European Geosciences Union General Assembly 2019
Vienna, Austria, 6 – 13 April 2019
HS3.2: Spatio-temporal and/or (geo)statistical analysis of hydrological events, floods, extremes, and related hazards

Stochastic investigation of rainfall and runoff series from a large hydrometeorological dataset

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1. Abstract

We investigate the recently published CAMELS dataset, which is one of the most comprehensive large-scale datasets in terms of river flow timeseries and attributes of catchments minimally impacted by human activities. We examine the stochastic properties of daily river flow and rainfall series and investigate the links between the two at various lags, through climacogram-based stochastics tools (i.e. the climacogram and cross-climacogram) examining the variance versus spatio-temporal scale. We also explore the impact of various climatic and geophysical catchment attributes such as seasonality and timing of precipitation, aridity, mean catchment slope and soil conductivity, on the identified rainfall-runoff stochastic relationships.

2. Introduction

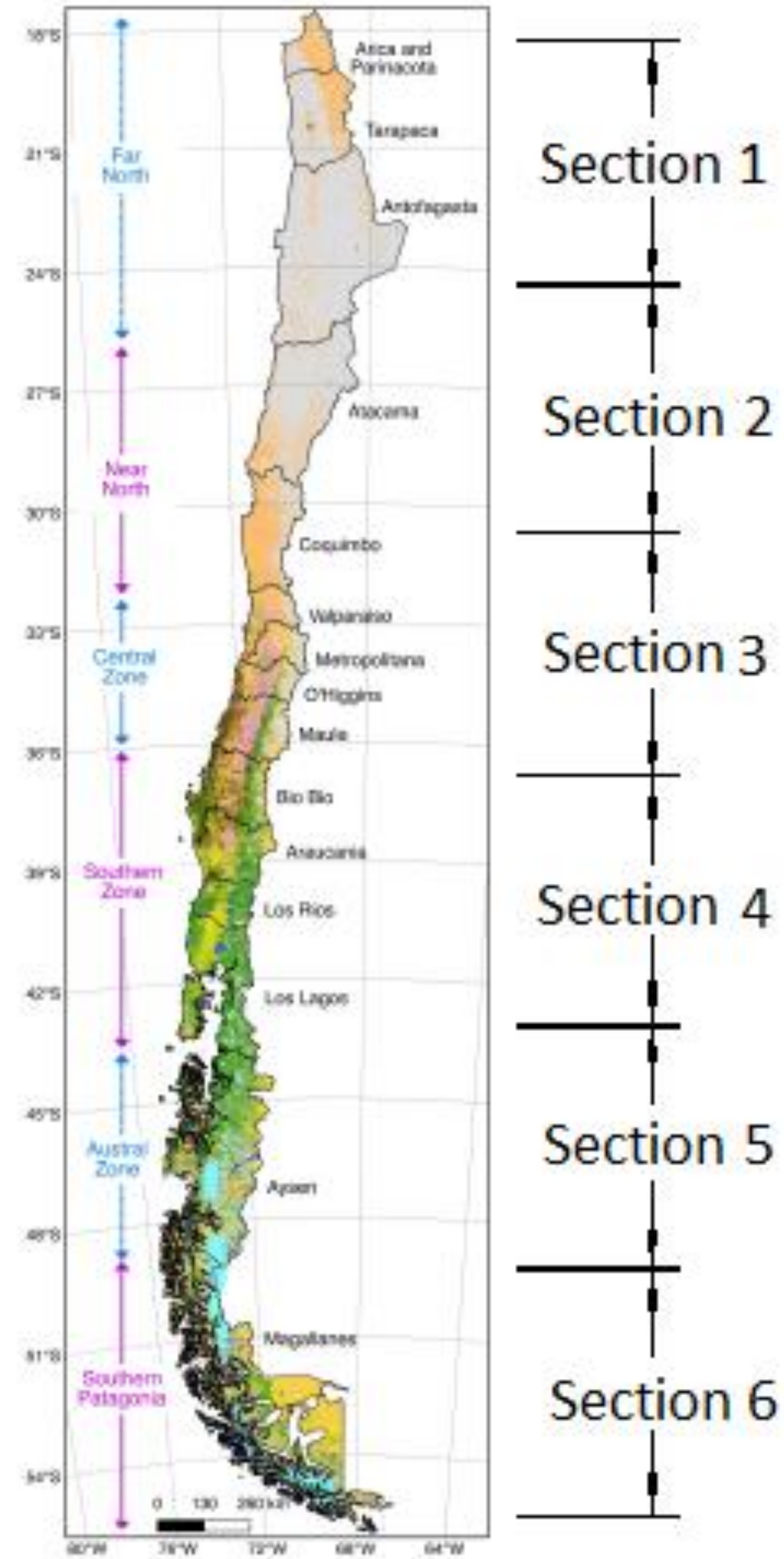
Rainfall-Runoff modeling is one of the most classical applications of hydrology. It has the purpose of simulating the peak river flow or the hydrograph induced by an observed or a hypothetical rainfall forcing. **Uncertainty** is also a key factor that influences hydrological variables [3]. The latter is expected to increase if we consider the uncertainty in the temporal dynamics of the rainfall-runoff relationship. In this study, we investigate the **rainfall-runoff dependence at various lags and temporal scales** by means of a new stochastic tool, the cross-climacogram [1], which originates from the climacogram (i.e. variance of the avereged process vs. scale) that entails several advantages over the autocovariance and the cross-covariance [4].

Large-sample hydrology has been recognized as a fundamental piece in order to study the influence of the physical attributes. The rainfall-runoff relationship is influenced by the **physical attributes** of the catchment like elevation, the size of area, geophysical attributes. A common approach for the analysis of large numbers of catchments is to explore interrelationships between catchment attributes describing **landscape, climate and hydrologic behavior**. These attributes are usually calculated based on topography, soil types, geology, land cover and hydro-meteorological datasets. We examine these relationships and we investigate which dependencies are the strongest.

3. Data Set and Study Area

CAMELS-CL relies on **multiple data sources** (including ground data, remote-sensed products and reanalyses) to characterize the hydroclimatic conditions and landscape of a region where in situ measurements are scarce. The dataset includes **516 catchments** and provides boundaries, **daily streamflow records and basin-averaged daily time series of precipitation** (from one national and three global datasets), maximum, minimum and mean temperatures, potential evapotranspiration, and snow water equivalent. **Hydro-climatological indices** are calculated using these time series, and leveraged diverse data sources to extract topographic, geological and land cover features. For the precipitation the mswep dataseries were used. The Multi-Source Weighted-Ensemble Precipitation (MSWEP, Beck et al., 2017) version 1.1, is a new global precipitation dataset released in June 2016, with a 3- hourly temporal and 0.25º spatial resolution, specifically designed for hydrological modeling.

The area covered by CAMELS-CL corresponds to continental Chile, that spans **4 300 km along the north-south axis**, a territory with a distinct geographical configuration that changes along the axis.



The six sections that the Chilean territory was divided into [2](Modified)

4. Methodology

We calculate the rainfall-runoff cross-correlations for lags ranging from 0 to 30 and the **correlograms** for the 516 stations of the dataset. We try to determine at which lag cross-correlation for all the stations is the strongest and how it fluctuates as the lag changes**. Cross-correlation between catchment attributes and the rainfall-runoff relationship** are calculated for lag 1. Additionally, the change in the previous relationship is calculated for lags ranging from 0 to 30 and plotted.

To determine the **dependence** of the rainfall and runoff processes at various lags we also use the cross-climacogram presuming that it has a scaling behavior. Replacing the concept of cross-correlogram of two stationary processes $x(t)$ and $y(t)$ the *standardized cross-climacogram* (SCC) for scale k and lag h is defined as:

$$\rho_{xy}(k,h) = var\left[\frac{\underline{X}(k)}{2\sqrt{\Gamma_x(k)}} + \frac{\underline{Y}(k+h)-\underline{Y}(h)}{2\sqrt{\Gamma_y(k)}}\right] = var\left[\frac{\underline{X}(k)/k}{2\sqrt{\gamma_x(k)}} + \frac{(\underline{Y}(k+h)-\underline{Y}(h))/k}{2\sqrt{\gamma_y(k)}}\right]$$

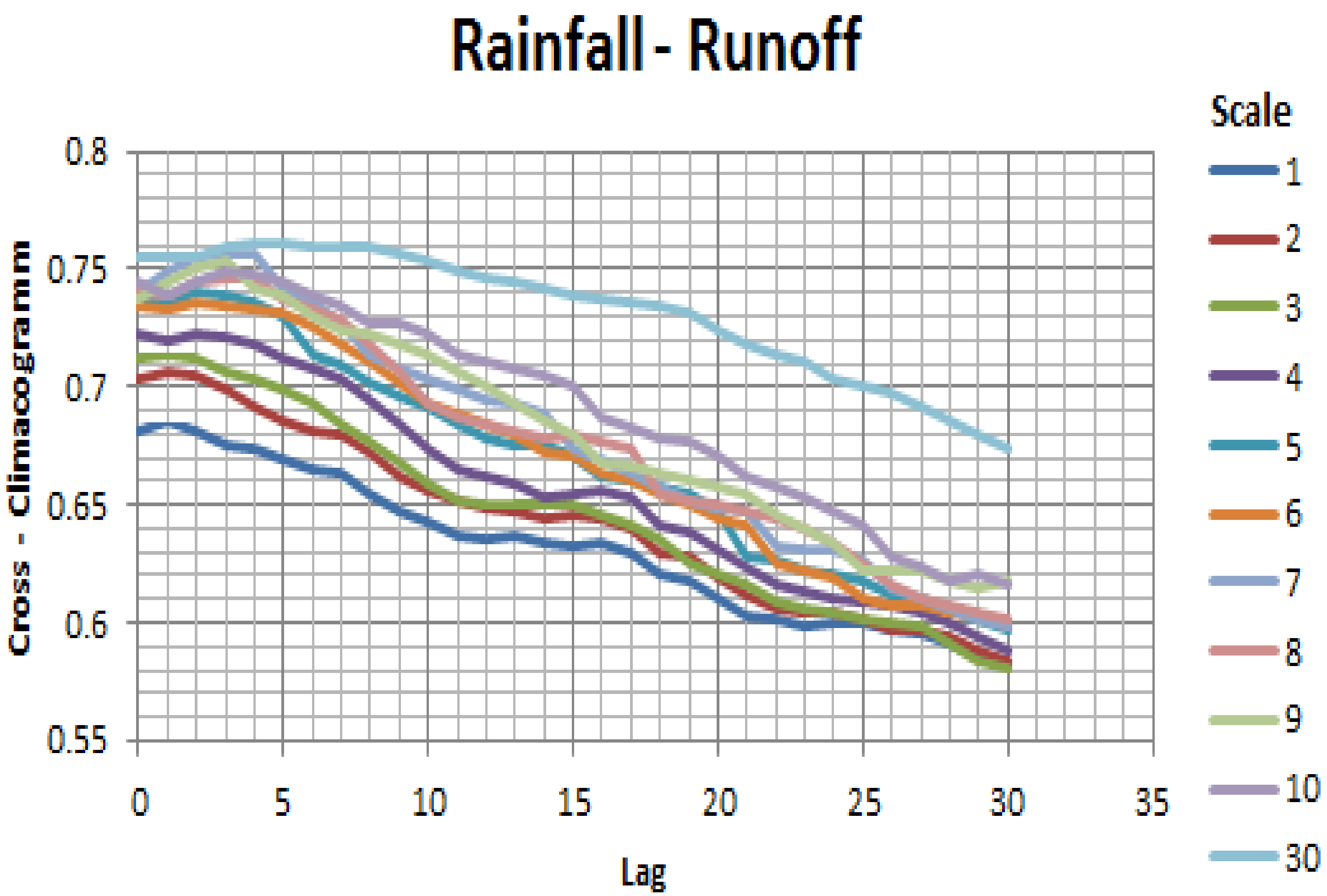
5. Catchment Attributes

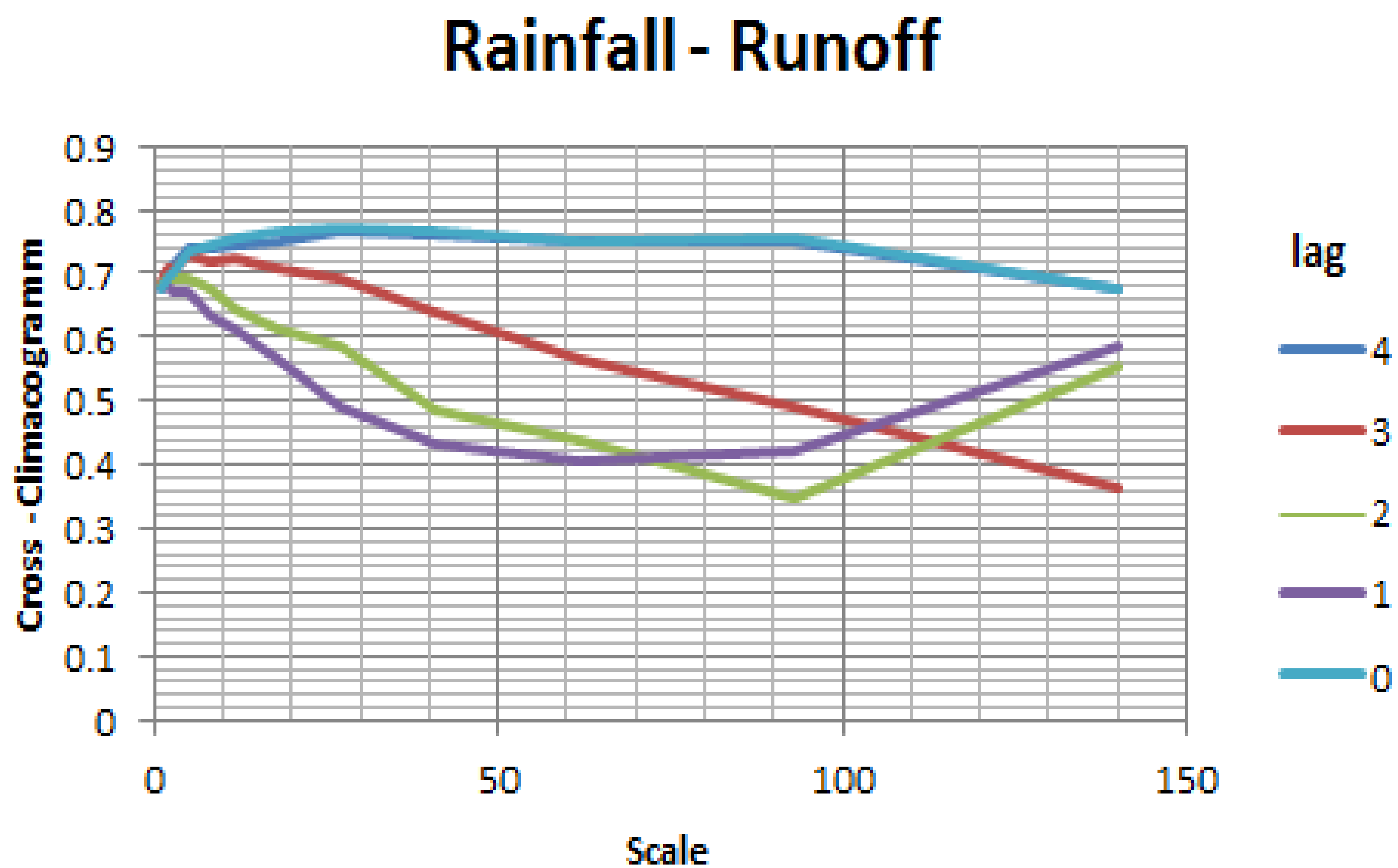
CAMELS-CL incorporates 64 catchment attributes. For the calculation of cross-correlations in this study, the following 5 were used:

- **aridity** : calculated as the ratio of mean daily PET (pet_mean) to mean daily precipitation (p_mean_i).
- **p_seasonality** : seasonality and timing of precipitation estimated using sine curves to represent the annual temperature and precipitation cycles positive (negative) values indicate that precipitation peaks in summer (winter) values close to 0 indicate uniform precipitation throughout the year)
- **slope_mean** : catchment mean slope.
- **area** : catchment area.
- **elev_gauge** : gauge elevation (catchment outlet) obtained from the 30-m ASTER GDEM elevation data and the location provided by DGA.
- **runoff_ratio** : runoff ratio (ratio of mean daily discharge to mean daily precipitation)

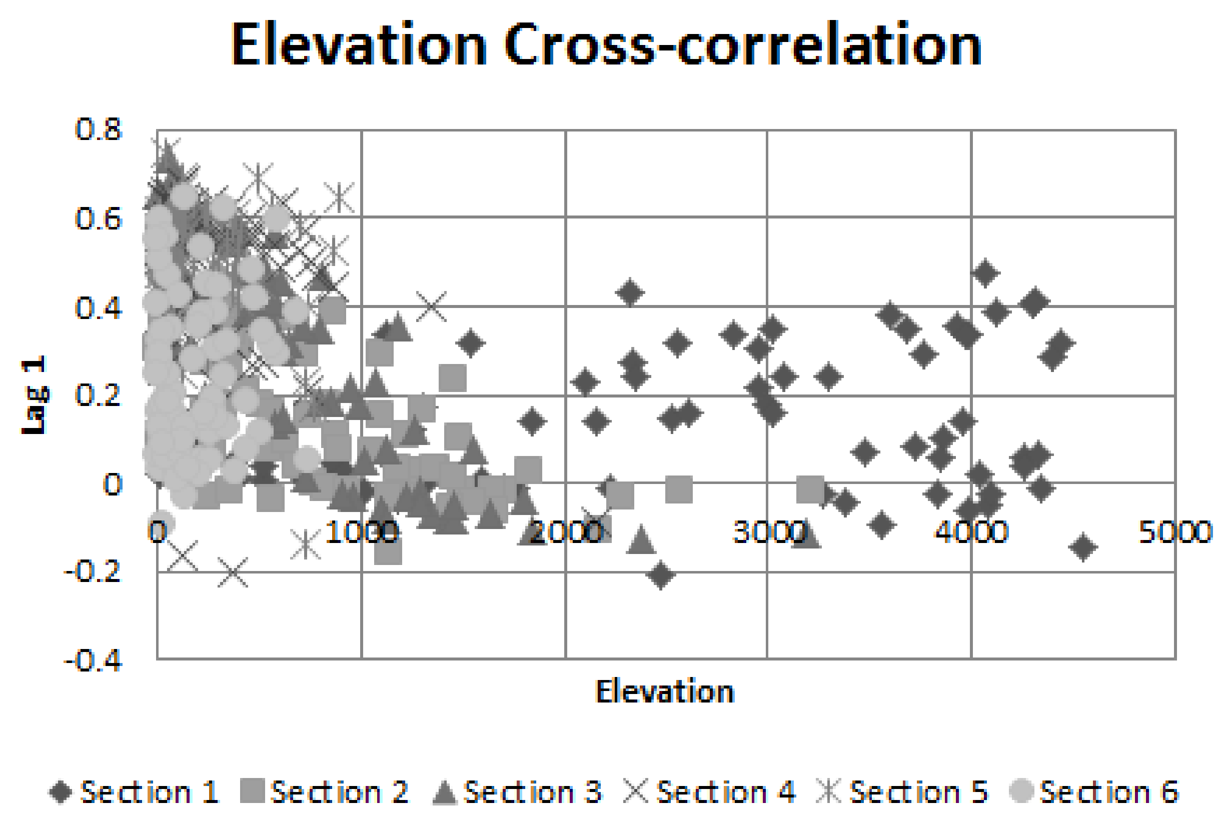
The stations were plotted as 6 sections, one for each section of Chile with distinct geographic configuration.

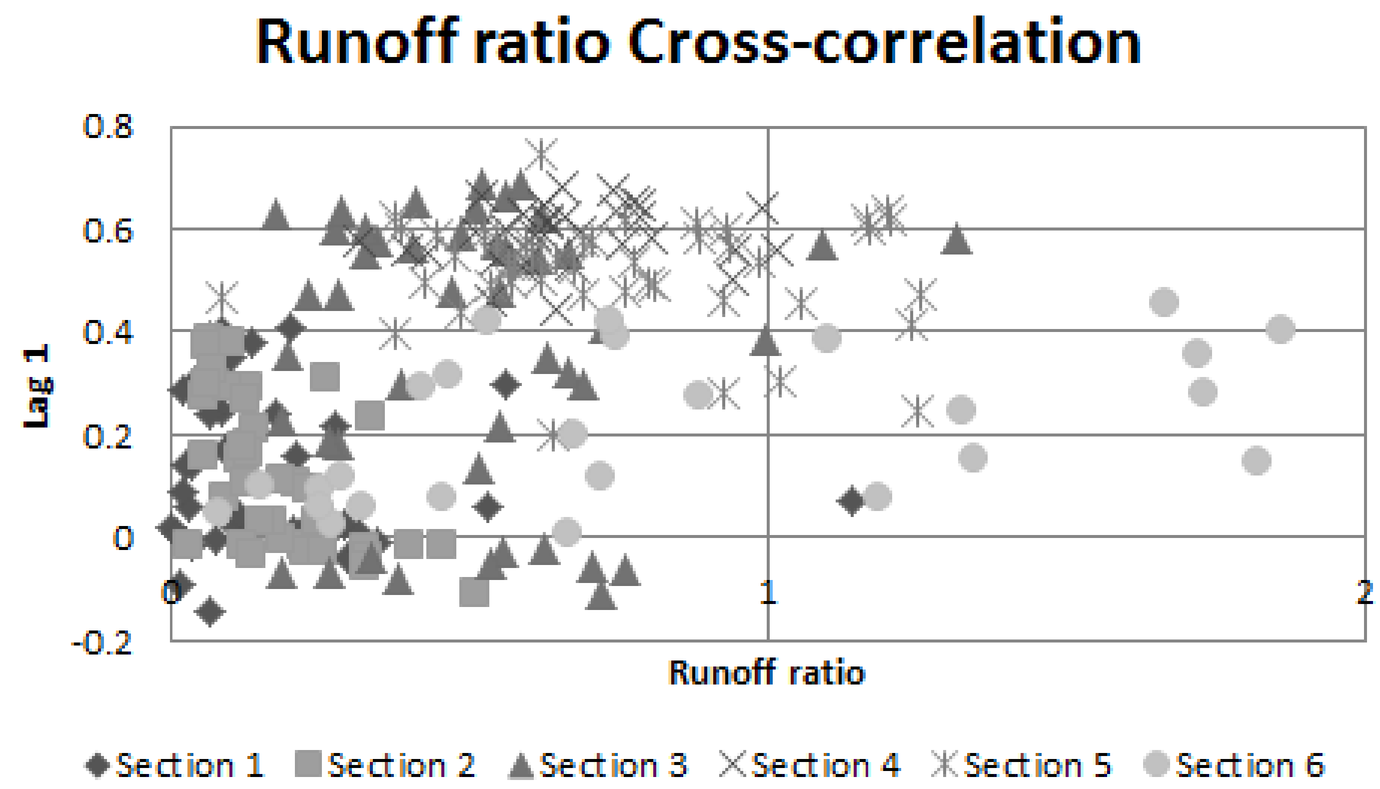
6. Cross-Climacograms "Rio Caque En cimiento station"

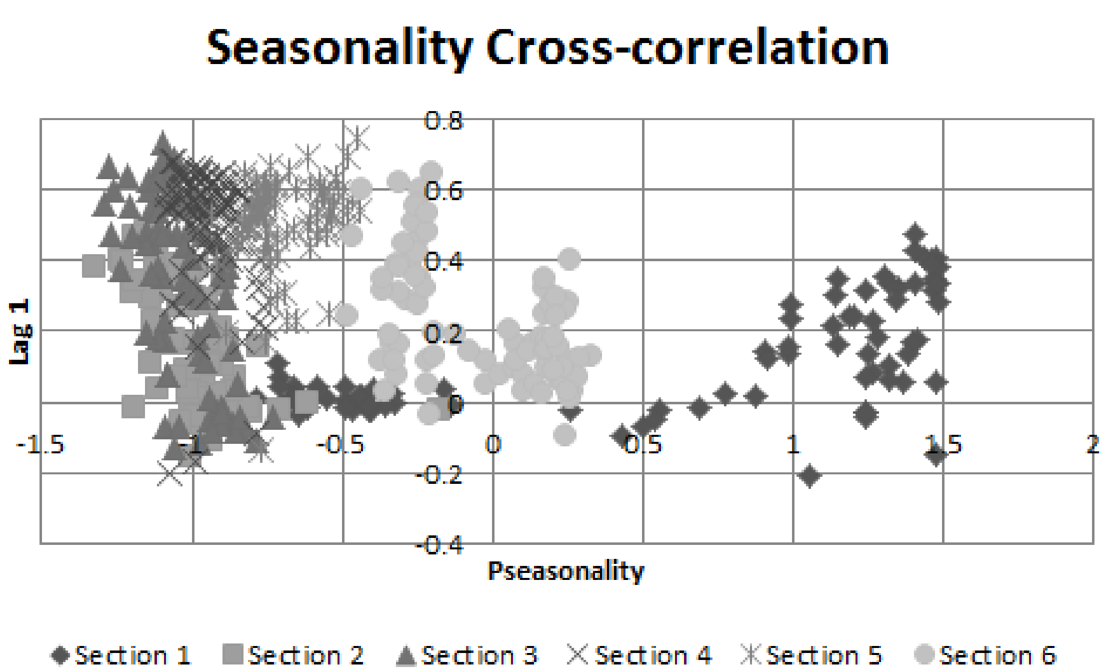


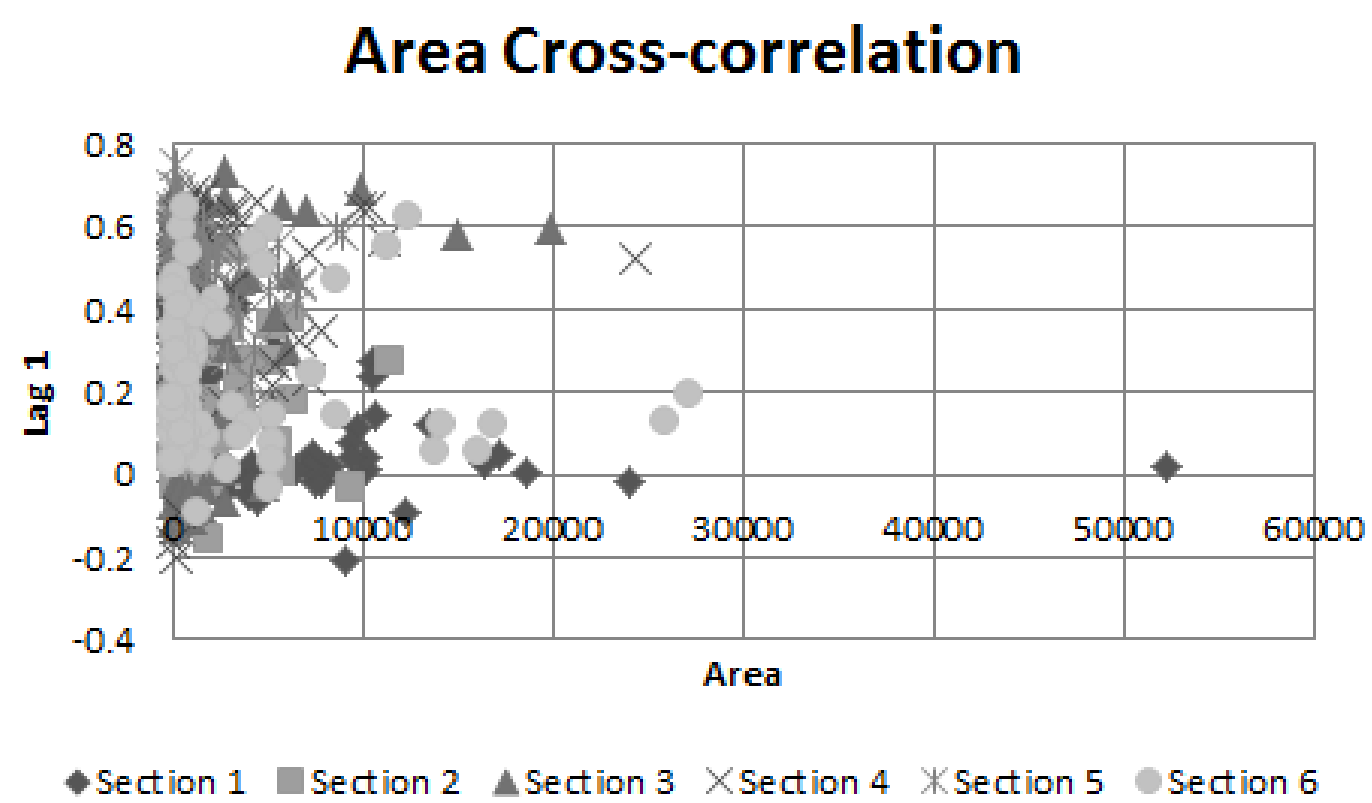


7.Rainfall-Runoff Cross-correlations with physical attributes (1)

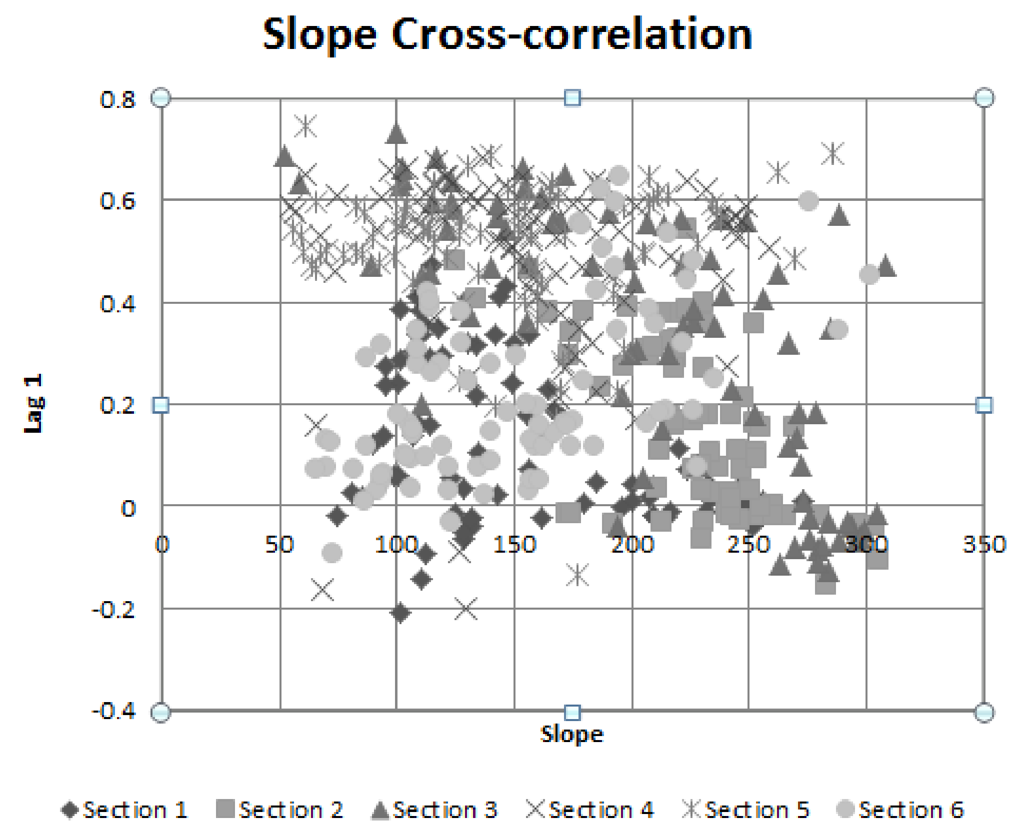


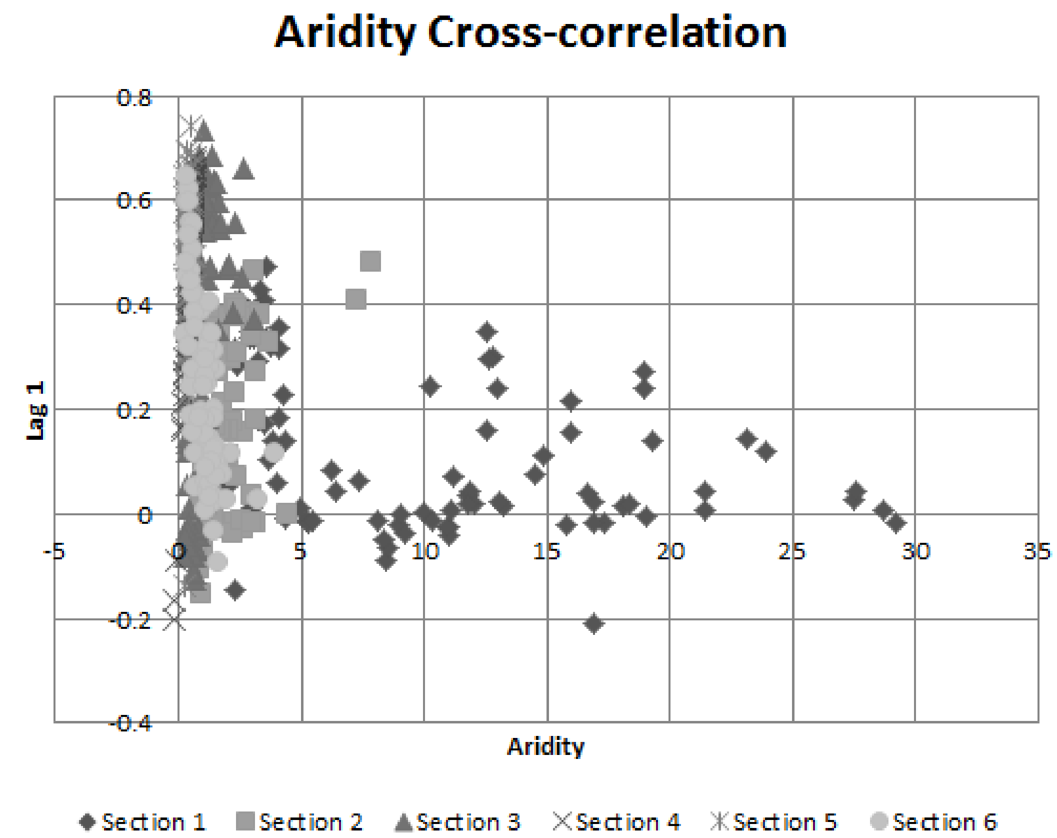


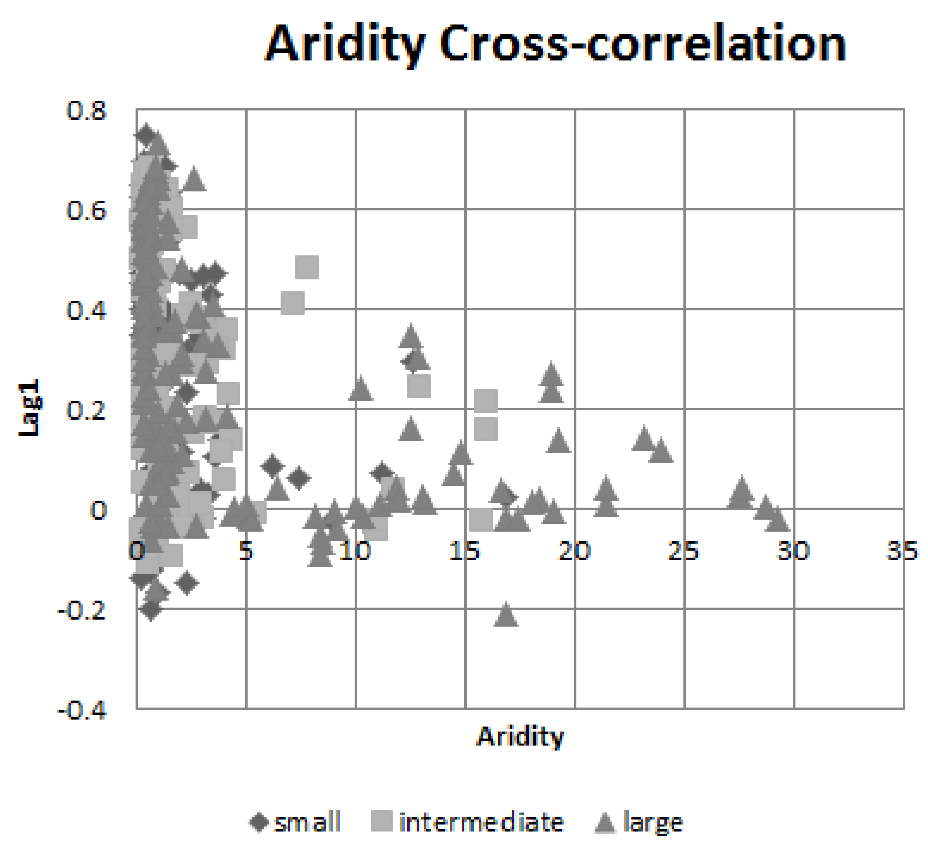


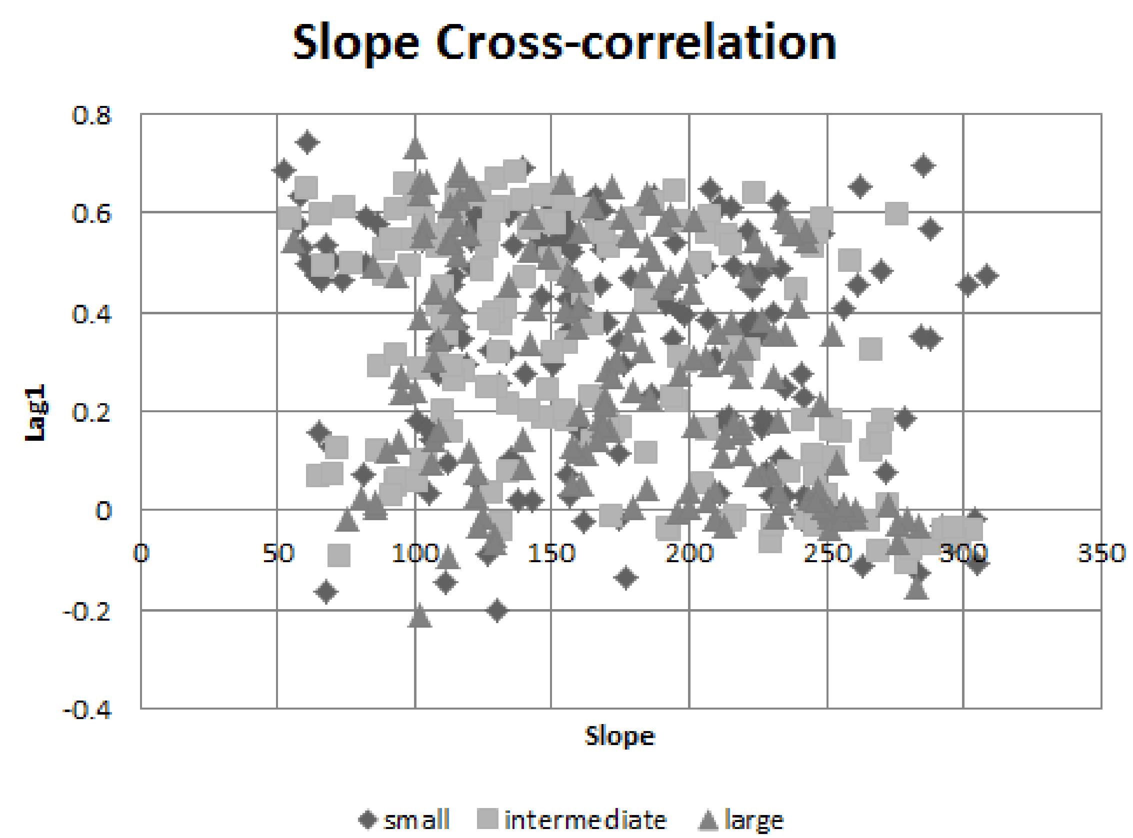


8. Rainfall-Runoff Cross-correlations with physical attributes (3)

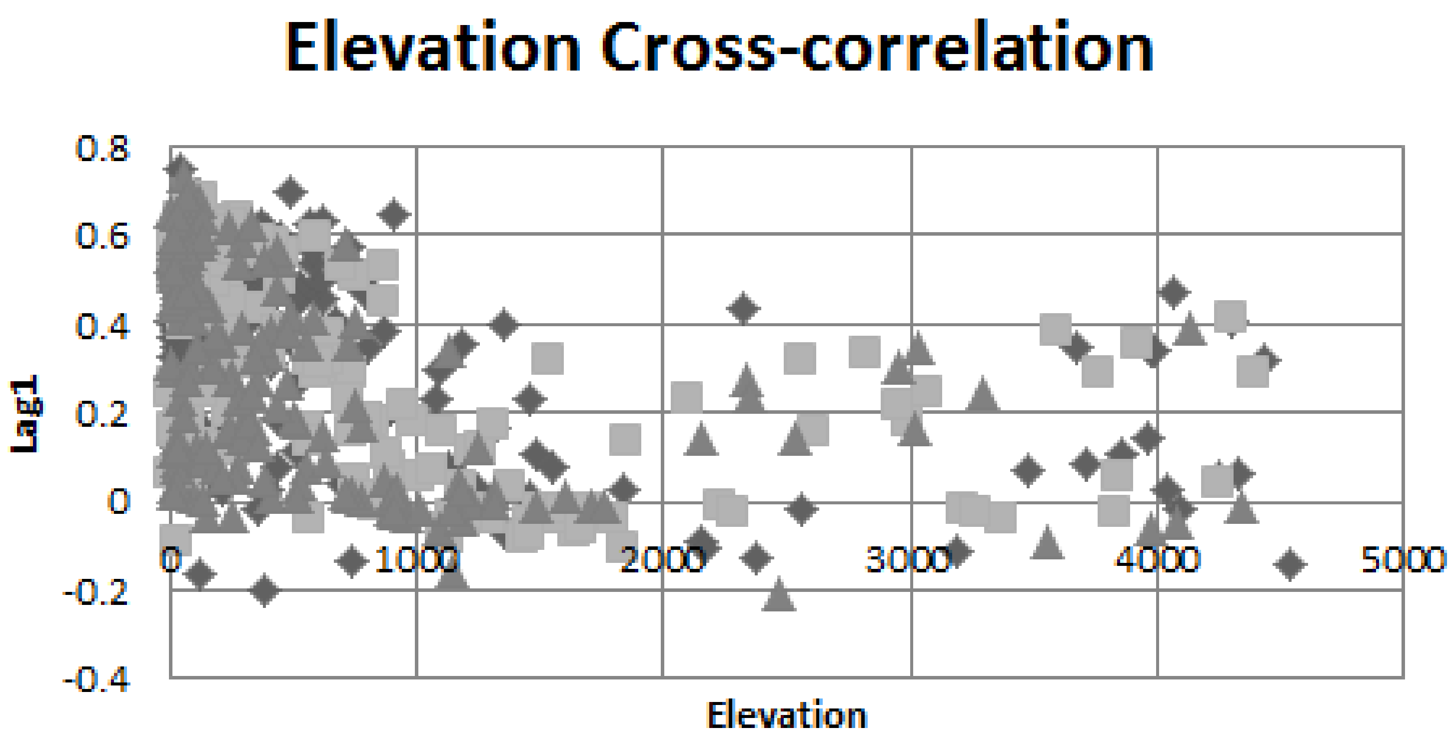


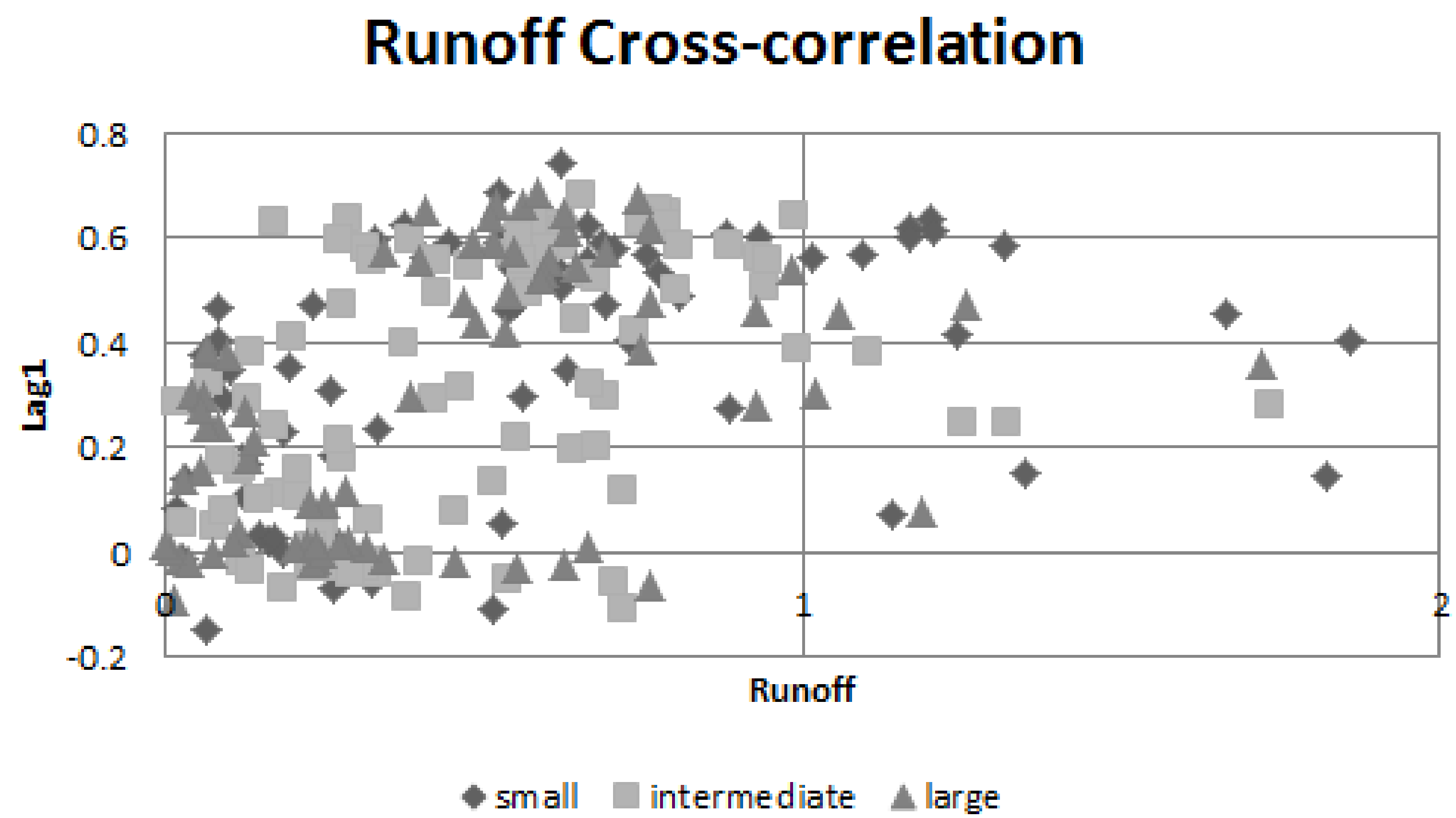


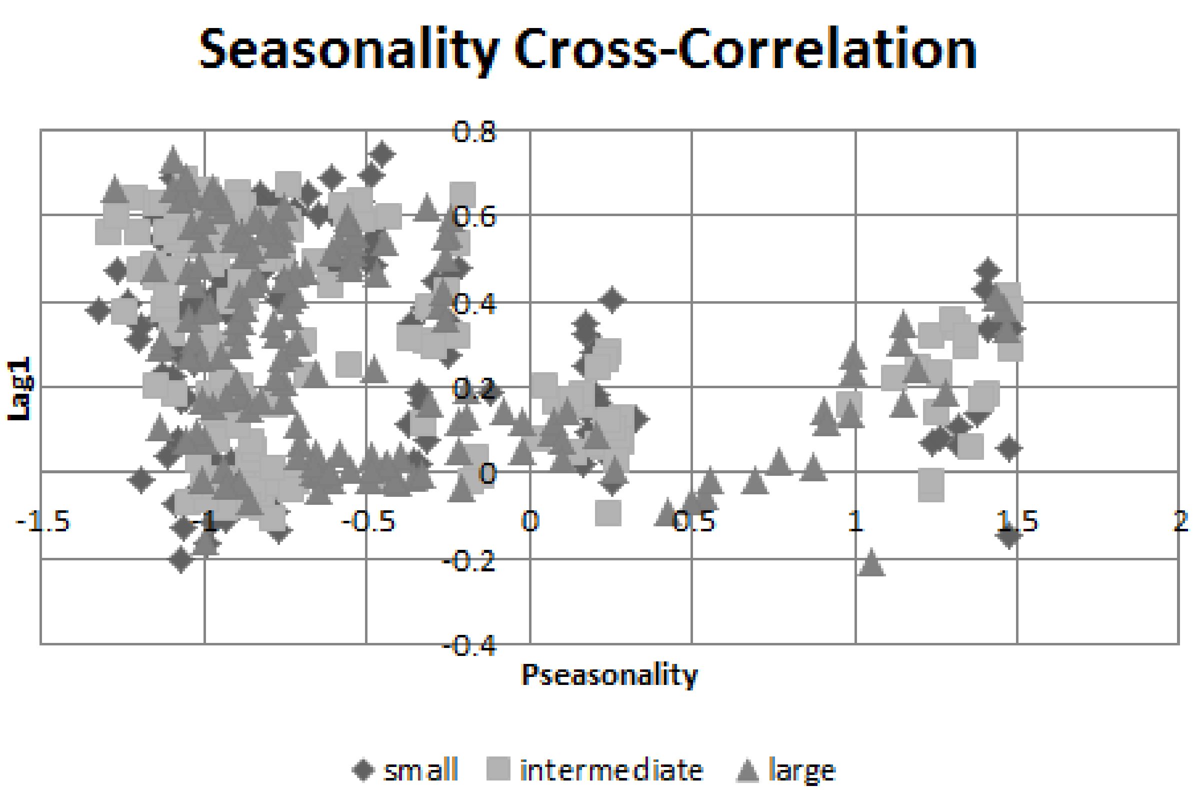




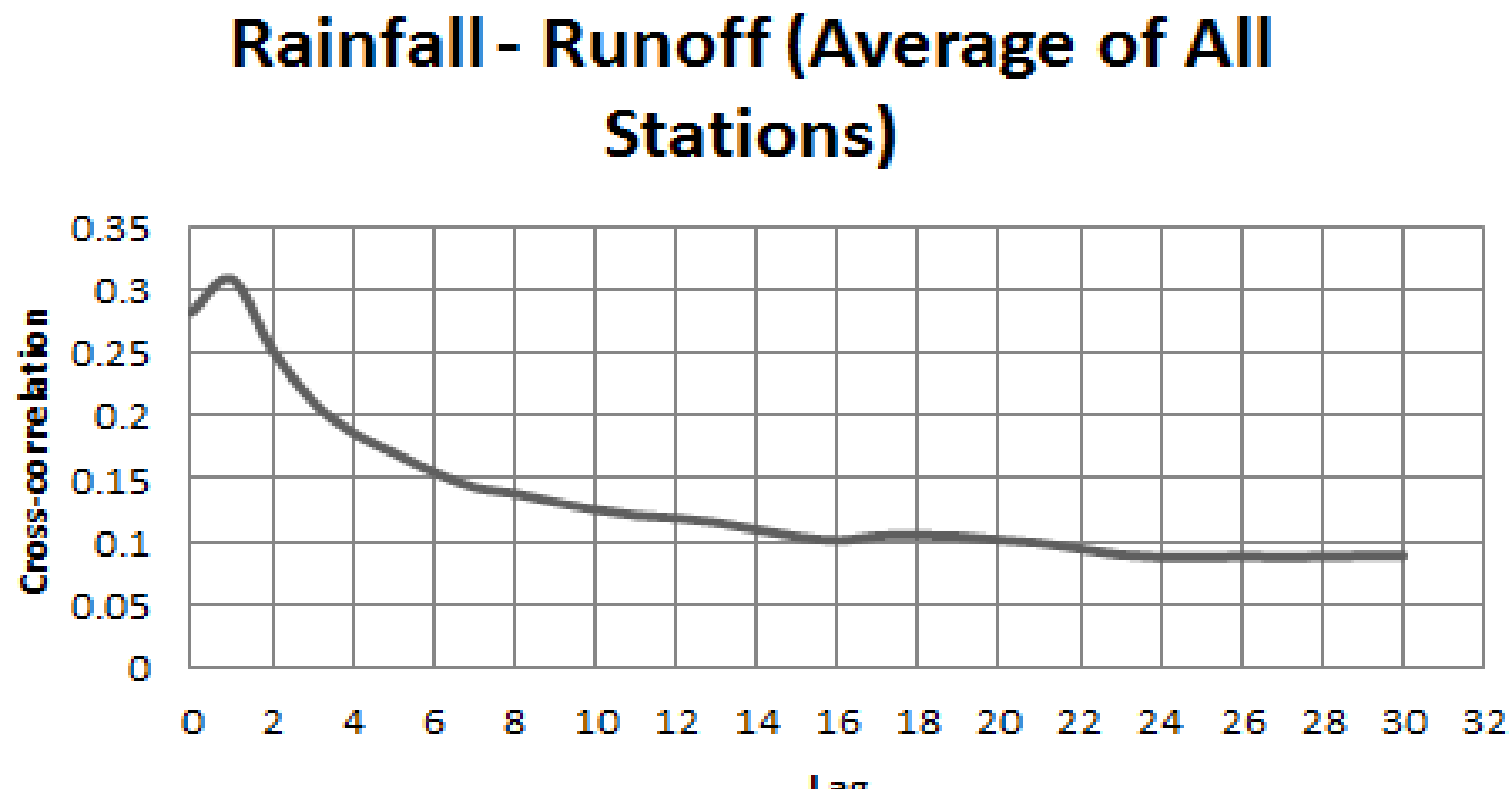
9. Rainfall-Runoff Cross-correlations with physical attributes (4)

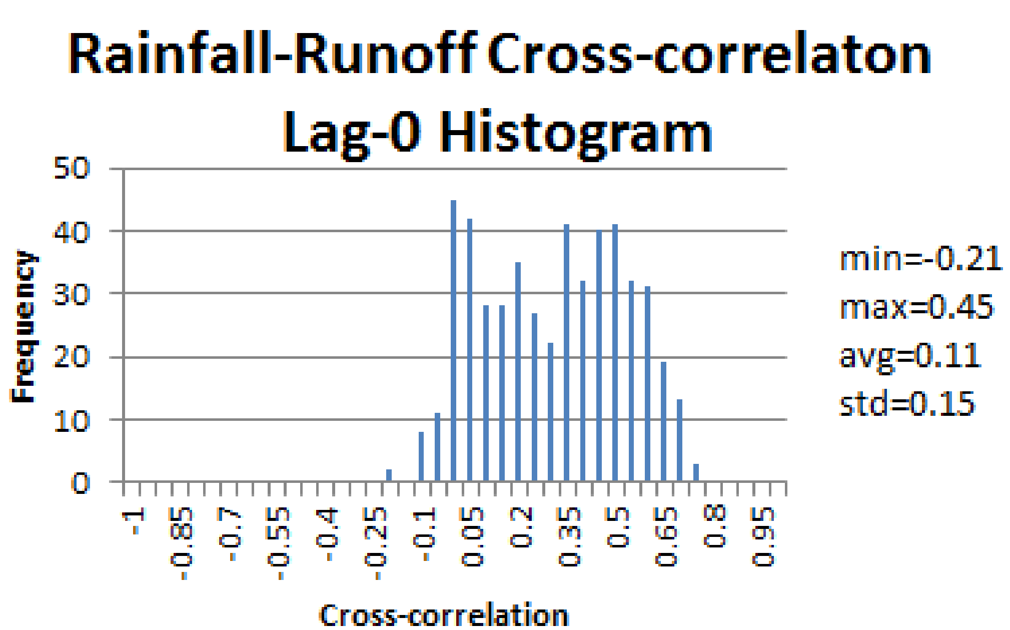


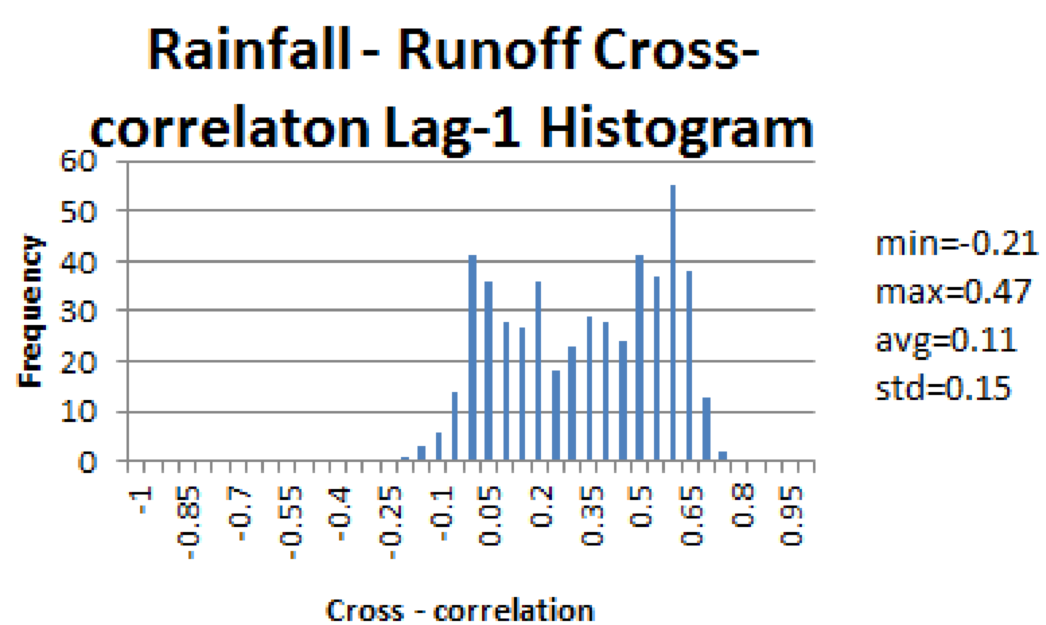


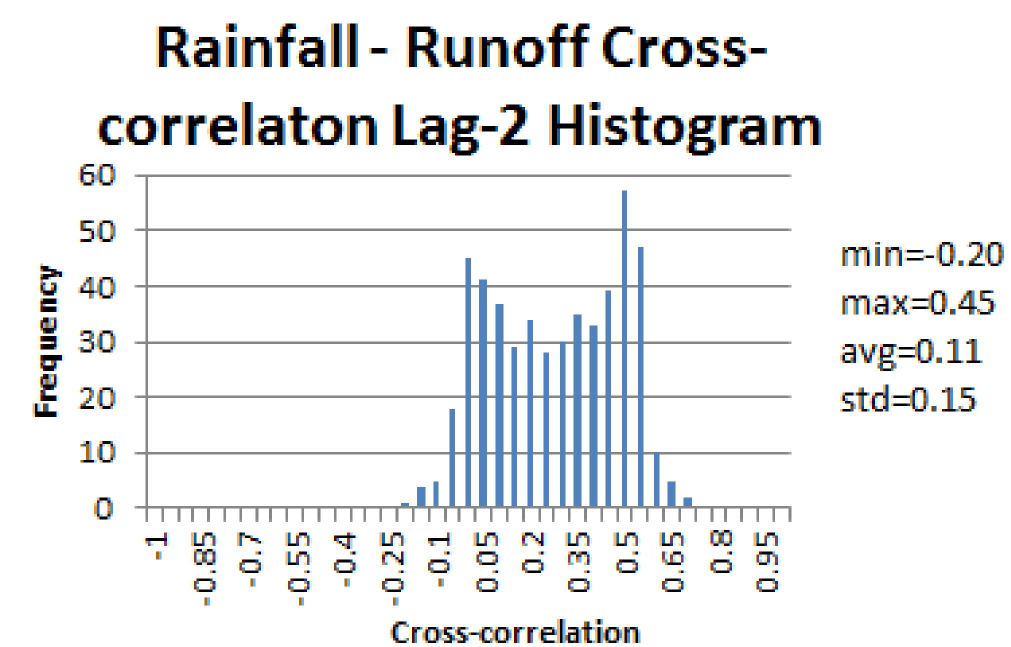


10. Results – Rainfall Runoff relationship









11. Conclusions

Using the CAMELS-CH dataset we have investigated the stochastic relationship of rainfall-runoff and its dependence on the catchment attributes. Our main conclusions are:

- The **strongest rainfall-runoff correlation** exists at the lag 0 and lag 1 for most gauges as expected, and converges to zero approximately after lag 14.
- The **influence of the physical attributes on the rainfall-runoff correlation depends on the lag**, and generally decreases with increasing lag, with the exception of the slope, whose impact on RR correlation increases till lag 10.
- The **aridity** and **elevation** have the largest effect on the cross correlation between rainfall-runoff.
- Using the cross-climacogram, we were able to identify the stochastic relationship of rainfall-runoff at various lags and temporal scales, at the station of "Rio Caque En cimiento" .
- Catchment area doesn't influence the cross correlation between rainfall and runoff and other physical attributes.
- The above findings and the stochastic methodology utilized may be proven useful to the understanding of the rainfall-runoff dynamics at various scales and the stochastic modeling thereof.

12. References

- [1] Koutsoyiannis, Demetris. (2018). Knowable moments for high-order characterization and modelling of hydrological processes. 10.13140/RG.2.2.14876.59529.
- [2] Alvarez-Garreton, Camila & Mendoza, Pablo & Boisier, Juan P. & Addor, Nans & Galleguillos, Mauricio & Zambrano-Bigiarini, Mauricio & Lara, Antonio & Puelma, Cristobal & Cortés, Gonzalo & Garreaud, Rene & Mcphee, James & Ayala, Alvaro. (2018). The CAMELS-CL dataset: catchment attributes and meteorology for large sample studies – Chile dataset. Hydrology and Earth System Sciences Discussions. 1-40. 10.5194/hess-2018-23.
- [3]Koutsoyiannis, Demetris. (2010). A random walk on water. Hydrology and Earth System Sciences. 14. 585–601. 10.5194/hess-14-585-2010.
- [4] Dimitriadis, Panayiotis & Koutsoyiannis, Demetris. (2015). Climacogram versus autocovariance and power spectrum in stochastic modelling for Markovian and Hurst–Kolmogorov processes. Stochastic Environmental Research and Risk Assessment. 29. 10.1007/s00477-015-1023-7.