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How is water availability related to the land use and morphology of an inland valley wetland in Kenya?

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ABSTRACT

Small inland valley wetlands contribute substantially to the livelihoods of rural communities in East Africa. Their conversion into farmland is driven by water availability. We quantified spatial-temporal dynamics of water availability in a headwater wetland in the humid zone of Kenya. Climatic conditions, soil moisture contents, groundwater levels and discharge data were monitored. A land-use map and a digital elevation model of the valley bottom were created to relate variations in soil moisture to dominant land uses and valley morphology.

Upland crops occupied about a third of the wetland area, while approximately a quarter of the wet, central part of the valley bottom was designated for flood-tolerant taro, grown either by itself or in association or in rotation with upland crops. Finally, natural vegetation was found in 3% of the mapped area, mainly in sections with nearpermanent soil saturation.

The HBV rainfall-runoff model's overestimation of stream discharge during the long dry season of the hydrological year 2010/2011 can be explained by the strong seasonal impact of water abstraction on the wetland's water balance.

Our study vividly demonstrates the necessity of multi-method approaches for assessing the impact of management practices on water availability in valley bottom wetlands in East Africa.

1. Introduction

Communities which access and utilize wetland resources are referred to as 'wetland communities'. For such communities in East Africa, wetlands supply a significant proportion of annual food needs (Kangalawe and Liwenga, 2005) and, furthermore, contribute substantially to rural welfare (McCartney and van Koppen, 2004; Schuyt, 2005). With the declining quantity and quality of upland areas available for agricultural production (Maitima et al., 2009), rural populations increasingly depend on wetland resources with year-round or at least seasonally available soil moisture (Dixon and Wood, 2003). This is especially important for crop production during the "hungry" season, during which water stress limits upland production. The projected climate change scenarios, particularly the increasing spatial-temporal variability of precipitation (Collins et al., 2013; Giannini et al., 2008), may, on the one hand, accelerate the dependence on wetland resources. On the other hand, they also highlight the increasingly important future role of valley bottom wetlands as buffer systems against more extreme high and low flows (Wood and van Halsema, 2008).

Small wetlands of less than 500 ha have often been neglected in research although they are far more abundant and cover a much larger total area than larger wetlands in East Africa (Mwita et al., 2013). Unlike studies on West African inland valleys (de Ridder et al., 1997; Rodenburg et al., 2014), only few studies on the East African region address the impact of land and management practices on the systems' hydrological regimes (Dixon, 2002). This gap in research may be attributed to the scarcity of hydrological data and the lack of information on land-use patterns, among other reasons.

In Kenya, freshwater wetlands cover between 3 and 4% of the country's surface area (National Environment Management Authority Kenya, 2009). The annual loss of wetlands, primarily

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due to drainage for agriculture, has been estimated to be 7% (Gichuki et al., 2001). An understanding of hydrologic conditions in relation to prevailing land-use types is thus necessary in order to prevent management practices from negatively affecting the wetlands' ability to provide their diverse "ecosystem services", which comprise provisioning, regulative, cultural and supportive services (Millenium Ecosystem Assessment Board, 2005).

Hydro(geo)logical wetland studies focus on water table fluctuations as well as time series of either sub-surface flow or river flow (Böhme et al., 2013). As the hydrological behaviour of wetlands is often controlled by processes in their catchments, lumped or semi-distributed conceptual rainfall-runoff models can be used to represent the effective response of the entire catchment, e.g. to climate and land-use changes (Troy et al., 2007).

Agricultural production potential is determined in particular by the quantity, spatial distribution and the dynamics of plant available moisture in the rooting zone of wetland soils. By controlling penetrability, temperature regime and aeration status, the last of which is closely linked to the rate of mineralization processes and nutrient release, soil moisture status is not only relevant to the water supply for plants, but is also closely linked to the physico-chemical conditions of plant growth in general (Robinson et al., 2008; Thomsen et al., 1999). This hydrological parameter is influenced by land and water management practices, as well as by climatic conditions (precipitation, evapotranspiration), valley morphology controlling runoff and the depth of the groundwater table. Therefore, soil moisture can serve as an integrated indicator not only of alterations in a wetland's hydrological regime, but, in a broader context, also of its capacity to provide the full range of ecosystem services which reach far beyond providing agricultural products.

Our paper aims to assess water availability in relation to land-use practices and valley morphology in an inland valley of the humid zone of Central Kenya. The main objectives of the study were:

- to describe the land use and morphology of the inland valley bottom,
- to characterise its hydrological regime, and
- to analyse spatial and temporal variations in soil moisture and to relate these to the morphology of the valley bottom and the adjacent fringe/lower slope.

For this purpose, we generated a land-use and elevation map of the valley bottom. This information was combined with in-situ measurements of soil moisture and groundwater levels. A semi-distributed rainfall-runoff model was then applied to relate the wetland's stream discharge to the catchment's hydrological response to rainfall events.

2. Materials and methods

2.1. Study area

The study site was the Tegu valley, one of the small wetlands which are common in the higher rainfall areas of Western and Central Kenya (Howard, 1992). The wetland of the Tegu stream lies at 1720–1840 m altitude in the upper reaches of the Tana River, south of Mount Kenya (Fig. 1). The underlying geology is part of the pleistocene Mt. Kenya volcanic series from the mountain's main eruptive episode (Baker, 1967). Trachytes, olivine trachytes and mugearites can be found at the southern slopes of Mt. Kenya in the area of the Tegu valley. Rainfall occurs in a bimodal pattern with peaks in April and November (Jaetzold et al., 2006) and an intervening dry season between June and September (Böhme et al., 2013). Intensity and duration vary from year to year (van der Sombroek et al., 1982). Annual rainfall reaches about 1450 mm (Karatina Agricultural Office, in Jaetzold et al., 2006), and the mean annual temperature is around 18 °C (Kenya Meteorological Department, 2010).

For the purpose of this study, we have applied Andriesse et al., (1994) definition for inland valley wetlands. These are defined as "upper reaches of river systems, comprising valley bottoms and minor floodplains which may be submerged for part of the year, their hydromorphic fringes, and contiguous upland slopes and crests". Fringe areas are transition zones between the valley bottom and the side slopes (Windmeijer and Andriesse, 1993). Soils of the valley fringe and lower slope are formed from colluvial deposits, whereas the central part of the valley is made up of colluvial-alluvial deposits.

In terms of vegetation ecology, the study area is assigned to the class of marshes (Tiner, 2009), which are "dominated by herbaceous vegetation and flooded for all or most of the growing season or periodically". This definition is in accordance with the classification of the Ramsar Convention, according to which the study area falls under the class of permanent freshwater marshes (Ramsar Convention Secretariat, 1994).

The catchment area of the stream headwater wetland comprises 2.3 km^2. Steep slopes border the valley bottom, their inclination ranging from 5 to 36%. The upland soils are classified as Nitisols with a clay and sand content of about 50% and 40%, respectively (Kamiri, 2010). These soils are used for the cultivation of coffee, diverse food crops and napier grass (*Pennisetum purpureum*). Moreover, exotic (*Graveria* spp., *Eucalyptus* spp.) and native (*Prunus africana*) tree species are commonly encountered, and homesteads with home gardens (containing vegetables and fruit trees) are located in the upper slopes. The average farm size is 1.02 ha, and the average size of the wetland fields is 0.22 ha (Sakané, 2011).

The deep and poorly drained Dystric Fluvisol of the valley bottom contains between 54% and 79% clay (Böhme et al., 2013). Therefore, the study site fulfils the criteria for riverine wetlands which develop due to impeded drainage in the valley bottom. While the water flow in the central river bed is permanent, it is seasonal in the upstream valley head (Fig. 1). Farmers have established a network of small canals in order to divert excess water during seasons of high rainfall and allow for irrigation at times of low rainfall. Further detailed information on the biophysical characteristics of the Tegu inland valley have been published in Böhme et al. (2013), Kamiri (2010), and Sakané (2011).

Few sections of the valley bottom wetland were not being cultivated during the field campaigns (2009–2011). Reasons are unconfirmed but are possibly lack of labour, weed infestation or excess moisture. These uncultivated sections were either left to lie fallow or were covered with natural wetland vegetation (mainly *Cyperus* spp.). The largest part of land at the valley bottom is cultivated with subsistence crops (mainly maize, *Zea mays*), taro (*Colocasia esculenta*), either for market sale or private consumption, and diverse horticultural crops (mainly *Brassica* species). The types (inorganic as well as organic) and quantities of fertilisers applied vary according to usage (Sakané, 2011). As the production of maize in the valley bottom is constrained by high water tables, it is usually cultivated on raised beds. Taro cultivation occurs under flooded conditions and entails labour-intensive land preparation involving clearing and ploughing. Vegetables are mainly cultivated along the well-drained valley fringes. In 2010, fish ponds were constructed downstream of the upper weir (Fig. 1) in order to generate additional sources for income for the wetland communities.

Due to the close proximity to the Karatina municipality, which has one of largest open markets in Sub-Saharan Africa, farmers of the Tegu wetland have good market access for selling their