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Modelling the forest and woodland-irrigation nexus in tropical Africa: A case study in Benin

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ABSTRACT

Major increases in food production are needed to feed the rapidly growing population of sub-Saharan Africa. Increased application of irrigation has often been identified as one of the main pathways to agricultural intensification. However, water flows, in particular during the dry season, often depend upon the water regulation services provided by forests and woodlands which are increasingly subject to land conversion as well as degradation from the overexploitation of wood resources. Insight in the trade-off between land conversion in sub-Saharan African uplands and sustaining water flows is, therefore, urgently needed. In this paper, we develop a general modelling approach for analysing the effects of deforestation on the availability of water for irrigation at the watershed level, and we apply the approach to the Upper Ouémé watershed in Benin. We use controlled modelling experiments based on the Soil and Water Assessment Tool (SWAT) in addition to copula functions to quantify surface water availability and irrigation potential under prevailing forest and woodland cover as well as varying forest and woodland extents. We undertake these comparative analyses for two irrigation development scenarios that are defined based on different levels of sustained water flows in the Upper Ouémé river network. Our analyses show that conservation of prevailing forests and woodlands in the Upper Ouémé watershed is needed to allow the development of 80% (15,000 ha) or 71% (20,000 ha) of the irrigation potential in the dry season depending on the scenario. At the prevailing forest and woodland extent, the loss of around 40 ha of forest and woodland area reduces the irrigation potential by 1 ha depending on the scenario. Our irrigation potential calculations are based on the water requirements of rice which is the most water intensive crop grown in the study area. For other crops, the ratio will be lower (i.e. less forest and woodland area is required to sustain 1 ha of irrigated crop production). The relation between forest and woodland extent and irrigation potential is, however, not linear, and more hectares of forest and woodland are needed to support 1 ha of irrigated crop production with increasing deforestation. This is relevant for trade-off analysis, where it needs to be noted that the forests and woodlands not only generate water regulation services but also provide other ecosystem services including fuelwood, timber, opportunities for livestock grazing and carbon sequestration.

1. Introduction

Food insecurity is a major problem in sub-Saharan Africa. Still, one in every four persons in this region is undernourished and agricultural productivity remains the lowest in the world (FAO et al., 2015). With the population of sub-Saharan Africa estimated to double by 2050 compared to 2015 estimates (an increase of 1.2 billion people), there is an urgent need to increase food production (UN, 2015). Current productivity levels for major food crops are inadequate to meet projected demand (Alexandratos and Bruinsma, 2012). Improving food security requires the sustainable management of many production factors such as water availability, soils, nutrients, crop health etc. The limited use of irrigation in particular has been consistently cited as a major factor for the low productivity levels (Burney et al., 2010; You et al., 2011; Xie et al., 2014). Currently, about 97% of cropland area in sub-Saharan Africa is rainfed with less than 4% irrigated (You et al., 2011). Investments in irrigation are regarded as a potential means to improve food security and as a strategy for poverty reduction in sub-Saharan Africa (Dillon, 2008; FAO, 2008; You et al., 2011; Nkhata, 2014; Xie et al., 2014). For example, in northern Benin irrigated land dedicated to vegetable

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production significantly increased local vegetable availability resulting in increased consumption and household income especially in the dry season (Burney et al., 2010). Hence, there has been a renewed interest in both small-scale and large-scale irrigation developments in recent years. For example, one of the targets in the Africa Water Vision 2025, adopted by the African Union member states, is to double the size of irrigated area in this region by 2025 (UNECA et al., 2003). An FAO study forecasted that, as a consequence of the ongoing intensification of the agricultural sector, irrigation water withdrawal in sub-Saharan Africa would increase from 96 km^3 to 133 km^3 per annum between 2005 and 2050 (Alexandratos and Bruinsma, 2012).

Planning for new irrigation schemes requires an assessment of long-term water availability especially during the critical dry seasons (Gustard et al., 2004). Such an assessment is used to define the potential area that can be irrigated by the supply source. Availability of water for irrigation is influenced by climatic factors; however, anthropogenic influences such as deforestation that alter the water flow regulation service provided by forests and woodlands can also be a major factor. For example, deforestation can reduce soil infiltration capacity and alter the partitioning of precipitation between overland flow and soil infiltration (and subsequently groundwater recharge) (Costa et al., 2003; Giertz and Diekkruger, 2003; Giertz et al., 2005; Hess et al., 2010; Schilling et al., 2014). In addition, there is considerable evidence that seasonal availability of water (especially in the tropics where there is a distinct wet and dry season) can be affected by deforestation leading to increased peak flows in the wet season that can lead to flooding (Bradshaw et al., 2007; McCartney et al., 2013; Tan-Soo et al., 2014); and reduced base-flow in the dry season that can lead to streamflow droughts (Guo et al., 2000; Pattanayak and Kramer, 2001; Tallaksen and van Lanen, 2004; Simonit and Perrings, 2013). In general, in tropical regions with seasonal rainfall, the distribution of streamflow throughout the year is of greater importance to food and water security than total annual water yield (Bruijnzeel, 2004). Currently, the rate of tropical deforestation especially in lower income countries remains significant (Sloan and Sayer, 2015) despite the reduction in the rate of net global deforestation over the past 25 years (1990–2015) (FAO, 2015b). For example, between 2010 and 2015 there was a 1.1% (50,000 ha per annum) decrease in forest area in Benin (FAO, 2015b). The understanding of linkages and interrelationships among forests and woodlands, water and food production is, therefore, critical to support strategies for food and water security while ensuring provision of multiple forest ecosystem services. Although there is a number of studies that connect deforestation to water flows (e.g. TEEB, 2010; McCartney et al., 2013; Simonit and Perrings, 2013; Brookhuis and Hein, 2016) to date there are very few studies that explicitly link deforestation to irrigation potential (e.g. UNEP, 2012).

In this study, we conduct a quantitative analysis of the linkages and relationship between forest and woodland conservation, surface water availability for irrigation and irrigation potential. We

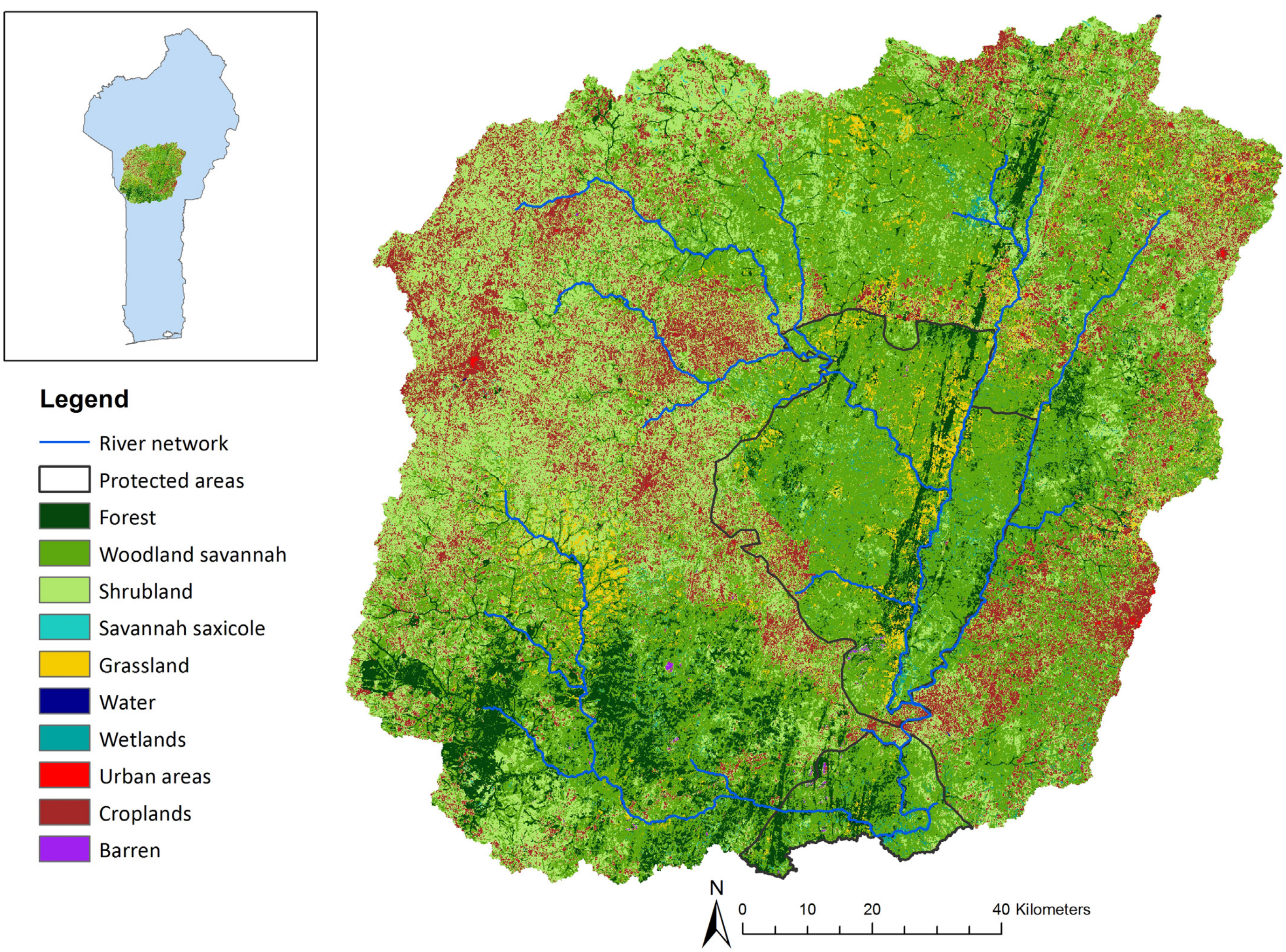

Fig. 1. Land cover, protected forest and woodland areas and river network of the Upper Ouémé watershed. Land cover data from Judex and Thamm (2008).