# Separating hydrological drought from water scarcity in Mexican catchments


- Omar Cenobio-Cruz[1] ocenobioc@iingen.unam.mx
- Agustín Breña-Naranjo[1] jbrenan@ii.unam.mx
- Adrián Pedrozo-Acuña[1] apedrozoa@ii.unam.mx

[1] Instituto de Ingeniería, Universidad Nacional Autónoma de México, México. Circuito Escolar s/n, Ciudad Universitaria, Delegación Coyoacán, Ciudad de México, C.P. 04510


## Introduction

Separating the effects of climate and human activities on catchments hydrology is critical to improve water resources management. Because of the increasing pressure on water resources. it is important to differentiate between natural (drought) and human (water scarcity) effects on the hydrological system. Human or social factors often aggravate the effects of drought (Wilhite & Glantz, 1985). Drought is defining by (Tallaksen & Van Lanen, 2004), as a period of below-normal water availability with natural causes, whereas that water scarcity refers to overexploitation of water resources when demands for water is higher than availability (Van Loon & Van Lanen, 2013).

## Objectives

Separating the effects of climate and human activities on catchment hydrology to understand how surface water availability will respond to future climate and anthropogenic effects in Mexico.

## Study zones and data

We analyzed two different cases located in western (temperate) and eastern (tropical) Mexico watersheds located. In the first case, the impacts of dam construction (El Humaya reservoir) on the streamflow regime downstream were analyzed. In the second case, a paired-catchment approach was used, in which the study timeline was divided as an "undisturbed period" (before significant population growth) and "disturbed period" (during population growth).

- Precipitation and potential evaporation for La Antigua and Nautla catchments was obtained from in-situ measurements. For the Humaya catchment, these variables were obtained from the Global Land Data Assimilation System (GLDAS-NOAH).
- Streamflow information was obtained from gauging stations.

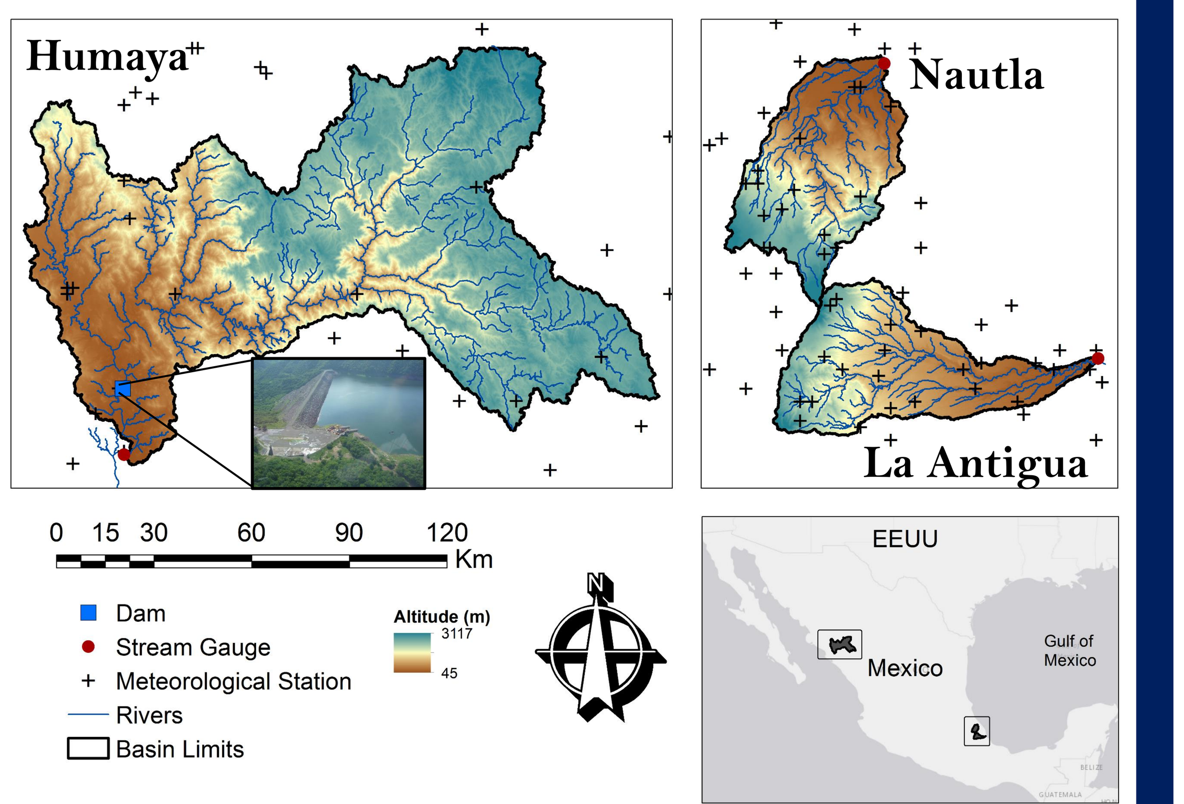


Fig 1. Location of the study catchments in Mexico.

## Methodology

- The HBV light model (Seibert, 2005) was used to simulate catchment streamflows.
- Calibration of the model was done with observed streamflow. The agreement between simulated and observed discharge was evaluated by the Nash-Sutcliffe efficiency index.
- A variable threshold method (Fleig et al., 2006; Tallaksen & Van Lanen, 2004) was applied, in this case, derived from the 80$^{th}$ percentile of the long-term flow duration curves (FDC).

Different approaches were used to quantify human influence on streamflows:

- **Observation modelling framework***: (Van Loon & Van Lanen, 2013) Reconstruct the hydrological regime that would have occurred without human influence and compare with the observed (anthropogenic) time period.
- **Paired-catchment approach***: using observation data from a reference (natural) and a disturbed (urbanized) neighbor catchment. The catchments must have (relatively) similar characteristics.
- **Inflow-storage approach**: Through standardized indices of precipitation, inflow and storage, we can easily identify that magnitude, direction and trends of dry conditions for these variables. Moreover, correlating inflow and reservoir storage can help explaining whether deficit periods in storage can be attributed to streamflow drought or to reservoir operation policies.

*In the first 2 cases, the most important part is the anomaly analysis, which allows to separating drought and water scarcity. This work obtains anomalies of hydrological time series so that we can infer temporal deviations from normal conditions.

## Humaya catchment (inflow-storage approach)

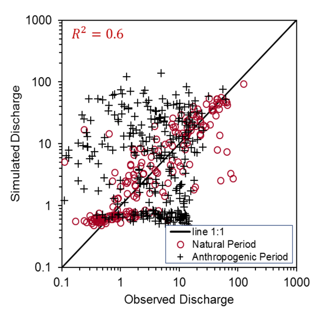


Fig 2. Simulated vs. observed discharge for different periods (natural and anthropogenic) transformed to log scale

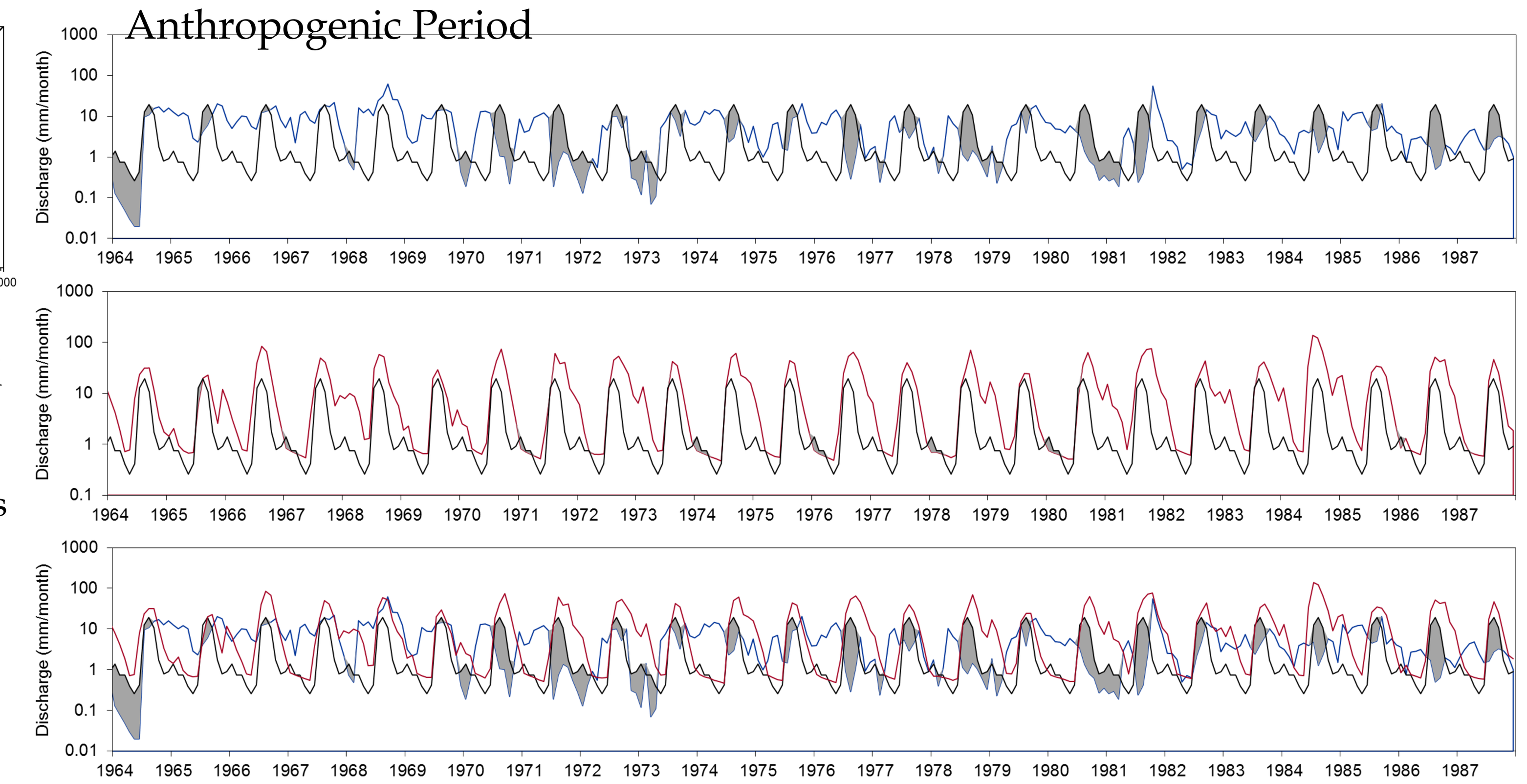


Fig 3. Anomalies in streamflow in the disturbed period; upper panel: observed streamflow (gray areas shows combined effect of drought and water scarcity), middle panel: naturalized streamflow (gray areas shows drought); lower panel: comparison between observed and naturalized streamflow (gray areas shows water scarcity)

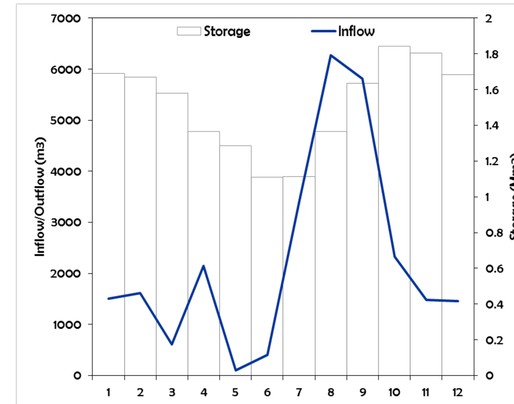


Fig 4. Average monthly reservoir storage (white bars) and inflow (blue line) for 1964-1999.

| r | Overall | Wet Period | Dry Period |
|---|---|---|---|
| P-S | 0.58 | 0.33 | 0.55 |
| P-Q | 0.28 | 0.10 | 0.65 |
| Q-S | 0.65 | 0.52 | 0.84 |

Table 1. Coefficient of correlation (r) between precipitation, streamflow and reservoir storage.

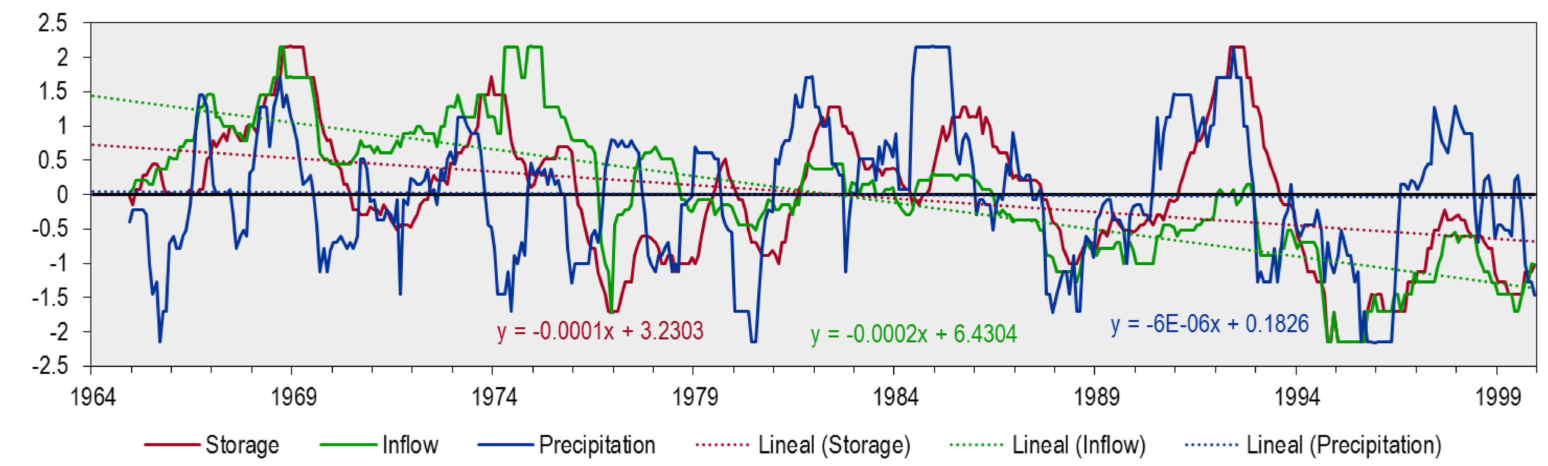


Fig 5. Standardized indices of precipitation (blue), streamflow (green) and reservoir storage (red).

## La Antigua & Nautla catchments (paired-catchment approach)

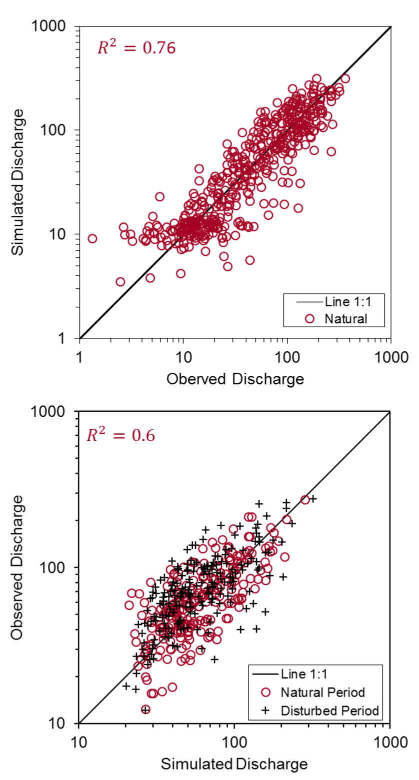


Fig 6. Simulated vs. observed discharge for La Antigua (top) and Nautla (bottom) catchments

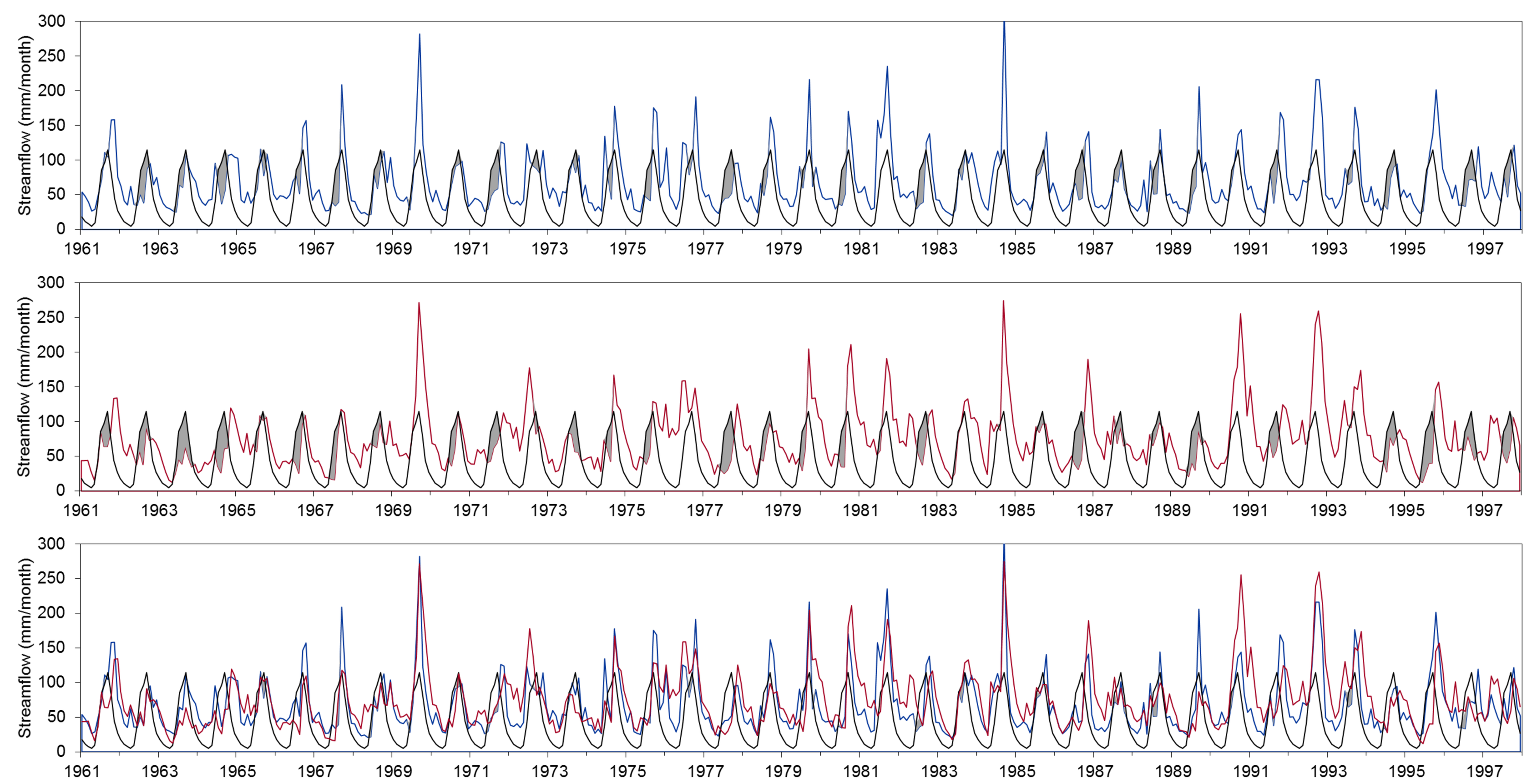


Fig 7. Anomalies in streamflow for the disturbed period; upper panel: observed streamflow (gray areas show the combined effect of drought and water scarcity), middle panel: naturalized streamflow (gray areas shows drought); lower panel: comparison between observed and naturalized streamflow (gray areas display water scarcity)

| | No. Drought Events | Deficit (mm) | | | Duration (month) | | |
|---|---|---|---|---|---|---|---|
| | | Max | Min | Mean | Max | Min | Mean |
| La Antigua (Reference) | 10 | 99.8 | 8.3 | 47.5 | 7 | 3 | 4.5 |
| Nautla (Urbanized) | 18 | 156.5 | 40.5 | 103.4 | 5 | 3 | 3.6 |

Table 2. Anomaly characteristics for both catchments

For each drought characteristic, an estimation of the human impact on hydrological drought was estimated using the following equation (Rangecroft et al., 2016) :

$$\%\ of\ change = \left(\frac{Q_{anthropogenic} - Q_{natural}}{Q_{natural}}\right) * 100$$

| | Natural | Anthropogenic | % of change |
|---|---|---|---|
| No. Events | 10 | 18 | +80 |
| Max. deficit | 99.8 | 156.5 | +56.9 |
| Average deficit | 47.5 | 103.4 | +117.6 |
| Max duration | 7 | 5 | -28.6 |
| Average duration | 4.5 | 3.6 | -21.0 |

Table 3. Percentages reported are the natural change ($Q_{natural}$) relative to anthropogenic change ($Q_{anthropogenic}$)

## Conclusions

- **For the temperate watershed, after the construction of dam, the operation of the reservoir reduced hydrological drought conditions but water scarcity occurred periodically every year.**
- **Inflow-storage approach provides information about trends of each variable, for this case, precipitation remained steady, however, inflow showed a moderate decline while storage displayed a more substantial decline, hence suggesting that evapotranspiration has increased over the study period. It also indicates that reservoir management has improved as the impacts of streamflow deficit on storage have been less severe as in the early years. The combination of both approaches are complementary.**
- **In contrast, the tropical watershed experienced more cases of (natural) hydrological drought. According to the paired-catchment approach, hydrological drought has become more frequent and severe due to population growth, however, the average and maximum duration of dry spells have decreased.**

## References


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