Hydraulic-hydrologic model for the Zambezi River using satellite data and machine learning techniques

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Problem statement

The Zambezi River Basin, in Southern Africa, is home to approximately 30 million people and covers nearly 1 400 000 km^2. It is shared by eight countries hosts ecosystems of unparalleled value (e.g. the Kafue Flats, the Zambezi-Chobe Confluence, the Mana Pools and the Barotse Plains) and has an impressive hydropower potential (nearly 5000 MW of installed capacity plus some additional 6830 MW foreseeable in a 20-year horizon) containing two of the largest reservoirs in the world (Kariba and Cahora Bassa).

In terms of integrated water resources management, the riparian states face grave challenges; some of those being the preservation of natural ecosystems, the achievement of synchronized dam operations, the development and implementation of better flood forecasting systems (tenths of thousands are affected by rising waters) and the planning of future water allocations towards an equitable use of the river's resources. In order meet these challenges, adequate modeling tools must be developed.

Objectives

In line with the Competence Center Environment and Sustainability (CCES) funded African DAms ProjecT (ADAPT), the PhD project is to contribute to the creation and enhancement of a general purpose daily time step semi-conceptual hydraulic-hydrologic model for the Zambezi, providing guidelines and methodologies applicable to similar basins. Focus will be given to model calibration and validation techniques.

Methodology

On a first stage, the work focused on bibliographic research, with particular interest on the hydrology of semi-arid basins, remote sensed data applications and machine learning techniques. Also, emphasis was placed in gathering base data for the hydrological model, such as digital elevation maps, discharge, rainfall and evapotranspiration.

Being data scarcity one of the main difficulties associated with preparing an accurate, yet reliable hydrological model of the Zambezi, the following phase was dedicated to data series extension.

Modelling work started by the development of a preliminary model. Lessons learnt from this effort will be used for model structure improvement and the development of hybrid (classical – machine learning) hydrological submodels.

Results

Up to date, the research has been focused on preliminary but necessary work, such as the acquisition, preparation and operationalization of hydrological and topography inputs, the development of algorithms for automatic model construction and the evaluation of hydrological impacts of existing impoundments (Figure 1).

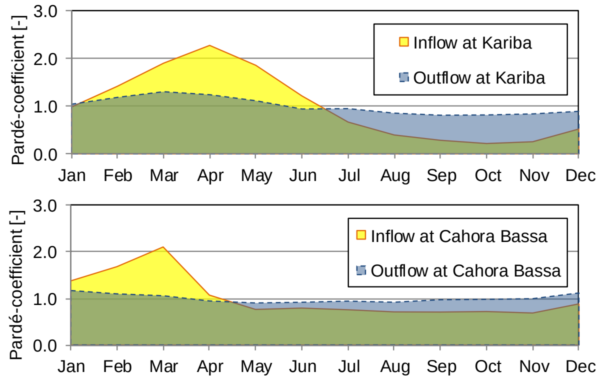

Figure 1. Pardé-coefficients quantifying seasonal water transfers in the Kariba and Cahora Bassa reservoirs.

With the aim of extending model calibration periods, research was also conducted in optimal rainfall interpolation techniques at large spatial scales (in Figure 2 the true TMPA 3B42 rainfall estimate is recreated using a restricted set of pixels – in black – through several techniques)

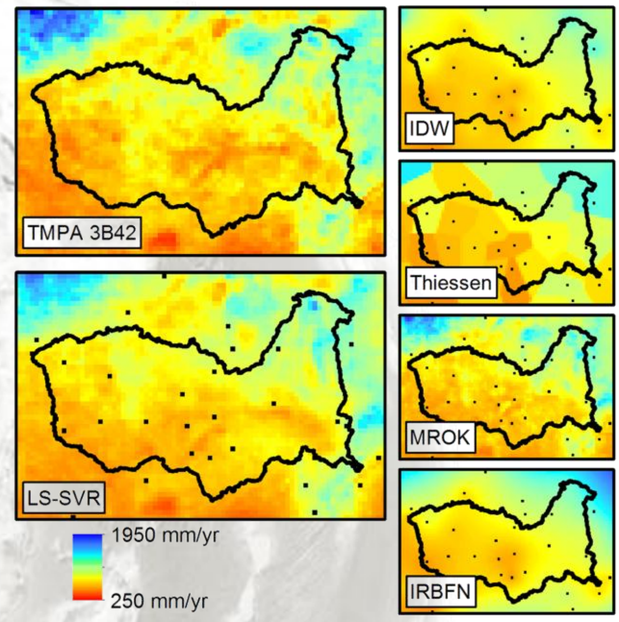

Figure 2. Rainfall interpolation at large spatial scales. The true TMPA3B42 rainfall estimate on top left is reproduced by several techniques using information in the black squares. Emphasis is given to the novel LS-SVR technique.

With a flexible operation of the hydrological model, future work will emphasize the development of a versatile semi-automated calibration methodology, based on the concept of Bayesian inference, the evaluation of the performance gains attainable by coupling the semi-conceptual hydrological model with machine learning techniques, and the assessment of the quality of hydrological forecasts.