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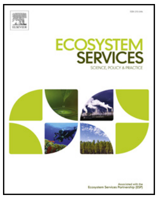

Integrated modelling for economic valuation of the role of forests and woodlands in drinking water provision to two African cities

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ABSTRACT

Rapidly growing economies often have high population growth, resulting in agricultural expansion in rural areas and increased water demand in urban areas. Conversion of forests and woodlands to agriculture may threaten safe and reliable water supply in cities. This study assesses the regulating functions and economic values of forests and woodlands in meeting the water needs of two major cities in Tanzania and proposes an integrated modelling approach with a scenario-based analysis to estimate costs of water supply avoided by forest conservation. We use the process-based hydrological Soil and Water Assessment Tool (SWAT) to simulate the role of woody habitats in the regulation of hydrological flow and sediment control. We find that the forests and woodlands play a significant role in regulating sediment load in rivers and reducing peak flows, with implications for the water supply from the Ruvu River to Dar es Salaam and Morogoro. A cost-based value assessment under water treatment works conditions up to 2016 suggests that water supply failure due to deforestation would cost Dar es Salaam USD 4.6–17.6 million per year and Morogoro USD 308 thousand per year. Stronger enforcement of forest and woodland protection in Tanzania must balance water policy objectives and food security.

1. Introduction

Africa has experienced a rapid increase in urban population in the last 20 years (Brikké and Vairavamoorthy, 2016), driven by the combined effects of natural increase and rural-to-urban migration (Anderson et al., 2013; Dos Santos et al., 2017). It is expected that by 2040, 50% of the African population will live in cities (AfDB et al., 2014). In addition, economic growth is likely to increase water demand by a rate higher than population growth alone (Cole, 2004). These developments will create significant pressure on existing, aging infrastructure and services including water (Larsen et al., 2016). Many cities depend on natural habitat and climatic conditions in upstream areas to deliver water through river systems (McDonald et al., 2013). At the same time, this urbanisation process puts additional pressure on catchments and regional natural habitats (Cumming et al., 2014). For example, many citizens in Sub-Saharan Africa still rely on catchment forests as their main source of energy, charcoal, creating a negative feedback effect on their water supply.

These dynamic urban–rural linkages, furthermore found in the supply of food, timber and other goods and the exchange and movement of people and information, call for a catchment approach to sustainable land-use planning. Land management has often aimed to improve services other than water quality or quantity, sometimes resulting in problems of supply and pollution (Brauman, 2015). Modelling how land-use change affects downstream ecosystem services flows under different scenarios helps to anticipate and mitigate unintended consequences (Haase and Tötzer, 2012). Although the impact of forests and woodlands on water quantity has been heavily debated (Bruijnzeel,

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2004; Sahin and Hall, 1996), it has been argued that the removal of these woody habitats from upslope catchments and their replacement by agriculture affects flow patterns and water quality downstream, varying with the biophysical characteristics of the forests (Ponette-González et al., 2015; Salman and Martinez, 2015). For example, reduced river flow in the dry seasons can affect ecosystem services benefits such as drinking water and hydropower provision, while higher flow rates in the wet seasons can increase the risk of flooding and soil erosion (Cui et al., 2007; Ellison et al., 2012). The potentially higher proportion of direct overland runoff in the absence of woody vegetation can affect water supply as it increases sedimentation rates (Cunha et al., 2016); the additional sediment fills up reservoirs, and higher sediment loads in the rivers force water companies to turn off their pumps. Sedimentation can, therefore, impose a significant cost on citizens downstream, who will need to cope with lower water volumes or impaired water quality, especially in the dry seasons, with knock-on effects for their health and wellbeing and increased costs of water treatment (Keeler et al., 2012; Rozario et al., 2016).

The quantitative assessment of the impact of upstream forest loss on urban populations requires understanding of the location where the service is supplied, the spatial and temporal flows of the water ecosystem services, the demand and actual use of the services (or disservices) by beneficiaries, and features in the landscape that affect the flows (Bagstad et al., 2014; Villamagna et al., 2013). Timing, place, quantity and quality of water supply regulation are affected by landscape and ecosystem changes (Ponette-González et al., 2015), and are often felt off-site, but predicting hydrological responses to land-use change is challenging (Bagstad et al., 2014; Guswa et al., 2014; Villamagna et al., 2013). Integrated modelling provides an understanding of the link between natural woody habitats and water-related ecosystem services relevant to human wellbeing (Lele, 2009). However, the lack of integrated approaches and over-simplification of hydrological processes is one of the main limiting factors for accurately valuing these services (Dennedy-Frank et al., 2016; Sharps et al., 2017). Existing ecosystem assessment tools such as Co$tingNature, ARIES and INVEST do not typically use local data or disaggregated land cover categories, are less applicable at smaller spatial scales, and often fail to account for seasonal variation in hydrological flows (Pandeya et al., 2016; Vigerstol and Aukema, 2011).

Morever, forests and woodlands do not produce water *per se*, and so valuation of the total annual volume of water supplied has very limited policy relevance for understanding forest-related water services beneficial to people (Lele, 2009). Valuing the cost or benefit of a *change* in a specific service provision throughout the year resulting from a *change* in forest quality or quantity is a more useful approach when aiming to value forest ecosystem services (Balmford et al., 2011; Daily et al., 2009).

Many previous studies, particularly in data-poor settings, have abstained from providing economic values for water-related services, or from linking economic values to changes in land use and subsequent forest functioning (Campbell and Tilley, 2014; Maes et al., 2012; Terrado et al., 2014). Existing monetary valuation evidence is limited; for example, the TEEB (The Economics of Ecosystems and Biodiversity) valuation database (Van der Ploeg and De Groot, 2010) provides only eight references and ten value estimates from primary studies for water-related benefits provided by tropical forests, of which none are from Africa. The value of landscape management for water related ecosystem services is hard to determine because of the lack of understanding of the dynamics of water ecosystems and interactions between land and water systems, and because the preferred quantity and quality depend on water users and time of year, and crucially; more water is not always better (Brauman, 2015; Schaafsma et al., 2015).

The aim of this paper is to (a) assess to what extent the presence of forests and woodlands regulates the availability of water throughout the year in two major African cities, and (b) provide an estimate of the economic value of this regulation service. We tackled these aims by linking the outputs of the process-based model, the Soil and Water Assessment Tool (SWAT), to an economic valuation of the regulation service of woodland and forest ecosystems. Through a comparison of scenarios with and without tree-dominated ecosystems, we provide estimates of the monetary value of water regulation by forests and woodlands, and the distribution of benefits among different socio-economic groups. We demonstrate that our methodology is applicable to data scarce areas with a case study on the Ruvu catchment in Tanzania (Fig. 1).

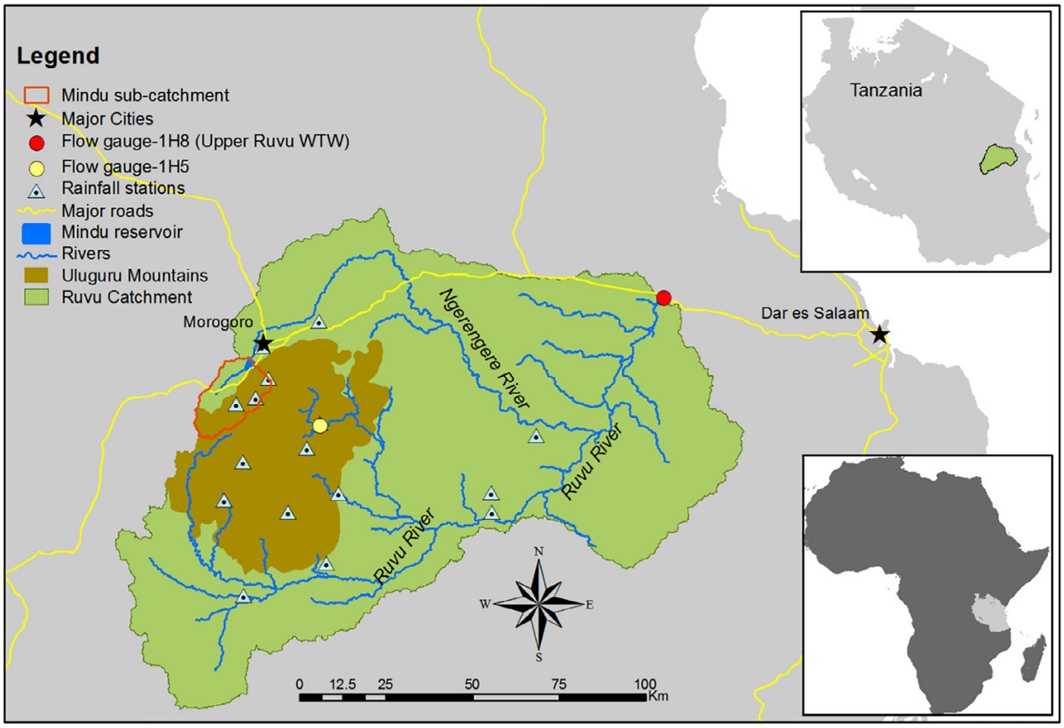

Fig. 1. Ruvu catchment map.