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Finding sustainable water futures in data-sparse regions under climate change: Insights from the Turkwel River basin, Kenya

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ABSTRACT

Study region: the Turkwel river basin, Kenya experiences a high level of water scarcity due to its arid climate, high rainfall variability and rapidly growing water demand.
Study focus: Climate change, variability and rapid growth in water demand pose significant challenges to current and future water resources planning and allocation worldwide. In this paper a novel decision-scaling approach was applied to model the response of the Turkwel river basin's water resources system to growing demand and climate stressors. A climate response surface was constructed by combining a water resource system model, climate data, and a range of water demand scenarios.
New hydrological insights: The results show that climate variability and increased water demand are each important drivers of water scarcity in the basin. Increases in water demand due to expanded irrigation strongly influences on the resilience of the basin's water resource system to droughts caused by the global climate variability. The climate response surface offers a visual and flexible tool for decision-makers to understand the ways in which the system responds to climate variability and development scenarios. Policy decisions to accelerate water-dependent development and poverty reduction in arid and semi-arid lands that are characterised by rapid demographic, political and economic change in the short- to medium term have to promote low-regrets approaches that incorporate longer-term climate uncertainty.

1. Introduction

Sustainability of global freshwater is under increasing threats due to changing hydroclimate and abstraction to satisfy rapidly growing water demand (Hall et al., 2014; Wada et al., 2014). Understanding how socio-economic change put additional stress on water resources and translating the scientific evidence into policy decisions are critical steps towards ensuring sustainable water use and allocation (Sadoff and Hall, 2015; Dadson et al., 2017). Regions where development is most acutely needed are often those where data to inform long-term investment decisions is most severely lacking. This paper analyses the drivers of water scarcity in a data-sparse river basin and offers insights that can inform and challenge approaches to water resources planning in data-sparse regions in other basins worldwide.

In East Africa, severe droughts often cause water and food crises affecting millions of people and livelihoods (FEWS NET, 2017). About 3.4 million people in 23 arid and semiarid Kenya counties required food assistance during the second half of 2017(Kenya Food Security Steering Group, 2017). Turkana County was one of the most severely impacted (NDMA, 2017). Highly variable water

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resources and reduced flows in the Turkwel River trigger large human and livestock migration in search of water across country borders to Uganda and Ethiopia (Johannes et al., 2015). Despite the critical importance of water in the basin, the impact of hydroclimatic variability and demand growth on the water resources of the basin remains poorly understood, owing to the lack of scientific studies and limited biophysical data.

The objective of this paper is to identify the main drivers of water scarcity in the data-sparse basin. We estimate the resilience of the basin's water resources system to hydroclimatic changes and growing water demand by modifying the decision-scaling method introduced by Brown et al. (2012) to account for the limited data availability. Using a water resources system model and historical climate data, we construct a climate response surface that shows the ways in which the system responds the climate stressors. Further, we assess the future climate risks using climate projections from Global Circulation Models (GCMs) and investigate the past impacts of the global climate variability using years with strong El Niño/Southern Oscillation (ENSO) events. Finally, we show the impact of growing water demand using various demand scenarios estimated based on different levels of existing or planned agriculture and various population growth rates. Our findings demonstrate the importance of climate risk analysis in development planning and potential climate adaptation measures in regions with limited data to inform long-term decisions.

2. Study area

The Turkwel River basin is located in north-western Kenya (Fig. 1). The river originates in the Uganda side of Mount Elgon and drains into Lake Turkana, the largest desert lake in the world (Avery, 2012), covering a total catchment area of 23,740 km^2. The basin has a complex hydroclimate with highly diverse topography and a marked south-west to north-east rainfall gradient. The southern highlands (SC1 and SC2) receive between 900 and 1749 mm/year; while the arid northern lowland plains (SC4) receive annual rainfall ranging from 99 to 400 mm/year. The basin experiences two rainy seasons: March–June (long-rain) and October–December (short-rain).

The river supplies water to several competing socio-economic sectors. Turkwel Gorge Dam (TGD, 37 km^2 reservoir area, Lehner et al., 2011) produces106 MW, which is the third largest hydroelectric power output of the country (KENGEN, 2017). Several small-scale irrigation projects depend on the river water or shallow boreholes linked to it. The total irrigated area was estimated to be 18 km^2 in 2013 (Maina et al., 2013), but it has continued to expand. The recently proposed Turkwel Multipurpose Project includes an irrigation scheme of 300 km^2 of land for sugar cane and food crop production (KVDA, 2013).

Lodwar town relies on groundwater in alluvial systems for municipal water supply. According to the most recent Kenya's official population and housing census, the population of Lodwar was 45,368 in 2009, and projected to exceed 75,000 in 2017 (CIDP, 2017). The recent discovery of oil in South Lokichar Basin located southeast of Lodwar town (Kuper and Haberer, 2016) and emerging industries could potentially abstract water from the river. In Kenya, environmental flows (EF) are defined as the Q95 (the 5 percentile flow) of the natural flow. The cascade of water abstraction points from the river and water loss (and flow regulation) from the dam can result in unmet EF requirements. This may cause water stress and conflicts among pastoralists who account for 55% of Turkana County population (Johannes et al., 2015).

3. Method

3.1. Climate risk assessment

Climate risk assessment in East Africa is subjected to high uncertainty in the precipitation projections (James et al., 2014; Dosio et al., 2015). Water resources models forced with the precipitation projections aggregates uncertainty by the cascade of models and could lead to a potential climate maladaptation (Wilby and Dessai, 2010). A novel decision support method, known as 'decision scaling' (Brown et al., 2012), was proposed, in which climate projections are used to inform decisions related to risk mitigation rather than being directly used as forcing to water resource models. The method has been applied climate risk assessment on the reliability of municipal water supply (Brown and Wilby, 2012), flood risk analysis (Steinschneider et al., 2015), suspended sediment transport (Bussi et al., 2016), and flood inundation and protection costs (Poff et al., 2016).

Here we apply the decision scaling approach to assess the resilience of the Turkwel basin water resource system to climate change and variability and to growing water demand. The method consists of three major steps: 1) identifying water-related risks through engagement with local stakeholders, 2) determining climate conditions that can lead to those risks and constructing a climate response surface, and 3) assessing climate risk using data from GCM climate projections.

3.1.1. Water-related risk in the basin

We identified water-related risks in the basin through meetings with local stakeholders and an ongoing engagement through REACH-Improving water security for the poor programme (https://reachwater.org.uk/). The frequent droughts, intensive upstream abstraction from the river, and flow regulation by the dam are perceived to cause water scarcity in the basin. We categorised the risks into four classes (Table 1) to depict the level to which the water demand is met and the degree of reliance on groundwater sources to satisfy the demand. The risk level could increase from low to high as a result of a reduced precipitation amount, a rapid increase in water demand, or a combination thereof. The severe risk level is the most unsustainable since it means that agricultural water demand cannot be met during the growing season potentially leading to crop failure, and that groundwater could severely be depleted.