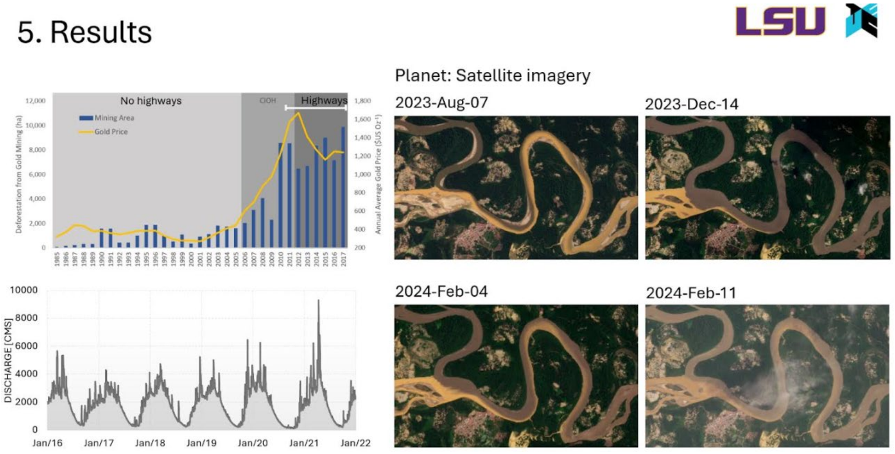
- In particular, surface runoff records the most significant increase , outperforming the other components on both monthly and annual scales. This change can be attributed to the increased availability of water in deforested areas, which leads to an increase in infiltration and surface runoff processes

- Evapotranspiration also results in a decrease both in monthly averages throughout the basin and in the deforested area. This change can be attributed to the reduction of the forest interception process

05. Conclusions

- The generated flows are being used for studies of sediment concentration change in rivers and their geomorphological variability as well as the mobility of mercury concentration in sediments.

- In order to improve calibration it is essential to study soil properties and vegetation types with advanced remote sensing methodologies.



5. Results

Planet: Satellite imagery

2023-Aug-07

2023-Dec-14

2024-Feb-04

2024-Feb-11

06. Next steps…

- Ways in which this study can be enhanced
    - Generating **soil moisture dataset** from remote sensing (SMAP…)
    - **Validating evapotranspirations** datasets from space borne remote sensing
    - Calibrating the model with **more than one variable**
    - Include additional analysis such as **deforestation predictions using remote sensing** to better understand the dynamics of land use change in the Madre de Dios watershed.

remote sensing

MDPI

Article

Hydrological Response Assessment of Land Cover Change in a Peruvian Amazonian Basin Impacted by Deforestation Using the SWAT Model

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Thank you !

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