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Development of a Non-Linear Integrated Drought Index (NDI) for Managing Drought and Water Resources Forecasting in the Upper Tana River Basin-Kenya

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ABSTRACT

This article uses the non-linear integrated drought index (NDI) for managing drought and water resources forecasting in a tropical river basin. The NDI was formulated using principal component analysis (PCA). The NDI used hydro-meteorological data and forecasted using recursive multi-step neural networks. In this article, drought forecasting and projection is adopted for planning ahead for mitigation and for the adaptation of adverse effects of droughts and food insecurity in the river basin. Results that forecasting ability of NDI model using ANNs decreased with increase in lead time. The formulated NDI as a tool for projecting into the future.

KEYWORDS

Absolute Sensitivity, ANN, Drought Forecasting, Non-Linear Integrated-Drought Index (NDI)

1. INTRODUCTION

Drought is one of the critical stochastic natural disasters that adversely affect water resource systems, people and ecosystems (Zarger et al., 2011; Jahangir et al., 2013). Drought is defined as a hydro-meteorological event on land characterized by temporary and recurring water scarcity. According to [15], the magnitude of the drought is indicated by the extent with which it falls below a defined threshold level over an extended period of time. Drought has been identified as the most complex natural hazards due to difficulty in its detection; when it occurs, it causes a devastating effect on fragile ecosystems and human society. Drought preparedness and mitigation depend upon timely information on its onset, and propagation in terms of temporal and spatial extent. Such information can be obtained if effective and continuous drought monitoring indices are used in drought evaluation. The study of spatial and temporal drought conditions has greatly been applied in planning and management of water resource systems such as water supplies, irrigation systems, and hydropower generation (Morid et al., 2007; Ceppi et al., 2014; Alaa, 2014; Okoro et al., 2014). These studies were undertaken in Lombarrdy region of north Italy, Bashar river basin, Mashtul pilot area of Nile Delta and the river basins in Imo state of Nigeria respectively.

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In Kenya, very notable droughts of 2009 and 2011 adversely affected the agricultural sector where crop yields were drastically reduced. During this period, the country's wheat yield dropped by 45% compared to the 2010 growing season (FAO, 2013). Similarly, between 2002 and 2010, Australia suffered a multi-year drought. The total wheat yield in Australia at the time dropped by 46% compared to the annual average level. In 2010, Russia suffered a long and severe drought which significantly affected the environment, human health and economy. In the US, the southern states experienced a severe drought in 2011while in 2012 more than 6.3 million persons were negatively affected by drought in China. During such drought episodes, people experienced challenges in food access and drinking water (FAO, 2013).

According to (Zoljoodi and Didevavarasl, 2013), there are four main categories of droughts. These include the Hydrological, Meteorological, Agricultural and Socio-economic droughts. The first three types are called the operational droughts and can be integrated into a drought management algorithm. Their relation can then be applied in development of water resource strategy in a river basin (Karamous et al., 2003). Propagation of hydrological and agricultural drought originates from meteorological droughts which develop from changing phenomena within the hydrological cycle.

Drought indices or models are used for assessment of occurrence and severity of droughts. The Drought Indices (DIs) were developed for specific regions using specific structures and forms of data input. There is limited information in the application of drought indices that combines both temporal and spatial drought evaluation at river basin scales. Drought has been assessed in terms of temporal and spatial domain using evapotranspiration mapping as illustrated by (Eden 2012). There are two broad categories of drought indices; satellite-based and the data driven drought indices (Belayneh and Adamowski, 2013).

The satellite Remote Sensing (RS) may be defined as the science and art of obtaining information of points, objects, areas or phenomena through analysis of data acquired by a sensor, which is not in direct physical contact with the target of investigation (Zoljoodi and Didevavarasl, 2013; Sayanjali,and Nabdel, 2013). The RS provides an aerial view of land, water resources and vegetation cover. This technique gives a spatial and temporal context of assessing drought and has the ability to monitor vegetation dynamics over large surface areas. Currently, there is a considerable interest in collecting remote sensing data at multiple time scales. Such data is used to conduct a near real time information management (Mulla, 2013). Examples of satellite drought indices are the Vegetation Condition Index (VCI), Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Water Supply Vegetative Index (WSVI) and Normalized Difference Drought Index (NDDI).

The Data Driven Drought Indices (DDDI) uses a single or a combination of hydro-meteorological variables as input parameters to assess drought intensity, duration, severity and magnitude. Some of the data driven indices as reported by Zoljoodi and Didevavarasl (2013) include; the Standardized Precipitation Index (SPI), Palmer Drought Severity Index (PDSI), Surface Water Supply Index (SWSI), Aggregated Drought Index (ADI), Effective Drought Index (EDI), Reclamation Drought Index (RDI), Crop Moisture Index (CMI) and Murger Index (MuI). These indices use different input data such as rainfall, temperature, catchment soil moisture content, snow water content, stream flow, storage reservoir volume, and potential evapo-transpiration (Zoljoodi and Didevavarasl, 2013). However, the suitability of the indices and their testing for Kenyan conditions has not been adequate. Therefore, Kenya does not have generic indices for drought forecasting. Due to scanty and lack of drought assessment indices that can be used for defining critical drought conditions in Kenya, this research assessed selected suitable indices.

The effectiveness of a drought index to detect drought at different spatial and temporal scales depend upon the input variables. A number of indices use very limited hydro-meteorological variables, and this makes them ineffective in their capability to assess drought. In this study, there was the need to develop an index that uses many variables for accurate evaluation of all the operational droughts and quantify water resources within a river basin. The main objective of this research was

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