Simbi: historical hydro-meteorological time series and signatures for 24 catchments in Haiti

Manuscript No. ESSD-2023-259

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Answer to the reviewer 3

We thank the Reviewer 3 for this detailed review and helpful comments. Please find below our replies to the Reviewer's comments. We provided the reviewer comments *in italic and blue*, the author's responses in black and the author's changes in the manuscript in *black and italic*.

Haiti is acutely vulnerable to natural disasters, yet it lacks an accessible hydroclimatic database for analysis. The paper provides a meaningful database, known as Simbi, to fill this gap. The database is undoubtedly valuable, and the paper is well-written. I only have minor comments as follows:

1. *it would be beneficial if the authors include a figure or a table detailing the data types, temporal extent, and other related information.*

   Table 2 and Table 3, which summarises the data used and produced in this study, has been added in section 3.5.

Table 2 - Summary of the datasets used in this study.

Datasets	Source	Period of data availability
156 monthly rainfall series	Moron et al., 2015	1905-2005
70 daily streamflow series.	BVH project	1920-1940
Paper archives contain daily rainfall series	BHS	1920-1940
Paper archives contain monthly air temperature series	BHS	1920-1940
NOAA 2OCR rainfall and air temperature daily database	Slivinski et al., 2019	Twentieth Century
BEST air temperature database	Rohde et al., 2013	Since 1753
SRTM DEM with a resolution of 90 m	Reuter et al., 2007	-
Shapefile of lithological classes on Haiti	CNIGS	-
Shapefile of aquifer classes on Haiti	CNIGS	-
Shapefile of land cover classes on Haiti	CNIGS	-
Shapefile of Haitian stream network	CNIGS	-

Table 3 – Summary of the datasets produced in this study.

Datasets	Period of data availability
Digitization of 59 daily rainfall series	1920-1940
Digitization of 23 monthly air temperature series	1920-1940
Rainfall, air temperature and PET series at catchment scale and at daily and monthly time steps for 24 catchments studied.	1920-1940
Simulated streamflow series at daily and monthly time steps for 24 catchment studied.	1920-1940
49 attributes for each of the 24 catchment areas studied	-

2. *In the Simbi database, some data have been sourced from previous studies. It is essential to explicitly describe the origins of the data within the database.*

   The origin of the hydro-meteorological data used in Simbi has been described in the introduction to the revised manuscript.

   Unfortunately, there are significant differences between countries in terms of the quality and quantity of hydroclimatic reference databases, as well as regarding access to these data. Some countries do not have such reference databases. This is the case of Haiti, whose territory is, moreover, highly exposed to natural disasters (Khouakhi et al., 2017; Burgess et al., 2018), and climate change (Peterson et al., 2002). At the same time, Haiti is facing the consequences of massive deforestation and anarchic urbanization (urban development that does not comply with planning regulations) in recent decades (Hedges et al., 2018; Tarter et al., 2018; Mompremier et al., 2022), resulting in increased vulnerability to hydroclimatic hazards. Currently, Haiti lacks a freely and easily accessible hydroclimatic database due to the absence of in situ hydroclimatic observations. The first hydrometric observations were conducted during the American occupation of Haiti, and began in 1919. American engineers from the Water Resources Service (WRS) of the United States Geological Survey (USGS) supervised these hydrological observations, that continued into the 1940s and exceptionally later. The data time series and a description of the methods used to collect them were published annually in the "Hydrographic Bulletin", summarizing 70 daily streamflow time series over the 1920-1940 period. After these two decades of streamflow observations, very few hydrological data were produced in Haiti (Pouyaud and Hoepffner, 1987). In addition to hydrometric observations, rainfall measurements started in Haiti around 1905 using 15 raingauges. Over time, the raingauge network became denser, with 25 stations operated by the "Petit-Séminaire Collège St Martial" (a school run by the Congrégation du Saint-Esprit), 38 by the "Direction Générale des Travaux Publics", and nearly 30 by other institutions, such as the" Frères de l'Instruction Chrétienne" (Pouyaud and Hoepffner, 1987).

   In 1977, the Haitian government initiated a project to make an inventory and digitize some available hydroclimatic time series. As a result, the 70 daily streamflow series for the period 1920-1940 and almost a hundred monthly rainfall series from the start of observations (~1905) until 1975 were digitized. In 2012, the Haitian government launched a second project named BVH (Bassins Versants Haïtien in French, i.e., Haitian catchments; Gaucherel et al. 2018) for compiling available hydroclimatic data, better understanding hydrology in Haiti and improving the management of water resources. Within this project, Haitian catchments were characterized using monthly streamflow data (Gaucherel et al., 2016) and rainfall data (Moron et al., 2015) and the relationships between their shape, relief, and *river sinuosity were investigated (Gaucherel et al., 2017, Bonhomme et al., 2013).Unfortunately, the two databases produced within the BVH project (monthly rainfall time series and monthly streamflow time series) have never been analyzed jointly, are not available online and remain limited for several hydrological analysis due to their monthly time step (monthly). Thus, these databases are underused to date.*

3. *In section 3.1.1, a rationale is needed to provide for selecting streamflow series that are hydrologically relevant.*

Several criteria were used to assess the quality of the flow series. These indices were used to select relevant streamflow time series.

Section 3.1.1 has been revised to better explain the flow series selection process.

3.1.1 Selection of streamflow series

An analysis of the 70 available streamflow series was performed to select the "hydrologically relevant" streamflow series. Four criteria were initially used to make this selection:

1. The annual hydrographic bulletins reported the accuracy with which rating curves were established through three ratings: "well established," "fairly well established," and "poorly established." Most of the streamflow series with "poorly established" rating curves were found to have significant measurement differences between periods.

2. Some hydrometric stations were located downstream of diversion channels or small dams used for irrigation. These streamflow series poorly represent the seasonality of streamflow, and are therefore considered to be influenced by human activities. These streamflow series were not used in the remainder of this study.

3. Some hydrometric stations were located downstream of resurgences or springs. These groundwater resurgences are beyond the scope of this study. Therefore, these streamflow series were not used in the remainder of this study.

4. The streamflow series that had less than 5 years of data were not used in the remainder of this study.

In addition to these four criteria, three other indices inspired by the paper of Gudmundsson et al. (2018) were used to assess the quality of the streamflow data. These three criteria were and are calculated as follow:

1. Number of days for which $Q<0$, where Q denotes a daily streamflow value. The rationale underlying this rule is that streamflow values smaller than zero are non-physical (Gudmundsson and Seneviratne, 2016).

2. Sequence of more than 10 equal consecutive streamflow values larger than zero. This index was selected because equal consecutive streamflow values often occur due to instrument failure or flow regulation (Gudmundsson et al., 2018).

3. Detection of outliers, i.e. unusually large or small streamflow values that could come from instrument malfunction. The calculation of these outliers is inspired by the papers of Gudmundsson et al. (2018): daily streamflow values are flagged as outliers if values of $\log(Q+0.01)$ are larger or smaller than the mean value of $\log(Q+0.01)$ plus or minus 6 times the standard deviation of $\log(Q+0.01)$ computed for that calendar day over the entire series. The mean and standard deviation are computed for a 5-day window centered on the calendar day to ensure that a sufficient amount of data is considered. The log-transformation is used to account for the skewness of the distribution of daily streamflow values and 0.01 was added because the logarithm of zero is undefined.

To summarize, the quality of the 70 streamflow daily series is described using 12 flags (1, 2, 3, 4, A, B, C, D, E, F, H and I), as detailed in the Table 1. Using these criteria, along with visual analysis to identify anomalies (i.e. non-natural records that may be erroneous streamflow values or anthropogenic influences that can lead to misinterpretation of actual *hydrological processes (Strohmenger et al., 2023)), 24 hydrometric stations "were identified as "hydrologically relevant" from the 70 available.*

4. *In Section 3.2.1, the description of "multiple raingauge combinations" lacks clarity. If the number of rain gauges is fewer than three, it is unclear how to utilize Thiessen polygons.*

Section 3.2.1 has been revised to better explain the process of selecting the relevant rainfall series.

3.2.1 Rainfall

Three sources of rainfall data were used to build catchment scale rainfall series: (i) NOAA 20CR rainfall data, (ii) data from all available raingauges, and (iii) data from several possible combinations of raingauges.

1. NOAA 20CR rainfall data

Catchment-scale rainfall series were calculated as a weighted average of NOAA 20CR rainfall. The weights are proportional to the area of the NOAA pixel overlapping the catchment. The areas of most catchments are significantly smaller than the NOAA 20CR pixel. Thus, neighboring catchments located on the same NOAA grid cell will have the same rainfall series (see Figure 3).

2. Reference rainfall at the catchment scale

For each catchment, an initial rainfall series, called "reference rainfall" hereafter, was calculated as a weighted average of monthly rainfall data from Thiessen polygons (Croley and Hartmann, 1985; Han and Bray, 2006). Due to the high percentage of missing data in most rainfall series, the weights obtained from the Thiessen polygons are not the same for all time steps. For each time step, the weights are calculated using the raingauges with available data. The use of "reference rainfall", i.e. the use of all raingauges including those with a high percentage of missing data may introduce non-stationarity in the catchment-scale rainfall series and may not be "relevant" for rainfall-runoff modelling. The low density of raingauges and the high spatial variability of rainfall in Haiti (Moron et al., 2015) make it difficult to apply methods to estimate missing data (Benoit et al., 2022; Di Piazza et al., 2011; Oriani et al., 2020). Therefore, gap-filling methods were not used.

3. Multiple raingauge combinations

All possible raingauge combinations are calculated for each catchment (combination of 1, 2, 3,..., n raingauges, where n is the number of available raingauges). If a single raingauge is available, its data is used as the catchment scale rainfall series (weighting coefficient = 1). If there are multiple raingauges available, their weighting coefficients are calculated from the Thiessen polygons. Catchment scale rainfall series with no missing data were used for rainfall–runoff modeling.

4. Selection of the "relevant" raingauge for rainfall-runoff modelling

The performance of a rainfall-runoff model improves with a better description of the rainfall input (Andréassian et al., 2001). The GR2M monthly rainfall-runoff model was therefore used to determine, for each catchment and at the monthly timestep, the "relevant" raingauges in this study. NOAA 20CR rainfall series, reference rainfall series and multiple raingauge combinations are used as inputs to the GR2M model and relevant raingauges are defined as those providing the best model performance.

The first 3 years of data (early 1920 to late 1922) were used to initialize the model, and a split-sample test (Klemeš, 1986), commonly used in hydrology, was implemented. This practice consists in splitting a streamflow time series into two distinct subperiods P1 and P2, the first for calibration and the second for evaluation, and then exchanging these two subperiods. The two subperiods P1 and P2 are chosen so that they have the same available streamflow lengths. The combination of raingauges with the best KGE score in evaluation *(average of the KGE in evaluation over the two subperiods) was considered as the most relevant for rainfall–runoff modeling.*

5. *The KGE equation is not correct. The equation in the bracket should be (1-r)^2+(1-\alpha)^2+(1-\beta)^2.*

the error in the KGE equation has been corrected.

The conceptual lumped GR2M and GR4J models are described in Appendix B. The KGE objective function (Kling–Gupta efficiency; Gupta et al. 2009) was used to evaluate the performance of both models. The KGE score is defined by the following analytical formula:

$$KGE = 1 - \sqrt{(1-r)^2 + (1-\alpha)^2 + (1-\beta)^2} \quad (1)$$

where r is the correlation coefficient, α is the ratio of the standard deviation of the simulated streamflow to the standard deviation of the observed streamflow, and β is the ratio of the mean of the simulated streamflow to the mean of the observed streamflow.

6. *In Figure 10, the average monthly streamflows of 48 catchments were calculated. However, there is considerable uncertainty due to data discrepancies in many catchments. Therefore, it is recommended to include confidence intervals in Figure 10.*

Due to the variability of flows in the 24 catchment sutdies, a range of values representing the 5% and 95% quantiles have been added to the figure in addition to the median streamflows.

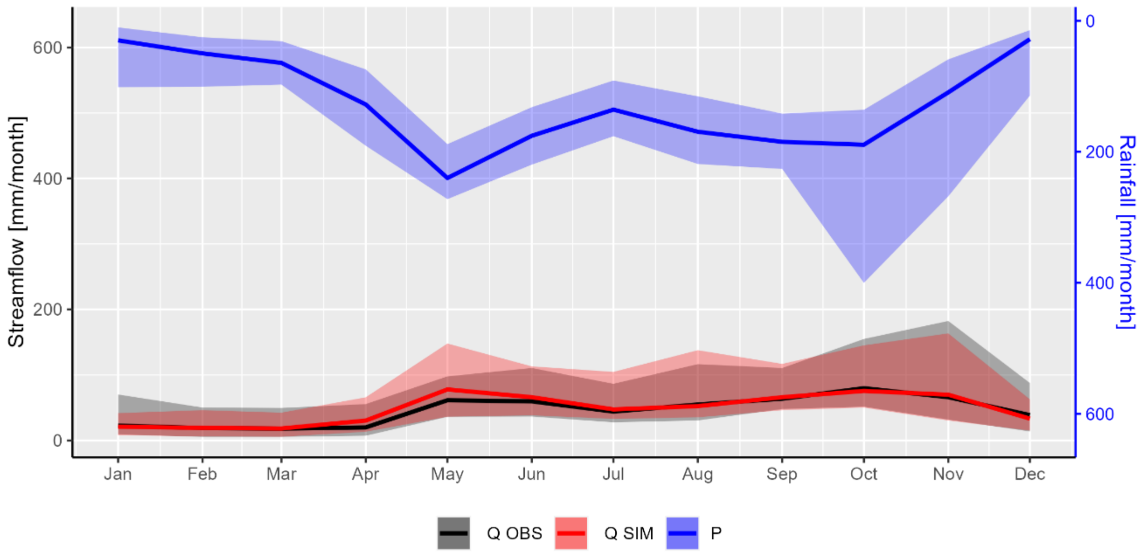

Figure 14 – Seasonality of rainfall (obtained by combining the relevant raingauges) in blue, observed streamflow in black, and simulated streamflow with the parameters calculated over the entire period of available data in red. The ribbons Values ranges have been estimated using represent the range of values between the 10th and 90th percentiles, while the thick line represents the median values for the 24 catchments studied.

7. *In Figure 10, providing reasons for the observed lags in the trend between rainfall and streamflow in Nov.*

Thanks for this comment, which could be the subject of future work on hydrology in Haiti. The second season of heavy rainfall in Haiti, from September to November, gradually moistens the soil until it is saturated. Although rainfall in November is relatively lower than in October, the steamflows in November are generally higher than in October due to soil saturation. However, this hypothesis needs to be further investigated in future work.

This analysis has been added to the revised manuscript.

Figure 14 shows the rainfall and streamflow regimes for the studied catchments. The results show a bi-modal rainfall/streamflow regime with two seasons of heavy rainfall/streamflow: the first season occurring around May and the second season between September and November, which corresponds to the cyclonic season. Rainfall is highly variable during the cyclonic season, with relatively heavy rainfall recorded in some catchments. The simulated streamflow represents well the seasonality of the observed streamflow (see Figure 14). However, simulated streamflows overestimate the observed values in May and underestimate them in November. In addition, the simulated streamflows slightly overestimate the low values in January. A time lag has been observed between the peak rainfall in October and the peak flow in November. This lag can be explained by soil saturation. The second season of heavy rainfall in Haiti, from September to November, gradually moistens the soil until it is saturated. Although the rainfall in November is relatively lower than in October, the streamflows in November are generally higher due to soil saturation. However, this hypothesis requires further investigation in future study.

8. *According to Simbi, can you provide a summary of the hydroclimatic characteristics of this region?*

The hydrological characteristics of the catchments studied were summarised in the form of graphical summary sheets such as the one presented in section 4.6 for one of the catchments studied.

Nevertheless, this sentence has been added in section 4.5.1 in order to highlight the general hydrological characteristics of the region.

Figure 14 shows the rainfall and streamflow regimes for the studied catchments. The results show a bi-modal rainfall/streamflow regime with two seasons of heavy rainfall/streamflow: the first season occurring around May and the second season between September and November, which corresponds to the cyclonic season. Rainfall is highly variable during the cyclonic season, with relatively heavy rainfall recorded in some catchments.