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D1.5 Report on catchment-scale hydrological models for the CELAC focal DRNs

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Abstract

This document synthesizes the hydrological research carried out at the three CELAC drying river networks (DRNs) investigated in the context of the DRYvER project. Given the differences in data availability and monitoring capability at each DRN, different approaches have been chosen to investigate hydrological inttermittency across the three DRNs. A conceptual model of streamflow generation using spatially distributed field observations of water level, isotopic and geochemical tracers has been developed at the Ecuadorian DRN (Cube River basin). It was concluded that geology through bedrock permeability plays a key role on hydrogical intermittence occurrence across this DRN. Measurements of discharge and spatial patterns of hydrological inttermitency have been developed at the Bolivian DRN (Upper Chico River basin). Analysis of these data are expected to increase knowledge about how temporal changes in discharge influence the spatial varibility of flow conditions (dry, pool, low) in the DRN. Hydrological and remote sensing observations in combination with physically based hydrological modelling have bee used to investigate hydrological intermittence at the Brazilian DRN (Umbuzeiro River basin). A methodological framework for the delineation of hydrological seasonality at the DRN has been developed. Results of the hydrological model show that although discharge has been succesfully reproduced, intermittence patterns are poorly represented by the model simulations. Remote sensing data, specifically Unmanned Aerial Vehicle (UAV) information collected in the framework of the project is expected to help undertand hydrology intermittence at the study area. Altogether, the data collected and results from research carried out at the CELAC DRNs help to further understand hydrological intermittence in currently understudied Neotropical environments.

Keywords: Neotropics, hydrology, intermittence, Chocó Forest, Caatinga, Inter-Andean Valley

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1 **Use one of the following codes:**
R=Document, report (excluding the periodic and final reports)
DEM=Demonstrator, pilot, prototype, plan designs
DEC=Websites, patents filing,press & media actions, videos, etc.
OTHER=Software, technical diagram, etc.
ORDP : Open Research Data Pilot

2 **Use one of the following codes:**
PU=Public, fully open, e.g. web
CO=Confidential, restricted under conditions set out in Model Grant Agreement
CI=Classified, information as referred to in Commission Decision 2001/844/EC.

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Introduction

Intermittent streams do not contain flowing water during part of the year because of strong seasonal changes in surface runoff and groundwater levels[1,2]. These streams represent more than half of the stream network length globally[3] and are unique habitats for freshwater biodiversity[4]. Even though the temporal cessation of flow in intermittent streams influences biodiversity and ecological processes causing a temporal rearrangement of freshwater communities[4,5], hydrological research in these systems is still limited[1].

Knowledge regarding the factors causing the temporal variation in flow conditions in intermittent streams in the Neotropics still lacks despite their rich biodiversity and high vulnerability to changes in land use and climate[6]. As a result, the DRYvER project seeks to fill this knowledge gap by investigating the hydrology of drying river networks in three CELAC countries: Ecuador, Bolivia, and Brazil. Such knowledge will not only allow to improve the comprehension of the hydrological dynamics of intermittent river networks in the neotropics, but also to enhance the management of local water resources. This report summarizes the data collected and the main findings generated in the context of the DRYvER project in the CELAC partner countries.

Hydrological Intermittence in CELAC Drying River Networks (DRNs)

Ecuador DRN: Cube River

Context

The Cube River basin (Fig. 1.) is located in northwestern Ecuador within the Chocó Forest ecoregion. The region is considered a global priority for conservation and research[7]. The region has one of the greatest densities of biodiversity and endemism on the planet[6,8], but has also suffered from intense changes in land cover in the last half century, including deforestation, agricultural expansion, cattle grazing, and afforestation with exotic tree species[9,10]. Long (6-7 months) dry periods in the region result in intermittent streamflow conditions[11]. This hydrological seasonality in turn influences key biological and ecological processes, and water availability and quality for the local population.

Despite of the importance of the Chocó Forest water resources, the hydrologic regime of rivers and streams in this ecoregion has not yet been studied. This factor together with the lack of long-term hydrometeorological records in the regions hampers the capacity to use conventional hydrological models to understand the factors driving hydrological intermittence and modelling the impacts of climate change in the region. Therefore, hydrological research at the Ecuadorian DRN focused on identifying the main water flow paths contributing to flow generation across the intermittent hydrological system of the Cube River basin. To this end, the collection of hydrological data at high temporal frequency (sub-hourly) in combination with geochemical and isotopic information collected during the six WP2 biodiversity sampling campaigns were used to develop a conceptual model of the factors controlling hydrological intermittence at the Ecuadorian DRN. In the following we include the results of the collected hydrological and hydrogeochemical information in the Cube River basin, and the developed conceptual model of hydrological intermittence based on those data.

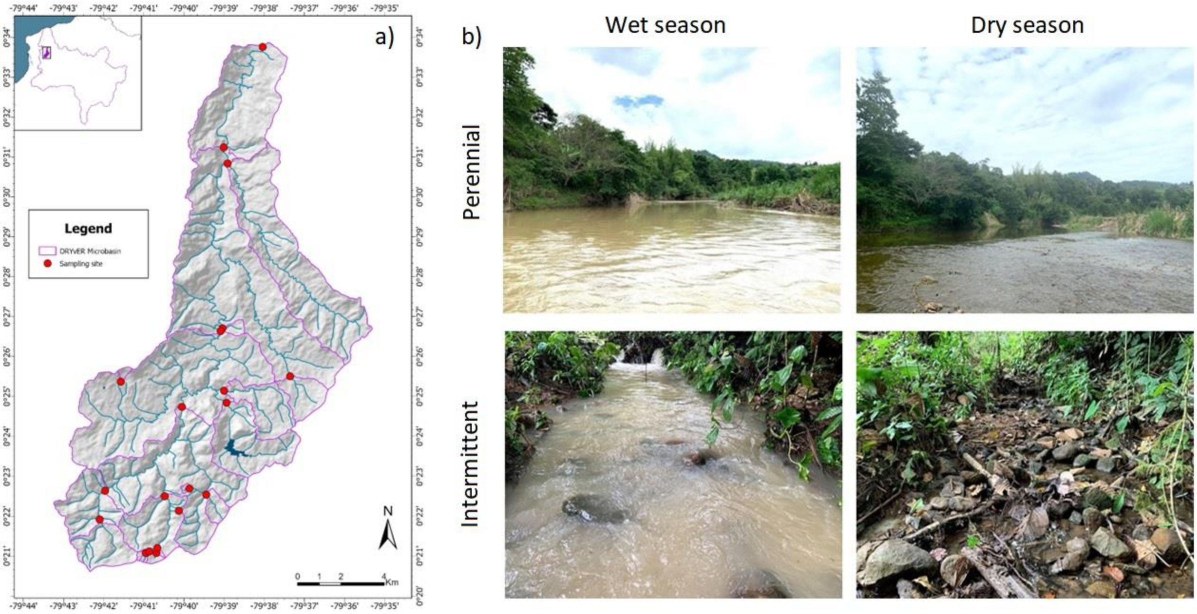


Figure 1. a) Map of the Cube River basin (159 km^2) located in the lower part of the Esmeraldas River basin (purple line in the inset map) showing the drainage network and the 20 sampling sites where hydrogeochemical data were collected during six monitoring campaigns in the period January-December 2021. b) Pictures of a perennial site (upper part) and an intermittent site (lower part) monitored during the wet and dry seasons in 2021.

Hydrological characterization

Water level loggers were deployed at five of the 20 sampling sites monitored within the Cube River basin. The water level data allowed to identify differences in hydrological dynamics of intermittent and perennial streams during 2021. The hydrographs of intermittent and perennial streams are shown in Fig. 2. Total flow for both sites was partitioned into baseflow (Q_B), subsurface flow (Q_{SS}), and overland (Q_O) flow. Results show that Q_{SS} and Q_O are higher in the intermittent stream as compared to the perennial stream (Fig. 2). Contrary, Q_B is lower in the intermittent stream in relation to the perennial stream. The recession times of baseflow (k_B) and shallow subsurface flow (k_{SS}) are lower in the intermittent stream and higher in the perennial stream.

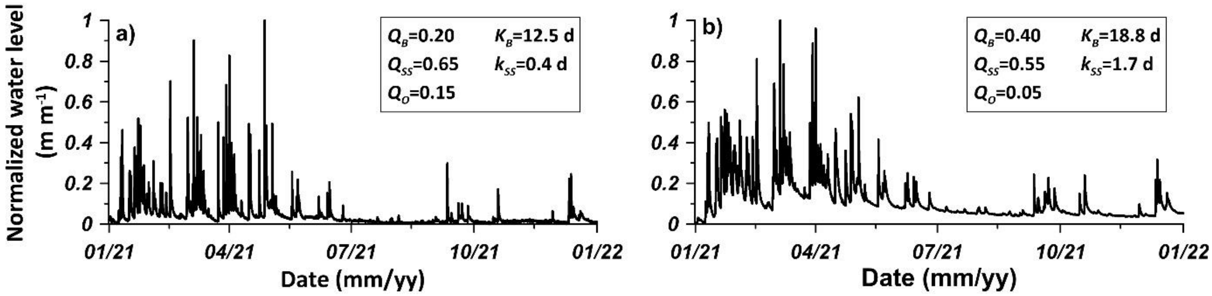


Figure 2. Hourly time series of normalized water level representing the hydrological behavior of a) intermittent and b) perennial streams within the Cube River basin during the period January-December 2021. Abbreviations: Q_B=baseflow contribution to total streamflow; Q_{SS}= shallow subsurface flow or interflow contribution to total streamflow; Q_O=overland flow contribution to total streamflow; k_B=recession time of baseflow; k_{SS}=recession time of shallow subsurface flow or interflow.

Isotopic characterization

Water samples for analysis of the stable isotopic composition of hydrogen-2 (δ^2H) and oxygen-18 ($\delta^{18}O$) were collected during the six sampling campaigns of the DRYvER project carried out in 2021 at the Ecuadorian DRN. The stream water $\delta^{18}O$ isotopic composition for the 20 sampling sites collected during the wettest (April-May, 2021) and driest (December, 2021) periods are shown in Fig. 3. The isotopic data shows that small intermittent streams located at the upper part of the Cube basin present depleted (more negative) $\delta^{18}O$ values during the wet season (sites 1-10 in Fig. 3a) than larger perennial sites located in the lower part of the basin (sites 11-20 in Fig. 3a). During the dry season, all catchments present similar isotopic composition regardless of their geographical location across the basin (Fig. 3b).

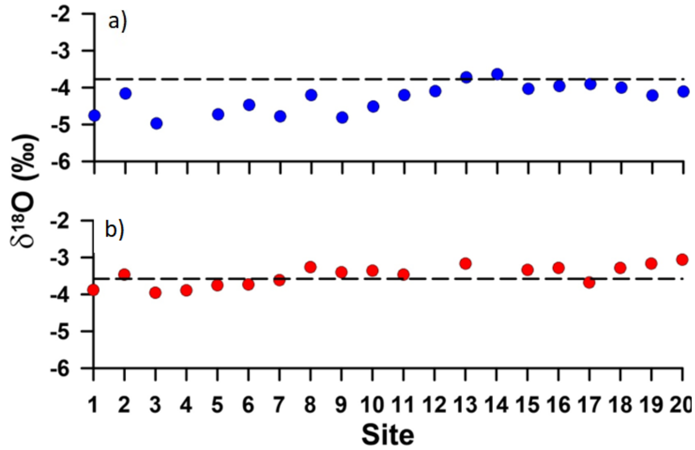


Figure 3. Oxygen-18 ($\delta^{18}O$) isotopic ratios in stream water samples collected at the 20 monitoring sites within the Cube River basin during a) and b) and driest periods in 2021. The dashed lines in a) represents the average $\delta^{18}O$ value (-3.7‰) of the samples collected at all monitoring sites during the six monitoring campaigns carried out in 2021 for reference.

Geochemical characterization

Water samples were also collected during the WP2 biodiversity monitoring for the analysis of the geochemical composition of stream water across the Cube River basin. The samples were analyzed for dissolved metals and nutrients, and this information was complemented by in-situ measurements of the physical-chemical characteristics of stream water. Table 1 presents a summary of the concentrations of the geochemical characteristics of the 20 sampling sites across the Cube River. The spatial variability of calcium concentration in stream water as a representative of the geological conditions across the study basin is shown in Fig. 4. The figure depicts that small headwater catchments tending to intermittent hydrological conditions present a lower concentration of calcium in comparison to the higher concentrations found in larger catchments with perennial flow.

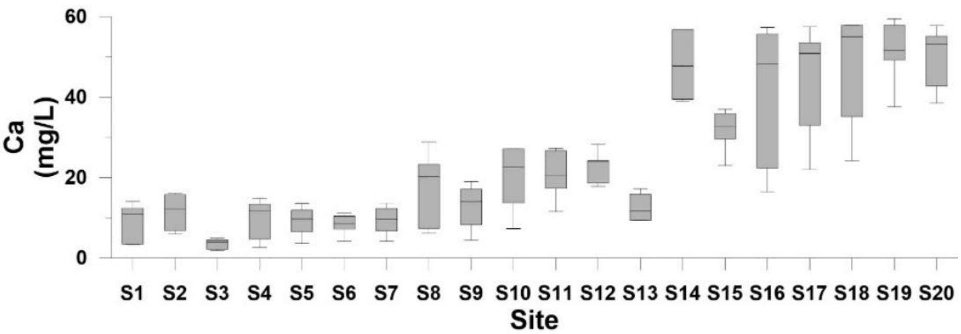


Figure 4. Boxplots of the concentration of Calcium at the 20 sampling sites monitored within the Cube River basin during six monitoring campaigns carried out in 2021.

Table 1. Median and standard deviation (Sd) of stream water physical-chemical parameters and solutes' concentrations of the 20 sampling sites monitored within the Cube River basin. All sites were sampled six times in 2021, except for site S14 (marked with * symbol) that completely dried during three sampling campaigns in the dry season. Electrical conductivity (EC) and temperature (T) are reported in µS cm-1 and °C, respectively. Solutes' concentrations are reported in ppm, except for Ba, Pb, and Mn that are reported in ppb. Green and red shading indicates the sites where the lowest and highest values of the monitored water chemical parameters were observed. EC=electrical conductivity, Alk=Alkalinity, T=Temperature, DO=dissolved oxygen, COD=chemical oxygen demand, and TOC=total organic carbon.

Site	Statistic	K	EC	Ca	Alk	SO4	Na	Mg	F	T	DO	P	Pb	COD	Ba	pH	Mn	TOC
S1	Median	3.3	132	11	44.8	24	5.6	3.91	0.05	21.6	7.6	0.28	5.4	13.4	61	7.3	8.7	2.7
	Sd	1.3	45	4.7	13.1	9.8	2	1.64	0.02	0.6	0.8	0.06	0.6	6.5	39.3	0.4	7.4	1.8
S2	Median	2.8	146	12.1	52.7	23.5	6.3	4.24	0.06	22.1	8.8	0.49	5.8	17.9	54.4	7.8	2.3	2.8
	Sd	0.8	48	4.5	18.7	5.4	2.4	1.49	0.02	0.4	0.2	0.17	2.1	27.3	35.5	0.4	1.1	1.3
S3	Median	1.2	69	3.9	20.4	10.1	4.3	1.77	0.04	21.8	5	0.27	6	17.3	40.7	6.9	13.2	1.8
	Sd	0.5	20	1.3	4.7	3.4	1.2	0.55	0.01	0.5	1.8	0.13	1.2	10.9	22	0.4	8.8	1.2
S4	Median	2.5	120	11.8	49.4	8.4	5.3	3.32	0.05	22.4	7.2	0.29	6.7	26.2	40.9	7.5	20.1	1.9
	Sd	0.6	46	5	18.8	3.4	2	1.28	0.02	0.9	0.8	0.18	0.7	9.2	20.4	0.6	8	1
S5	Median	2.5	114	9.7	44	17.2	5.7	3.24	0.06	21.5	8.4	0.31	5.4	14.5	43.5	7.6	0.8	2
	Sd	0.8	36	3.6	15	3	1.7	1.14	0.02	0.8	0.1	0.13	1.4	6.9	26.7	0.3	3.1	0.5
S6	Median	2.1	108	8.5	34	16.6	5.9	3.06	0.06	21.7	8.6	0.27	4.8	16.8	50.8	7.8	7.2	1.7
	Sd	0.6	30	2.5	9.4	4.5	1.6	0.98	0.01	0.8	0.5	0.4	2.1	6	35.3	0.5	5.9	0.5
S7	Median	2.7	131	9.7	41.4	17.9	8.2	3.57	0.06	21.5	7.8	0.3	4.9	20.2	58.8	7.5	8.3	1.8
	Sd	0.9	48	3.5	11.2	4.6	4.1	1.28	0.01	0.5	0.6	0.1	1.9	8.7	35.7	0.2	33.5	0.2
S8	Median	4.4	264	20.2	81.2	41.4	14.6	7	0.08	22.5	9	0.33	5.6	16.8	100.2	8	1.9	1.8
	Sd	1.8	112	9.1	33.8	15.8	8	3.08	0.02	0.8	0.2	0.16	2.3	6.5	58.4	0.3	0.5	0.6
S9	Median	3.3	181	14	60.4	29	9.1	5.26	0.07	23.1	8.9	0.39	5.3	20	67	7.8	1.7	1.9
	Sd	1.1	71	5.6	21.5	9.5	4.5	2.04	0.02	0.7	0.5	0.17	1.6	6	46	0.5	3.7	1.7
S10	Median	3.5	219	22.5	51.4	30.9	7.3	5.07	0.07	23.5	9.9	0.39	5.7	18.4	57	8.2	3.3	1.7
	Sd	1.1	78	8.3	22.3	9.6	2.9	1.81	0.02	0.6	0.8	0.14	2.4	38	30.9	0.6	3.7	0.9
S11	Median	3.8	223	20.4	69.6	34.7	9.8	5.52	0.08	24.2	8.8	0.35	5.6	22.2	63.4	8.2	4.5	2
	Sd	1.1	67	6.2	21.3	8.2	3.5	1.6	0.03	0.9	0.5	0.16	2.7	6.8	19.8	0.3	1.8	1.2
S12	Median	5.3	275	24.1	91.1	29.3	13.8	8.54	0.09	23	6.9	0.44	9.3	24.1	109.2	7.4	35	1.1
	Sd	0.9	29	3.4	15.4	6.9	3.5	1.22	0.02	0.7	0.8	0.19	4.8	15	17.6	0.2	17.7	0.3
S13	Median	3	132	11.7	53.3	10.1	6.4	3.49	0.07	24	7.9	0.46	6.8	31.8	46.4	7.6	21.1	2.6
	Sd	0.6	32	3.3	11	2.7	1.6	0.96	0.02	1.2	0.3	0.19	2	12	24.6	0.3	9	0.7
S14*	Median	6.5	488	56.1	94.3	151.5	13.9	8.02	0.14	26.1	8	0.48	8	25.8	183.1	7.7	35.6	1.5
	Sd	1.6	100	9.8	21	139.5	5.3	1.51	0.02	0.6	0.9	0.23	2.1	4.1	44.6	0	24	0.6
S15	Median	4.8	356	34.4	81	63.4	15.4	7.72	0.12	25.9	9.2	0.42	5.6	25.8	69.1	8	20.1	2
	Sd	0.9	79	5.9	20.7	39.4	3.7	1.19	0.03	0.9	0.7	0.21	3.4	5.5	24.9	0.4	9.4	0.5
S16	Median	4.5	391	48.3	92.1	74	9.8	6.92	0.09	24.5	8.7	0.48	5.5	28.8	97.2	8.3	7.6	2
	Sd	1.5	135	17.5	29.6	35.2	3.6	2.28	0.02	0.8	1	0.2	3.5	7.8	30.4	0.6	4.3	1
S17	Median	6.3	500	50.9	82.7	163.6	19.5	9.37	0.17	24.3	8.2	0.43	5.1	32	106.1	7.8	5.6	1.6
	Sd	1.6	136	13.9	26	81	7.5	2.04	0.04	0.5	0.7	0.22	4.2	14.2	22.5	0.3	32.3	0.6
S18	Median	8	519	54.9	93.5	108.2	22.3	8.11	0.13	25.3	9.7	0.43	5.3	23.8	78.8	8.6	1.7	2.1
	Sd	2.7	142	14.3	29.7	44.8	11.4	2.12	0.03	0.8	1.4	0.25	3.3	14	26	0.5	4.6	0.7
S19	Median	7.1	493	51.6	101.6	81.4	21.9	9.03	0.14	26.6	10	0.4	5.7	23.2	86.1	8.4	6.3	1.8

	Sd	1.6	81	7.9	15.4	121.3	6	0.74	0.02	0.7	2.2	0.31	5.5	7.7	17.1	0.4	2.1	0.7
S20	Median	6.8	517	53.2	118.2	88.5	19	8.88	0.14	26	9.4	0.46	4.1	27.5	90.7	8.2	16	1.8
	Sd	1.4	168	7.7	19.7	101.3	5.2	1.08	0.03	1.9	1.5	0.19	4.6	8.6	8.2	0.2	11	0.4

Conceptual model of hydrological intermittence

Based on the combined analysis of hydrological, isotopic, and geochemical information, a conceptual model of the main subsurface flow paths contributing to streamflow generation in the Cube River basin has been developed (Fig. 5). Shallow subsurface flow paths primarily through the thin litter and the organic horizon of the soil under primary and secondary forests mainly located in the upper, headwater areas of the basin dominate streamflow generation in intermittent streams presenting a low bedrock permeability that reduces the catchments subsurface water storage and thus its capacity to sustain baseflow during the dry season (June-December). The high water storage capacity of catchments possessing high bedrock permeability that is replenished with water during the rainy period (January to May) helps sustain streamflow generation year-round in perennial streams despite the limited contribution from the litter layer and the organic horizon of the soil that has been substantially reduced or completely removed due to deforestation and cultivation in the Chocó Forest ecoregion. Overland flow has not been observed in intermittent or perennial catchments during field sampling campaigns, and thus such streamflow generation mechanism is neglected from the conceptual model.

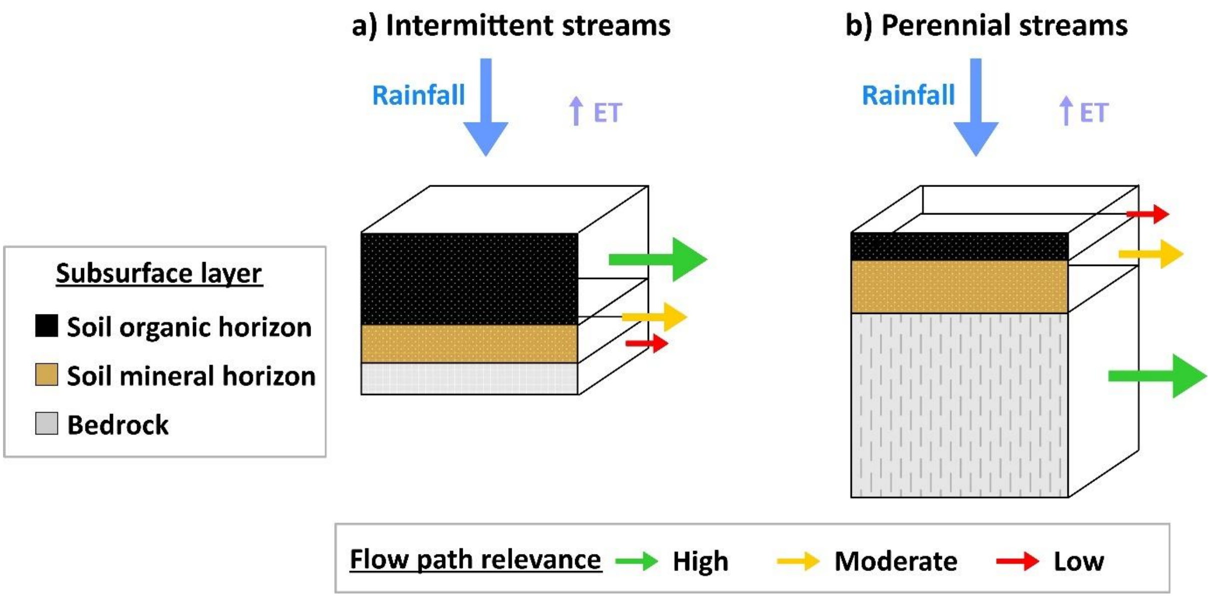


Figure 5. Delineation of water flow paths in an intermittent hydrological system of tropical streams under changing land use within the Cube River basin. The size and color of the horizontal arrows represents the relative importance of various subsurface water flow paths for streamflow generation in a) intermittent and b) perennial streams.

Bolivia DRN: Upper Chico River

Context

The upper Chico River basin (~92 km^2 drainage area) (Figure 6), is a seasonally intermittent system in the ecoregion of Inter-Andean Valleys of Bolivia. This basin connects downstream to the main course of the Río Chico, which is one of the tributaries of the Río Grande, one of the largest rivers in Bolivia and part of the Amazon Basin. The small headwaters of the Río Chico are an important source of drinking water supply for the city of Sucre where some areas of the city tend to experience water shortages during the dry season. Streamflow from the river is also used for agriculture and recreation in the middle and lower parts of the basin.

Due to the lack of historical hydrological data in this basin, it was not possible to develop projections of climate change impacts for this focal drying river network. Therefore, we monitored intermittence patterns over the river's drainage network, based on one to four bi-monthly spatial observations of hydrological condition (flow, isolated pools or dry) conducted at 22 monitoring sites over two years. In addition, to support these data, we deployed water level loggers at three of the 22 sites in the network.

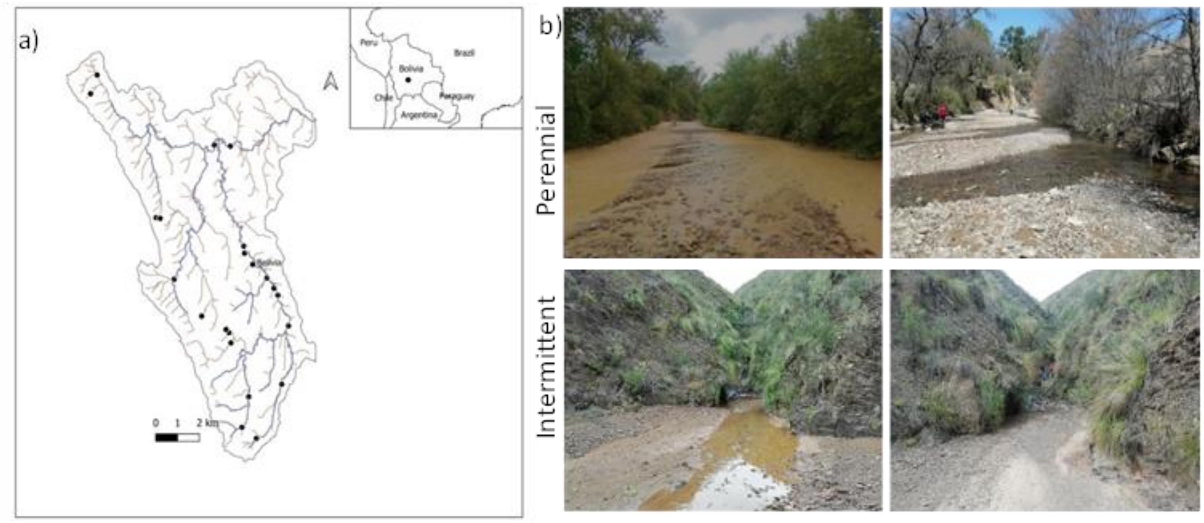


Figure. 6. a) Map of the Upper Río Chico basin (92 km^2) showing the drainage network and the 22 sampling sites (black dots) where hydrological conditions (flow, isolated pools or dry) were observed monthly during the period March 2021 to December 2022. b) Pictures of a perennial site (upper part) and an intermittent site (lower part) monitored during the wet (left) and dry (right) seasons.

Hydrological characterization

Observations of hydrological condition (flow:2, isolated pools:1 or dry:0) were carried out every two months during the rainy and dry seasons, while during the transition periods (April-May and October-November) the monitoring frequency was increased up to two observations per month, especially at intermittent sites. In the latter case, we averaged out the hydrological condition to a monthly time span.

Temporal changes in hydrological conditions in 2021 and 2022 are shown in Figure 7. Some sites within the DRN started to dry during May and June and the number of dry sites reached its maximum between September and October, despite the fact that in those months the first rains after the driest period occur. Streamflow at dry sites restarted from November-December until March-April. If we compare the pattern of intermittence between the two years, we observe that 2022 showed drier conditions than 2021. The main difference is that in March-April 2022 some sites already began to dry, and it took a longer period for flow to restart at those sites than the previous year.

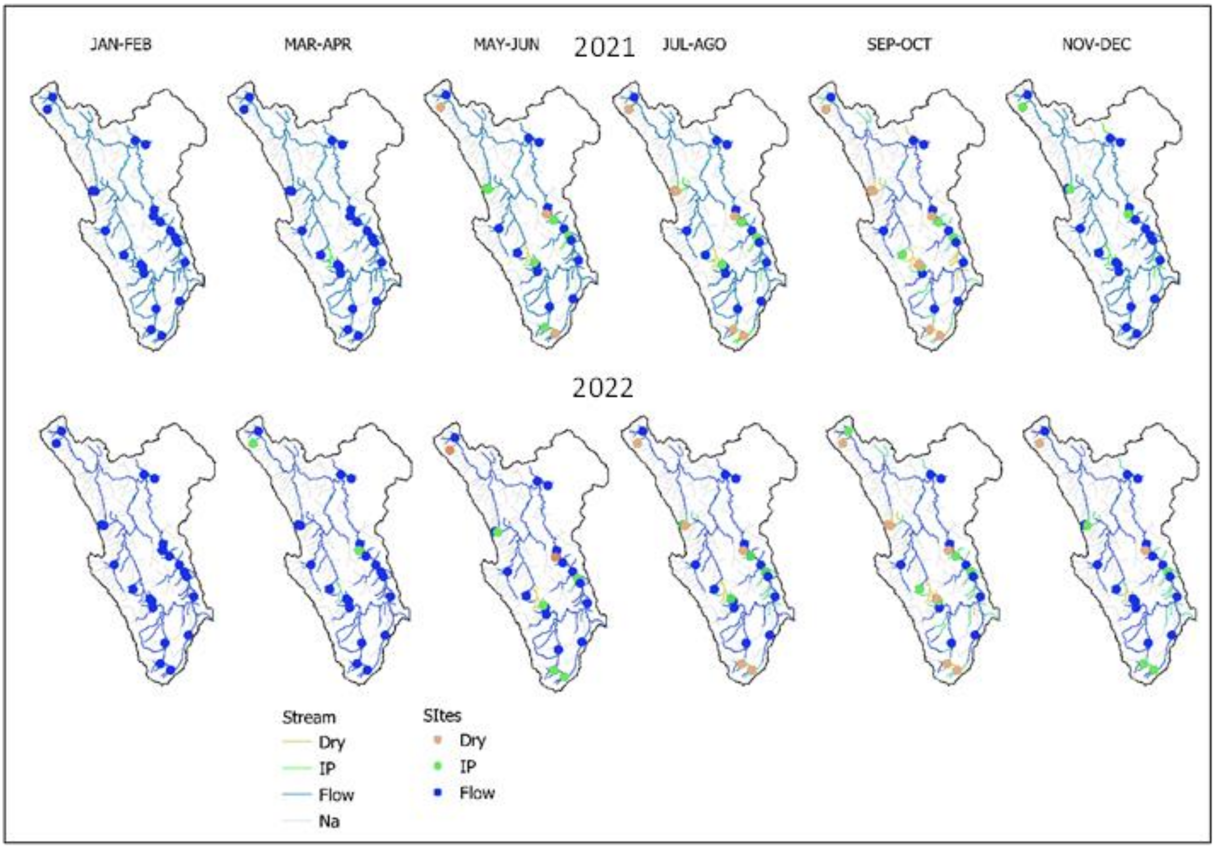


Figure 7. Temporary changes of intermittence conditions for the Upper Río Chico Basin. Up: year 2021, down: year 2022.

In addition to the observation of spatially distributed changes in hydrological conditions, water level loggers were deployed at three sites within the basin. Periodic measurements of discharge were also carried out during the period July 2021 to April 2023 to develop rating curves to convert the water level time series recorded by the loggers to discharge at the three monitored sites. After processing and filtering the raw water level data, the streamflow time series were obtained using the rating curves. Streamflow data for an intermittent and a perennial site are shown in Figure 8. Flow cessation at the intermittent site mainly occurred during the period May to November, with the rainy season occurring between December and March (Figure 8a). Even though streamflow decreased during the dry season at the other site, water flowed throuhgout the year at the perennial site (Figure 8b). Finally, at both sites, a rapid response of surface runoff to precipitation can be observed.

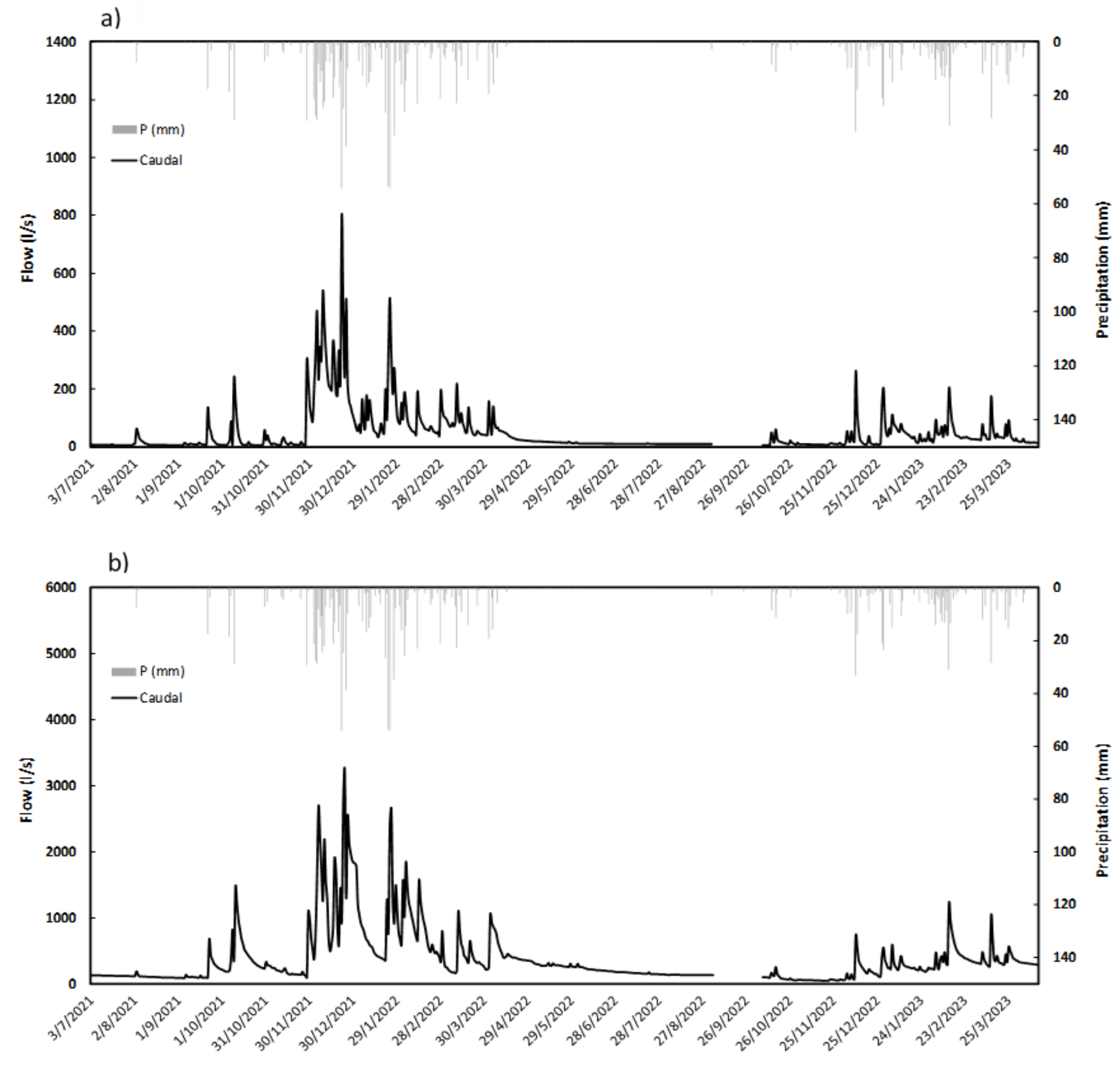


Figure 8. Daily streamflow and precipitation representing the hydrological behavior of intermittent (a) and perennial (b) streams within the Upper Rio Chico basin during the period July 2021 to April 2023.

Brazil DRN: Umbuzeiro River

Context

The Umbuzeiro River basin (URB, 965 km², Figure 9) is representative of the Brazilian semiarid region, with annual precipitation in regular years ranging between 500 and 600 mm, and annual potential evaporation varying between 2,000 and 2,600 mm. The URB is nested into the Jaguaribe River Basin (JRB, 75,000 km²), the largest watershed in the State of Ceará, which is responsible for the supply of approximately 4 million inhabitants, as well as the largest irrigation area in the State. The study area has been divided into several nested basins, such as Bom Nome, Barra, and Aiuaba (see lower Figure 9).

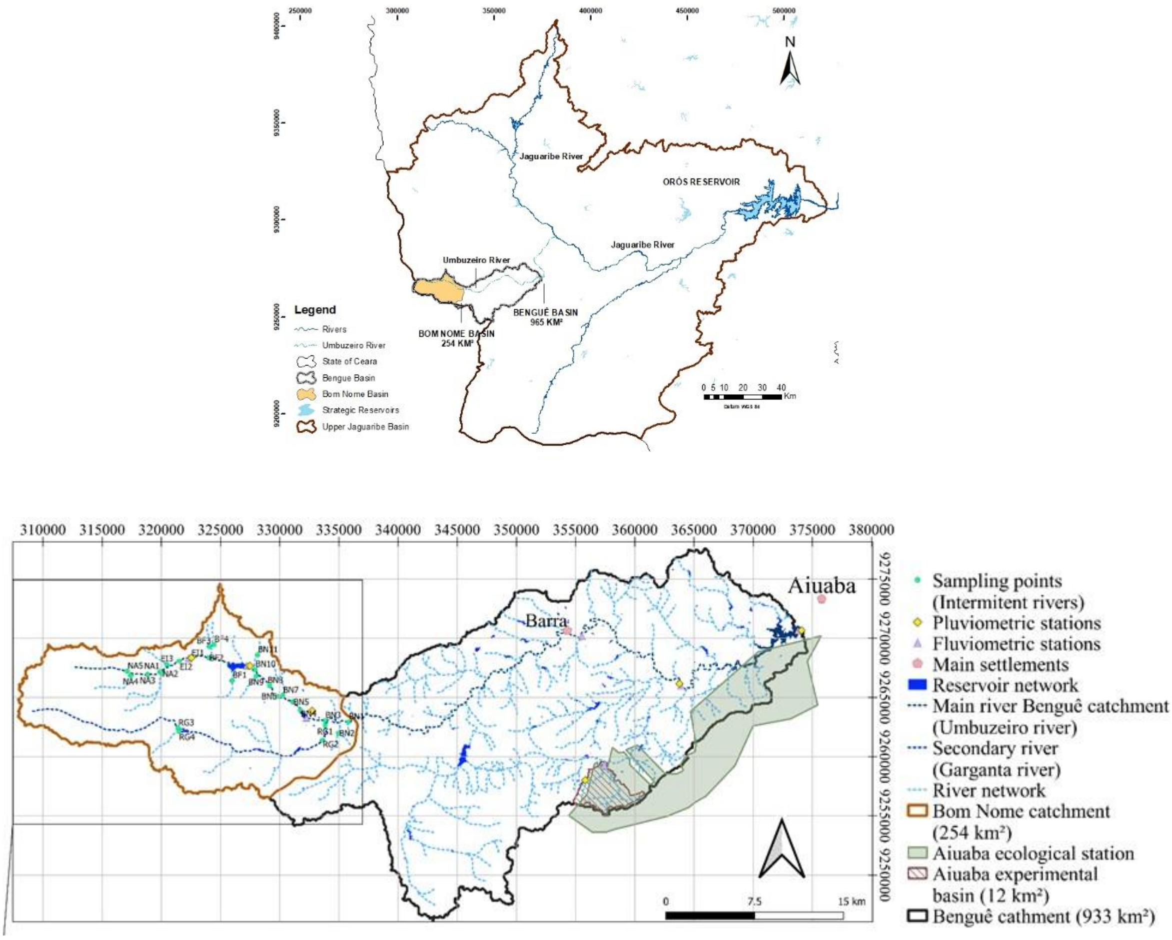


Figure 9. Location of the Upper Jaguaribe River Basin, Brazil (UJRB, upper map). Location and data-collection setup in the Umbuzeiro River Basin (lower figure), nested in the UJRB.

Hydrological characterization

To characterize the hydrology of the area, the Brazilian team monitored the study basin at different spatial scales. The Aiuaba Experimental Basin (12 km²) has been monitored continuously since January 2003 (hourly data); the Bom Nome sub-basin has been monitored since 2020; the Barra sub-basin since 2018; and the Umbuzeiro basin (controlled by the Bengue reservoir, near the city of Aiuaba) since 2000 (daily data).

The data provide a clear view of the hydrology of the URB, whose main feature is the river intermittence (Figures 10 and 11). The river in the lower part of the basin (catchment area of ~800 km²) flows not longer than two or three months per year, whereas in the upper basin (catchment area of ~100 km²), the river flows continuously less than two weeks in a regular year. However, if another intense rainfall event occurs, the river may flow again for a few days as observed in the hydrograph of Figure 12.

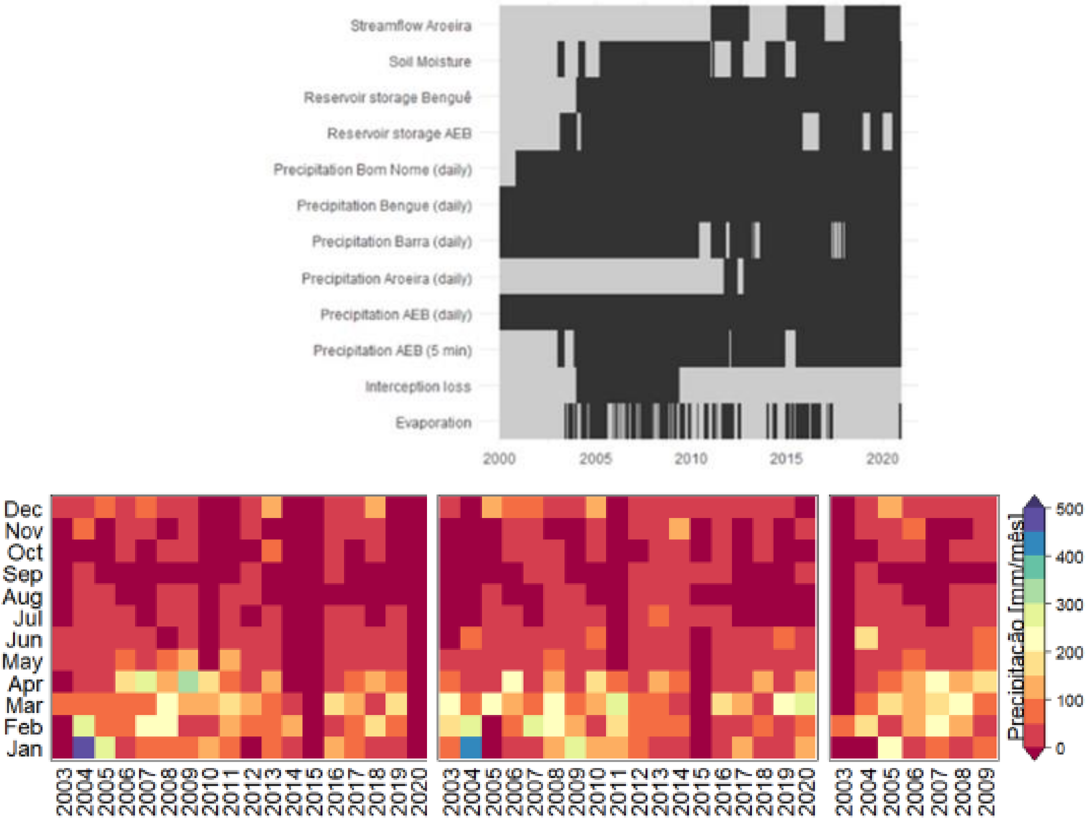


Figure 10. Example of available hydrological data at the Brazilian DRN. The upper figure shows data availability (dark color) for different nested basins, whereas the lower figure synthesizes the precipitation data for the whole URB.

(a) (b)

Figure 11. Pictures of the Umbuzeiro River in 2021 during pooled (a) and flowing (b) conditions.

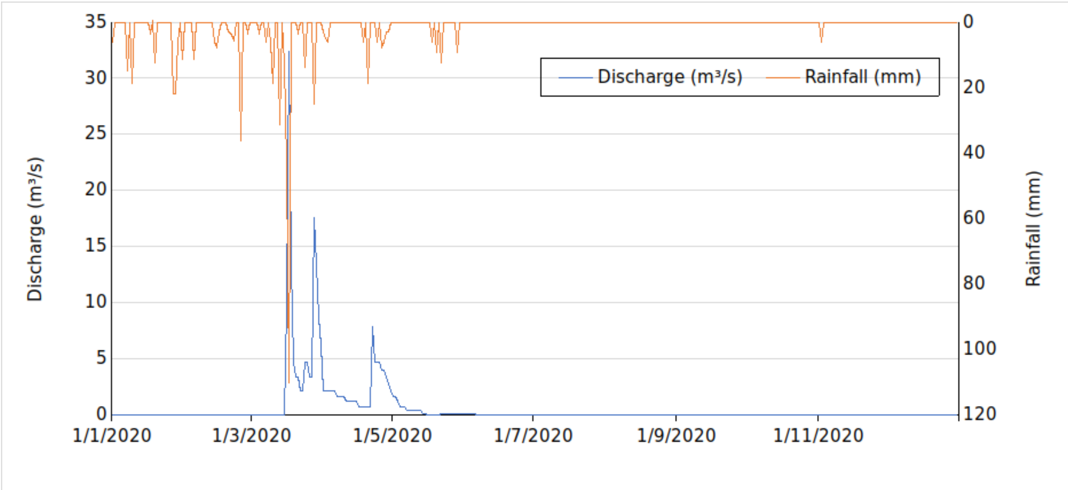


Figure 12. The intermittence as a key hydrological feature of the Umbuzeiro River: Measured discharges in 2020 (catchment area of ~ 800 km²).

Another initiative of the Brazilian team was to monitor the URB using remote sensing. Figure 13 shows 57 images of the Aiuaba Experimental Basin, showing the vegetation status (NDVI) during almost two decades. These results were key to interpret the seasonality of hydrological conditions across the area.

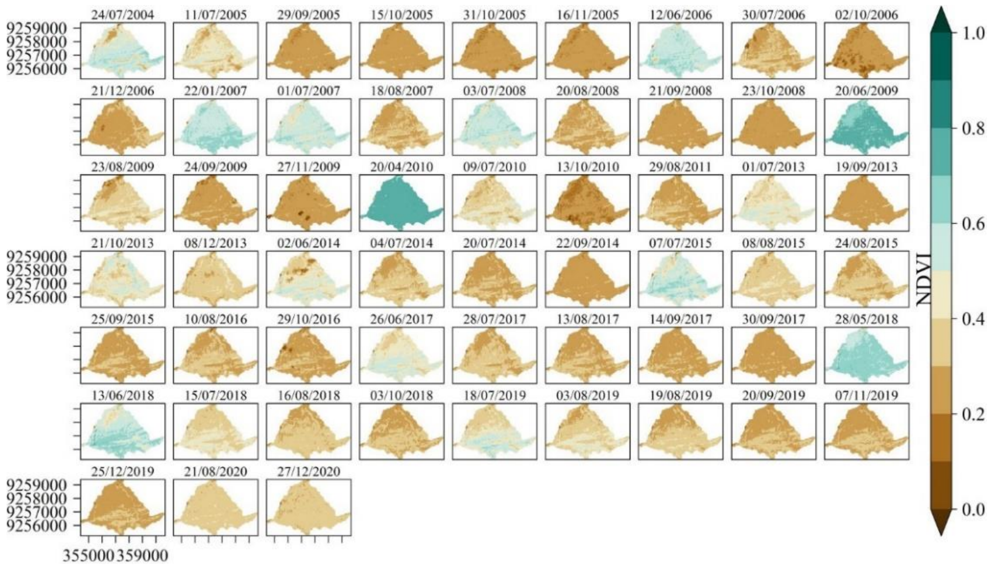


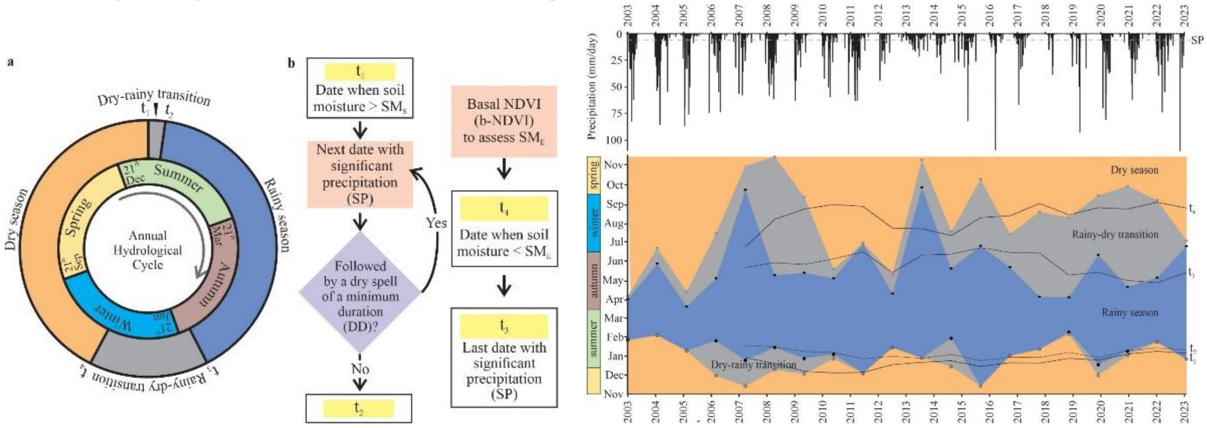
Figure 13. NDVI values for the Aiuaba Experimental Basin (12 km²), nested in the URB, 2003 - 2020.

Main results

The results of the research allowed to support a M.Sc. Thesis and the submission of three publications. Two other publications are being prepared and should be submitted in 2023.

1. Lima, G. D., Lima, T. B. R., Soares, N. S., de Araújo, J. C. (2022). Modelagem da intermitência e do escoamento no semiárido brasileiro: rio Umbuzeiro, Ceará. **Revista Ciência Agronômica**, 53.
2. Soares, N.S., Costa, C.A.G., Lima, J.B., Francke, T., de Araújo, J.C. Method for identification of hydrological seasons in the semi-arid Caatinga Biome, Brazil. Submitted to the **Hydrological Sciences Journal**.
3. Soares, N.S., Costa, C.A.G., Francke, T., Medeiros, P. H. A., Mohr, C., Schwanghart, W., De Araújo, J. C. (2023). Spatial distribution of intermittence in a Brazilian Semiarid River. In **EGU General Assembly Conference** Abstracts (pp. EGU-7066).

A relevant result was the development of a methodological framework for the delineation of hydrological seasonality (Figure 14a) using precipitation, vegetation, and soil moisture as proxy. The method has been applied to the area for the last 20 years (Figure 14b). The statistical analysis of the data showed that neither the precipitation amount (neither annually, nor seasonally) nor the number of rainy days for any season has changed in the last decades. However, the duration of the transition season (from wet to dry) is getting longer with time. This implies that runoff (and, therefore, water availability) is expected to decrease, enhancing river intermittence (Soares et al., submitted).



(a) (b)

Figure 14. Methodological framework for the delineation of hydrological seasonality (a) and its results for the period between 2003 and 2023 (b).

The modelling effort focused on the WASA (Water Availability in Semi-Arid Environment[13]) model. The WASA model was applied to the URB, whose results can be interpreted at several spatial scales. Lima et al.[12] found that the model, regardless the fact that it was calibrated to mimic the observed runoff, could not appropriately resemble flow intermittence carrying out a few simulations. Rodrigues et al. (in preparation) used a computer cluster and simulated more than 5,000 different combinations of the two most relevant model parameters (k-rain and k-soil). The results (Figure 15) showed that the best-fit parameterization for the first objective function (runoff, Figure 15a) fits better for moderate K-soil and low k-rain; whereas for the second objective function (intermittence, Figure 15b), the model mimics best for low k-soil and high k-rain. How to solve this inconsistency is still under analysis. Figure 16 shows temporal diagrams of some simulations.

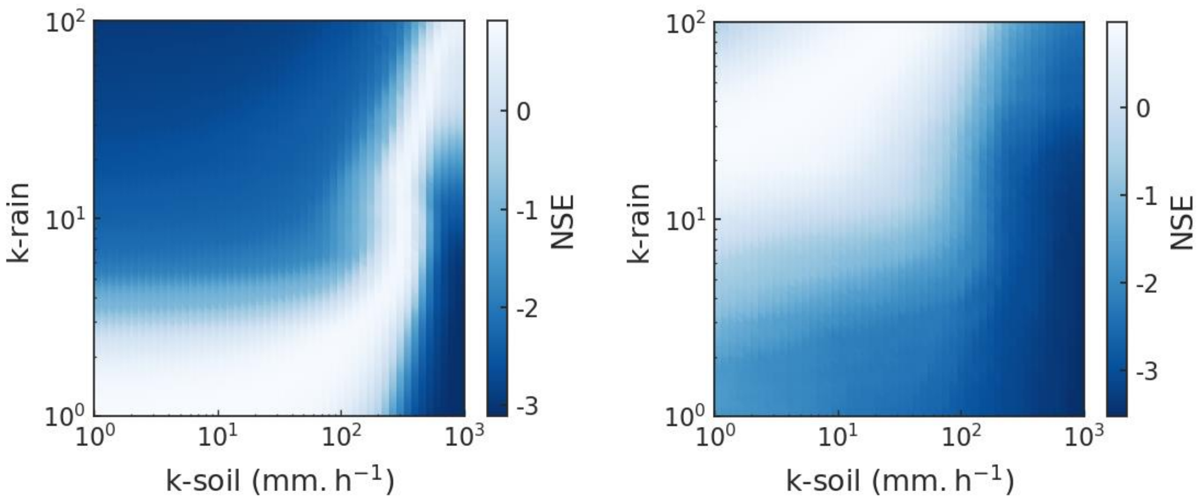


Figure 15. Result diagram of the WASA physical hydrological model applied to the URB for a two-decade period. Nash-Sutcliffe coefficient (NSE) for simulating runoff (a) and intermittence (b).

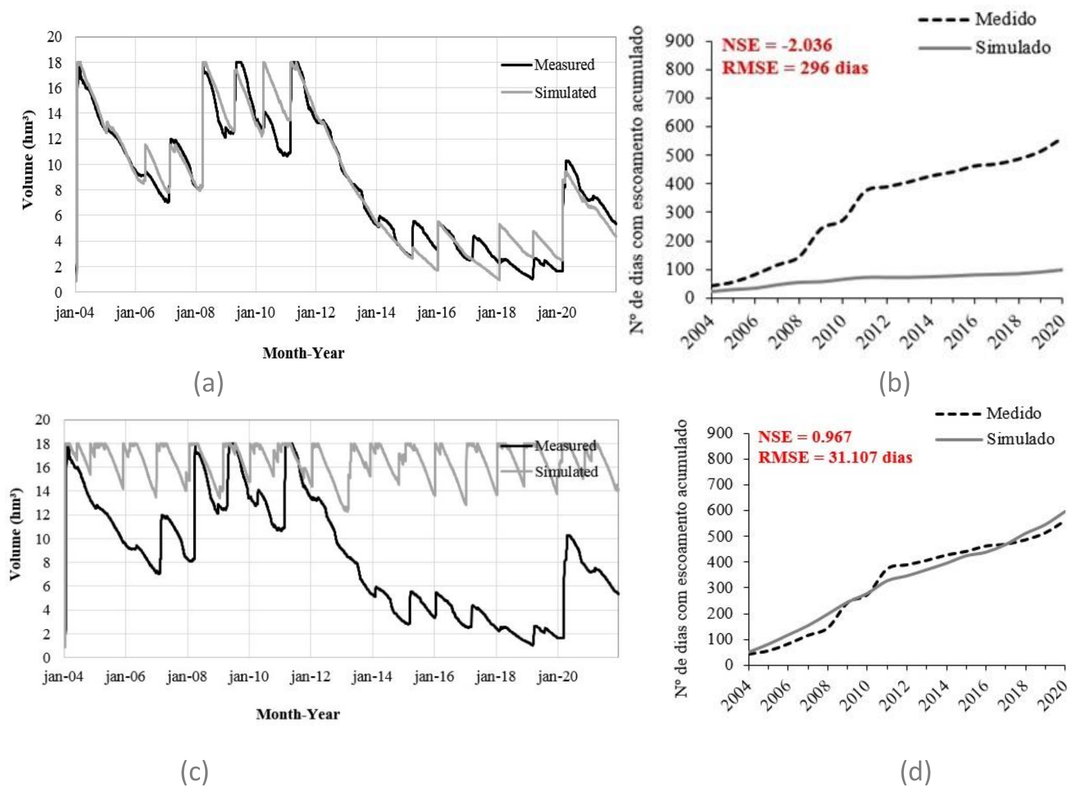


Figure 16. Temporal diagrams of WASA-model simulations. Runoff performance using best-fit parameterization in terms of runoff (a). Intermittence performance using best-fit parameterization in terms of runoff (b). Runoff performance using best-fit parameterization in terms of intermittence (c). Runoff performance using best-fit parameterization in terms of intermittence (d).

Finally, to obtain data from the DRN river network using satellite imagery for several years, we used UAV-generated data and field campaigns for two years as ground truthing (Figure 17). During this period we registered the occurrence of flow, pools and dry conditions in three reaches of the main DRN river (Umbuzeiro River) and in tributaries using UAV and in-situ observations (Figure 18). These data will allow the use of satellite imagery to extend our observation to the whole basin for a much longer period. The data are being analyzed by N.S. Soares (UFC doctorate student, staying one year at the University of Potsdam), and the results are expected to be submitted for publication in 2023.

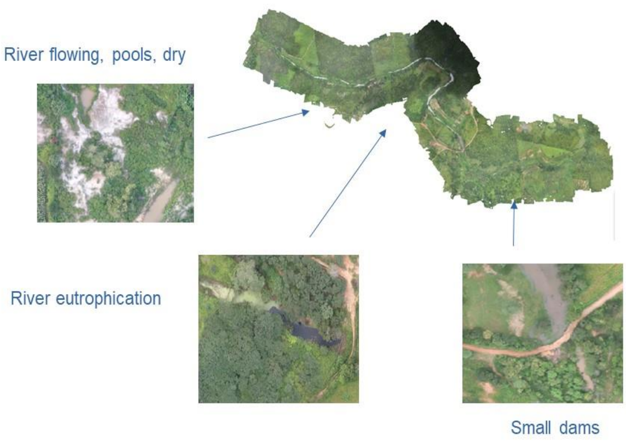


Figure 17. Method to identify dry, running, and pooled river reaches in the URB using remote sensing.

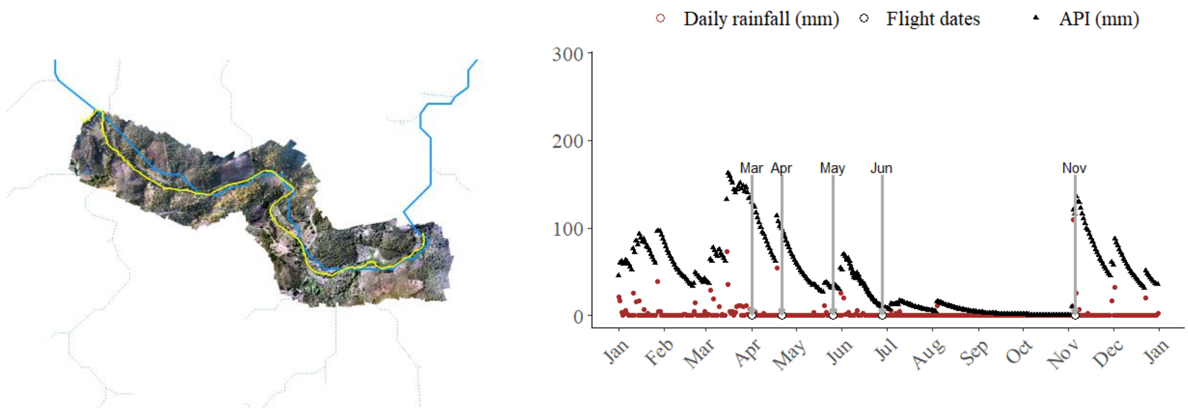


Figure 18. Monthly occurrence of flow, pool and dry conditions in the main DRN river and in tributaries using UAV and in-situ observation to aid using satellite imagery for several years.

Ongoing work

- A plublication of the conceptual model of hydrological intermittence in the Ecuadorian DRN is in preparation and expected to be submitted for peer-revision in September/October, 2023.
- The Brazilian team is working on the conclusion of two Doctorate Dissertations: Ms. Soares is developing a remote-sensing method to assess river-reach patterns (dry, running, pooled); whereas Mr. Rodrigues is modelling the basin using two decades of data. Two manuscripts are in preparation and should be submitted for publication shortly: [1] Soares, N.S., Costa, C.A.G., Francke, T., de Araújo, J.C. Spatial distribution of intermittence in a Brazilian semiarid river, to be submitted to STOTEN – Science of the Total Environment; and [2] Rodrigues, T.L., Medeiros, P., de Araújo, J.C. Simulation of runoff and intermittence of a semiarid river basin using a physically-based hydrological model, to be submitted to the Hydrological Processes.

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