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Quantifying and mapping of water-related ecosystem services for enhancing the security of the food-water-energy nexus in tropical data–sparse catchment

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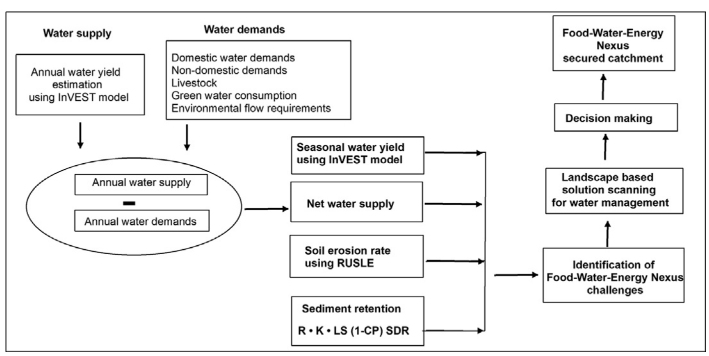
HIGHLIGHTS

- Losses in regulating capacities of ecosystem could lead to insecure the nexus food-water-energy.
- High annual water yield catchment may not satisfy the community's demand for water.
- Loss of soil due to climatic factors can be prevented through cover and land management.
- Management of water have a central role to improve the security of the nexus.
- The net budgets of water-related ecosystem services can be quantified and mapped in data–sparse catchments.

GRAPHICAL ABSTRACT



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ABSTRACT

The food-water-energy nexus concept helps to produce an integrative solutions to secure the water-related ecosystem services sustainably. This study aims to quantify and map water provisioning and soil erosion regulating services from both demand and supply sides in a spatially explicit manner. It considers the Wabe River catchment of the Omo-Gibe Basin in tropical data-sparse region of East Africa as a case study and uses the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) annual and seasonal water yield and sediment delivery models. The water demands and biophysical parameters data were collected from primary and secondary sources and prepared according to the requirement of the models. The models output were validated after conducting sensitivity analysis of the input parameters. The result shows that the rainfall amount of the catchment is highly seasonal, which causes the surface water to vary according to the seasons. The high annual precipitation and low actual evapotranspiration of the catchment resulted high annual water yields. However, the people in the catchment did not satisfied their domestic water demand as result of inaccessibility and poor management of the rain water. The high net supply of water, especially in the rainy season, carries detached top soil via heavy rainfall in the upper catchment areas. Even though the existing land cover and management practices contribute to sediment retention, a large amount of sediment is exported to rivers, which jeopardizes the food and energy security. Thus, the management of water is essential for enhancing the security of the food-water-

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energy nexus in the catchment. The methods applied in this study can increase spatial understanding of the water-related ecosystem services especially in data–sparse catchments of the tropics, and lead to improvement of water management to enhance the security nexus.

1. Introduction

Human livelihoods and economic activities are dependent on the closely related basic needs of food, water, and energy. Access to clean drinking water and sanitation facilities, sufficient and quality food, and adequate energy are essential for human well-being. These three resources are commonly dealt with individually and independently. However, in reality, they are closely interrelated and recently, the food-water-energy nexus approach has been developed to manage the resources (Karabulut et al., 2016). This approach was first conceived by the World Economic Forum (2011) to promote the inseparable links between the use of resources to provide basic and universal rights to food, water, and energy security (Biggs et al., 2015). To produce food, water and energy are needed, while to produce energy (hydropower), water is required, and to access water, energy is needed. Due to the complexity of the relationships among these three elements, they need to be considered simultaneously in decision-making (Bazilian et al., 2011; Rasul, 2016).

Ecosystems are the key source of providing water, food and energy. They are involved in the production of water, food, and energy, and thus, essential to understand ecosystems role in providing these benefits for human well-being (Karabulut et al., 2016). Water is a vital resource provided by ecosystems, which can sustain the food-water-energy nexus for human well-being (ten Brink et al., 2013). There are many ecosystem services that are derived from freshwater. Provisioning services such as water for drinking, power production, industrial use, and irrigation, and regulating services such as water purification and erosion control are some of the benefits provided by freshwater (de Groot et al., 2010). It plays a great role in both food and energy production, and in sustaining the ecosystems that support agriculture and other economic activities that are critical for achieving food security (Rasul and Sharma, 2016). However, agriculture and food production affect the water sector through land degradation, changes in runoff, and disruption of groundwater discharge (Khatri and Tyagi, 2015).

Erosion and sedimentation by water are natural processes that contribute to healthy ecosystems, but excessive erosion due to changes in land use affects water, food, and energy security (Blum, 2013). Soil erosion reduces water and nutrient retention, biodiversity, and plant primary productivity on agricultural land, which puts stress on food production, notwithstanding impacts on the ecosystem and water resources/power generation in the downstream (Pimentel and Burgess, 2013). Soil erosion increases water runoff, thereby decreasing water infiltration and the water-storage capacity of the soil (Schoonover and Crim, 2015). In addition, during erosion, organic matter and essential plant nutrients are removed from the soil and the soil depth is reduced (Pimentel and Burgess, 2013). Higher sediment yields lead to water eutrophication and the disturbance of fragile aquatic ecosystems due to non-point nutrient pollutants, heavy metals, and pesticides being transported with the soil particles (Issaka and Ashraf, 2017). Siltation of reservoirs compromises water supplies and hydroelectric power generation, thereby affecting renewable energy security (Kaunda et al., 2012).

While the food-water-energy nexus offers a promising conceptual approach, the use of this nexus methods to systematically evaluate water, energy, and food interlinkages or support development of socially and politically-relevant resource policies has been limited (Albrecht et al., 2018). In addition, there are a limited number of models and frameworks that address all food-water-energy together (Shannak et al., 2018). Recently there are number of studies related to the different ecosystem services by using ecosystem services mapping tools such as Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) (Biggs et al., 2015; Redhead et al., 2016) and Soil and Water Assessment Tool (ArcSWAT) (Karabulut et al., 2016; Schmalz et al., 2016).

Assessment of water-related ecosystem services not only helps to address water security problems but also enhances food and energy security through management of water (Biggs et al., 2015; Schmalz et al., 2016; Chen et al., 2018). Although studies related to food-water-energy nexus with the concept of ecosystem services has recently grown, only few studies have considered both water supply and demand of water-related ecosystem services which is essential to know the gap (de Roo et al., 2012; Karabulut et al., 2016). This makes difficult for studies to draw reliable solutions for the interlinkages problems of the water, food, and energy sectors through integrated land use management. Thus, this study aimed to quantify and map the supply and demand of the water provision and soil erosion using the mapping tools of InVEST to identify the nexus problems of water, food, and energy, and to draw landscape based planning and management solutions.

2. Materials and methods

2.1. Study area

The quantification and mapping of water-related ecosystem services to enhance the security of food-water-energy nexus was performed by considering the Wabe River catchment in tropical regions of the Eastern Africa. The Wabe River catchment is one of the largest tributaries of the Omo-Gibe River basin originating from the northeast part. The source of the Wabe River is the Gurage Mountain chain. The Omo-Gibe River basin is situated in the southwestern part of Ethiopia, and it is Ethiopia's second largest river system next to the Blue Nile (MoWR, 2001). The basin flows from the northern highlands through the lowland zone to discharge into Lake Turkana at the Ethiopia/Kenya border (Fig. 1). In the basin, the Ethiopian government constructed three dams, and planned additional two dams. The Wabe River catchment is located between 08°21′ and 08°30′ N and 38°05′ and 37°49′ E, and the elevation range is between 1014 and 3611 m above sea level. In total, it has 32 subwatersheds and covers a drainage area of about 1860 km^2.

This catchment selected due to the land use is primarily used for subsistence agriculture, and the intensification and poor management of agriculture has a serious effect on the conservation and sustainable utilization of the land and water resources of the area (Woldetsadik, 2003). In the rainy season, the runoff in the catchment carries large amount of eroded soils and sediment with nutrients. This area lacks detailed and updated information with spatially explicit maps since most of the basins of Ethiopia have only master plans which were prepared 20 years ago (MoWR, 2001) that would assist the management of water resources and support food-water-energy nexus security. The 2003–2014 meteorological stations data shows that the Wabe River catchment's maximum temperature ranges from 20 °C (in the wet season) to 39 °C (in the dry season), while the minimum temperature is in the range 0 °C–19 °C. The average temperature is 18 °C. The mean annual rainfall ranges from 1111 to 1374 mm.

2.2. Datasets

2.2.1. Land use land cover

The land use land cover (LULC) data for the Wabe River catchment was derived from the supervised classification of Landsat images of 2017 (OLI) with 30 m spatial resolution using ERDAS Imagine 2010