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Application of satellite products and hydrological modelling for flood early warning

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ABSTRACT

Floods have caused devastating impacts to the environment and society in Awash River Basin, Ethiopia. Since flooding events are frequent, this marks the need to develop tools for flood early warning. In this study, we propose a satellite based flood index to identify the runoff source areas that largely contribute to extreme runoff production and floods in the basin. Satellite based products used for development of the flood index are CMORPH (Climate Prediction Center MORPHing technique: 0.25° by 0.25°, daily) product for calculation of the Standard Precipitation Index (SPI) and a Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) for calculation of the Topographic Wetness Index (TWI). Other satellite products used in this study are for rainfall-runoff modelling to represent rainfall, potential evapotranspiration, vegetation cover and topography. Results of the study show that assessment of spatial and temporal rainfall variability by satellite products may well serve in flood early warning. Preliminary findings on effectiveness of the flood index developed in this study indicate that the index is well suited for flood early warning. The index combines SPI and TWI, and preliminary results illustrate the spatial distribution of likely runoff source areas that cause floods in flood prone areas.

1. Introduction

Disasters cause much damage and distress in less developed countries with limited financial resources. Engineering structures to mitigate on devastating effects by an extreme event are often not in place whereas tools for early warning are not well developed. According to reports from the World Meteorological Organization (2009), approximately 70% of all disasters occurring in the world relate to hydro-meteorological events. Poor disaster management practices, limited financial resources and high population pressure are some common characteristics of less developed countries and often cause that large numbers of people are affected in case of extreme meteo-hydrological events such as floods or droughts. In countries like Ethiopia, floodings may cause enormous impacts on the environment and society in urbanized and rural areas with high population density in agricultural production areas close to river channels. Besides the tragic loss of lives, impacts of floods include damages to property and the environment. In many parts of Ethiopia, flood events are reported frequently. Floods are attributed to rivers that overflow the riverbanks to inundate the adjacent flood plains. Large scale riverine flooding in Ethiopia is common and typically observed in the flat, lowland parts of the river basin systems due to large runoff volumes as caused by high runoff production in upstream, mountainous areas (see Taddese et al., 2006). A major river basin with frequent flooding events is the Awash River Basin with largest part located in the Rift Valley (Guinand, 1999; Achamyeleh, 2003; NASA Earth Observatory, 2003). Awash River Basin probably is the most developed area in Ethiopia with major economic value for Ethiopia. Due to its strategic location and availability of land and water resources, the basin has high potential for economic development. In the basin, two large sugarcane factories as well as many large and small-scale irrigation projects contribute to the nation's development (Taddese et al., 2006). While less extreme flood events in the basin support livelihood of the population through flood irrigation, extreme events cause much damage for which a flood early warning system is needed urgently to mitigate on effects and to reduce on impacts.

Needs for development of Early Warning Systems (EWS) started to arise in 1970s and 1980s when the prolonged droughts and

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famines in the West African Sahel and in the Horn of Africa occurred. ESIG-ALERT (2004) reports that EWS has been developed to reduce societal risks and vulnerability, but also to support sustainable development. According to United Nations International Strategy for Disaster Redaction (UNISDR, 2009), an EWS is defined as:

> *"The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss."*

Currently various organizations across the world are involved in flood forecasting and early warning at national, continental and global scale. However, in Africa web-based information systems that serve for on-going transnational flood forecasting and early warning are limited in number (Table 1). In Ethiopia, in the Upper and Middle Awash River Basin, various initiatives address the problem of flooding (Abraha, 2006; Alemayehu, 2007). Some of the institutes in Ethiopia dealing with flood management, forecasting and early warning are Ministry of Water Resource and Energy (MoWE), Addis Ababa University (AAU), and National Meteorology Agency (NMA) of Ethiopia (Thiemig et al., 2011). Much effort on flood disasters in Ethiopia focus on strengthening rescue and relief arrangements during and after the events. Efforts to simulate runoff production and to predict flood behavior for flood early warning are limited. Poor gauging of rainfall and runoff in many Ethiopian river systems add to this aspect, besides that limited financial resources constrain efforts. Initiatives to develop a flood early warning such as e.g. for the Nile basin (World Bank, 2007) are not known. A well-known initiative for flood early warning in European river basins is the European Flood Alert System (EFAS).

In Ethiopia, the EFAS methodology has also been tested for Juba–Shabelle River Basin, which is adjacent to the Awash River Basin. The objective of the application was to develop a flood early warning system using various meteorological data sets produced by probabilistic weather forecasts and the LISFLOOD hydrological model (Thiemig et al., 2010). However, for reasons such as limited budget and lack of *in-situ* based gauge data, it proved that the procedure used by EFAS for Awash River Basin essentially was not possible. Therefore, an alternative method with different information sources must be developed.

The most important inputs to understand the hydrological processes that cause catchment runoff are hydro-meteorological observations. For early warning and to facilitate forecasting, hydro-meteorological data must be available in real time, or alternatively, must be forecast such as the European Centre for Medium-Range Weather Forecasts (ECMWF). Real time data can be provided from weather radars, satellites and or automatic gauging stations networks (Billa et al., 2006; Budhakooncharoen, 2004) whereas ECMWF and numerical weather prediction (NWP) data is available from large scale General Circulation Models (GCM). Burger et al. (2009); Thielen et al. (2009); Thiemig et al. (2011) and Alemseged and Rientjes (2015) show that NWP plays an important role in providing input for hydrological models for early warning.

For a better understanding of the main drivers that cause floods in Awash River Basin, it is very important to understand the catchment hydrological behavior and related runoff production processes that cause flood events. Hence, performing rainfall runoff and stream flow modelling is the first step. Rainfall runoff models are a simplified and conceptualized representation of the real world and serve as a tool to transform meteorological processes (i.e., rainfall and evapotranspiration) into the catchment runoff responses. There are various reasons for using rainfall runoff models. The main reason relates to the difficulty to measure the dynamics of hydrological processes that cause runoff production in space and time (Beven, 2012). Also measuring networks often all not well designed, with poor density and do not allow to represent processes in space and time domains that cause floodings. These aspects also often necessitates to use models. For this study the LISFLOOD model was selected which is a spatially distributed hydrological rainfall runoff model developed by the Joint Research Centre (JRC) of the European Commission for simulating hydrological processes that occur in catchments (De Roo et al., 2000). Most of the data sets used in this study are remote sensing products since Awash River Basin must be considered ungauged by the very low number or stream flow gauging stations as well as weather stations. Hence, satellite-derived products as inputs to a model for developing flood early warning system is advocated and tested in this study since adequate temporal and spatial coverage is provided. The use of satellite data may overcome constrains induced by poor data availability although satellite data requires bias correction before use (Habib et al., 2014; Haile et al., 2013).

The main objective of this study is to develop a flood early warning system for the upper and middle Awash River Basin by using satellite remote sensing products and hydrological modeling. Satellite data can be used in various ways to evaluate flood potential but also to predict a flood event in case of extreme rainfall in the basin. In this study we developed and propose the use of a spatially distributed flood index map to indicate runoff source areas for flood early warning. The flood index combines the Standard Precipitation Index and the Topographic Wetness Index. This study shows that a relation can be established between the topographic wetness and actual runoff production areas by extensive rainfall in the basin, and the actual locations where flood events have occurred.

2. Study area and data

2.1. Study area

The Awash River Basin is the fourth largest catchment (110,000 km^2) in Ethiopia and the seventh in terms of mean annual runoff (4.6 BM^3). The total length of the main course is some 1200 km and is the principal stream of an endorheic drainage basin covering parts of Oromia, Somali, Amara and Afar Regional States.

Table 1
Flood forecasting and early warning initiatives in Africa (after Thiemig et al., 2011).

Initiatives	Organizations/Institutes/Country
Flood forecasting initiative	WMO
Associated Program on Flood Management	WMO and GWP
Flood Risk and Response Management Information System	FAO-SWALIM
Early Warning and Humanitarian Emergency Information Centre	Republic of Sudan
SERVIR-Africa	NASA, RCMRD & CATHALAC
African Early Warning and Advisory Climate Services in Africa	ACMAD
Global Flood Alert System	Japanese Infrastructure Development Institute
Early Warning System for Flood Events	ITHACA