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Research Paper

Water availability and agricultural demand: An assessment framework using global datasets in a data scarce catchment, Rokel-Seli River, Sierra Leone

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ABSTRACT

Study region: The proposed assessment framework is aimed at application in Sub-Saharan Africa, but could also be applied in other hydrologically data scarce regions. The test study site was the Rokel-Seli River catchment, Sierra Leone, West Africa.
Study focus: We propose a simple, transferable water assessment framework that allows the use of global climate datasets in the assessment of water availability and crop demand in data scarce catchments. In this study, we apply the assessment framework to the catchment of the Rokel-Seli River in Sierra Leone to investigate the capabilities of global datasets complemented with limited historical data in estimating water resources of a river basin facing rising demands from large scale agricultural water withdrawals. We demonstrate how short term river flow records can be extended using a lumped hydrological model, and then use a crop water demand model to generate irrigation water demands for a large irrigated biofuels scheme abstracting from the river. The results of using several different global datasets to drive the assessment framework are compared and the performance evaluated against observed rain and flow gauge records.
New hydrological insights: We find that the hydrological model capably simulates both low and high flows satisfactorily, and that all the input datasets consistently produce similar results for water withdrawal scenarios. The proposed framework is successfully applied to assess the variability of flows available for abstraction against agricultural demand. The assessment framework conclusions are robust despite the different input datasets and calibration scenarios tested, and can be extended to include other global input datasets.

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1. Introduction

1.1. Introduction and background

Water security is closely tied to knowledge of existing water resources and the ability to use hydro-meteorological data to quantify these resources. Water resources management and allocation has traditionally been supported by quantitative tools (such as hydrological models) to reduce the uncertainty associated with subjective decision making. However, reliable water management decisions and policy continue to be constrained by data scarcity and unreliability, typically so in African contexts (Guzinski et al., 2014).

Long term monitoring of water resources requires well established observation networks which can provide data for hydrological modelling tools, which in turn aid in robust decision making. But in sub-Saharan Africa, the classical predicament of data unavailability due to incompleteness of existing records, poorly maintained data collection infrastructure and the reluctance to distribute existing data underpins the challenge of achieving adequate hydrological characterization in many catchments.

Decisions on water use and allocation are however still being made, with resultant over-allocation between competing uses, especially so agricultural water use, which accounts for an estimated 85% of continental water consumption (Valipour, 2015). The challenge in these contexts, therefore, is how to make meaningful and sustainable water allocation decisions in the absence of conventional hydro-meteorological data.

In Ethiopia, Bossio et al. (2012) explored the implications of large scale agricultural development within a context of hydro-meteorological data scarcity, concluding that the impacts of uncontrolled water allocations are primarily an aggravation of water scarcity for smaller scale stakeholders. In Sierra Leone, typified by extreme lack of water resources information, over-allocation of water resources for a green-field biofuels project has already impacted local water resources through the depletion of local streams (Ananae and Abiwu, 2011).

The availability of freely accessible global data sets from various sources including remote sensing, interpolation of scant ground data using climate models (reanalysis data) and a maturing hydrological modelling science field are providing options for complementing scarce observation data. Wagner et al. (2009) demonstrated the application of remotely sensed data in estimation of current and future water resources in data scarce catchments in West Africa, concluding that with inclusion of uncertainty (often these datasets suffer from high uncertainties resulting from physical sensor limitations and limited spatial-temporal coverage and resolution, see Prigent, 2010; Yong et al., 2014), outputs from modelling using remotely sensed data in poorly gauged basins are useful.

In the Senegal River basin, Stisen and Sandholt (2010) evaluated remote-sensing-based rainfall products for their capability in calibrating hydrological models for water resources estimation, concluding that models calibrated and forced by satellite data inputs have Nash-Sutcliffe Efficiencies (NSE), between 0.63 and 0.87, reflecting acceptable simulation of catchment water balance components.

Presently there are many hydro-climatological and other relevant datasets available that can help with the assessment of water resources (WMO, 2012) including, for example, the Global Historical Climatology Network (GHCN) dataset (Smith and Reynolds, 2005), MSWEP (Multi-Source Weighted-Ensemble Precipitation) dataset (Beck et al., 2016), Climatic Research Unit CRU TS 2.1/3.1 (Mitchell and Jones, 2005), Global Precipitation Climatology Centre (GPCC) dataset (Schneider et al., 2011), WorldClim (Hijmans et al., 2005), and the Shuttle Radar Topography Mission (SRTM) (Jarvis et al., 2008). The TIGER-NET initiative of the European Space Agency (ESA) is also advancing the production and application of a range of relevant satellite-based information products needed for water resources management in Africa (Guzinski et al., 2014).

There are also a whole range of established hydrological modelling methods that can be used in conjunction with these global datasets to provide a better assessment of needs and resources than using local data alone. However, these freely available datasets have mostly been restricted to scientific research and rarely been adopted for decision making on the ground.

Amongst other reasons, inadequate quantitative skills for analytical analysis has led to the restricted use of these datasets, as evidenced in the Nile Basin Initiative project in East Africa (Giupponi and Sgobbi, 2013). In assessing the limited uptake of remotely sensed data in Africa, Roy et al. (2010) and Kufoniyi (2009) cited the multiplicity of geospatial datasets and the resultant uncertainty as to how, when or even what dataset to deploy for decision making, as a key barrier. The lack of dependable methodologies to manipulate and extract these datasets for water resources assessment purposes underlines the challenge of applying them for decision making.

The aim of this paper is to present a simple yet effective framework which incorporates freely available remotely sensed global datasets and models that do not require sophisticated analytical capabilities, which are a barrier to the uptake of these datasets, to answer classical water resources questions in a real context in Sierra Leone where increasing agricultural, human and ecological demands, added to the pressures of climate change, calls for careful management of water resources.

1.2. Water quantity issues in the Rokel–Seli catchment

The Rokel-Seli has a drainage area of 8236 km^2 making it the third largest (in terms of size) of the nine major river systems in Sierra Leone. This watershed is of critical importance to the economy of the country, supplying water to the Bumbuna dam