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Original Research Article

# Spatial mapping and testing the applicability of the curve number method for ungauged catchments in Northern Ethiopia

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ABSTRACT

Understanding the spatial variability of land and water resources has significant importance for its planning, management, and utilization. It is also significant in understanding the response behavior of a catchment in order to model the basic physical processes. In this study, a weighted overlay analysis technique using ArcGIS was implemented for developing a geo-database of the standard curve number (SCN) in a catchment around Northern Ethiopia. The spatial data were used to investigate a 'standard curve number method' for the simulation of the direct runoff at the outlet of the catchment. Both spot based rainfall and runoff measuring techniques were adopted for deriving an instant observed flow measurement, and to make a comparison with the simulated flow values. The results showed that the model underestimated most of the simulated values with a coefficient of regression of $R^2 = 0.52$, with a proportion of higher variances between the simulated and observed runoff events. The result suggests that the accuracy of the model leaves room for significant improvement and the method could not be easily adopted in the catchment and other similar catchments in the semi arid regions of Ethiopia. For improving the prediction capacity of the model, further research in adjusting loss factors in the method is recommended. It is also suggested for developing a localized and modified SCN values by considering geologic, climatic and seasonal variation. The results of this study and the maps generated can be used for improving the hydrological understanding of the catchment. The study is useful for further investigation of the SCN methodology in other un-gauged catchments around the world.



## 1. Introduction

Knowledge of the spatial variability and hydrological behavior of catchments is a fundamental input to developing appropriate water resource planning and management actions (Chiang, Tsay, & Nix, 2002). The spatial variability of catchments are related to physical-based characteristics including soil, topography, climate, and surface runoff. Studying the interaction among these characteristics can also help in the development of predictive hydrological models, which are used for assessing water resource potential in the catchment at different spatial and temporal scales (Pilgrim & Cordery, 1993; Berhanu, Melesse, & Sleshi, 2013; Mallick, 2016).

The planning and design of most small to big water resource development projects has usually necessitated the estimation runoff potential within a targeted catchment (Silva & Oliviera 1999; Mekonnen, Melesse, & Keesstra, 2016). The availability and distribution of runoff recording instruments in most catchments is limited, especially in developing countries (Duan, Liu, Wang, Luo, & Wu, 2010). In such data sparse regions, different prediction models and tools have been developed and implemented for simplifying the estimation of runoff potentials. Some of these models have been developed using a lumped modelling approach with an empirical relation among triggering factors like soil, land use climate and topography, and the others based on distribution modelling concept considering the spatial variability of those factors (Beven, 2012; Pilgrim & Cordery, 1993).

Hydrologists of the Soil Conservation Services (SCS) developed a standard curve number (SCN) method for estimating the direct runoff generated in catchments, especially for providing instant runoff data in remote catchments without data recording equipment (Hong, Adler, Hossain, Curtis, & Huffman, 2007; Dile, Karlberg, Srinivasan, & Rockstrom, 2016). The method was developed based on the empirical relationship of total precipitation and basic physical characteristics of a given catchment such as soil type, land use, surface condition and antecedent moisture condition (United States Department of Agriculture [USDA], 1985). The method has

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been a widely used and accepted as a tool in hydrology, and incorporated into various computer based hydrological models (Woodward, Hawkins, Hjelmfelt, Van Mullem, & Quan, 2002). The method has been also used by most hydraulic engineers for design purposes in US and other parts of the world for computing the direct runoff generated in small to medium-sized un-gauged basins (Silveria, Charbonnier, & Genta, 2000; Hong et al., 2007). However, studies by different scholars have indicated that contrasting results were obtained concerning the accuracy of the model in simulating the direct runoff; for example, Kumar and Silveria et al. (2000) showed that the efficiency of the SCN method was good in estimating the direct runoff in the targeted catchments. However, case studies made by other scholars suggest that the SCN method usually underestimated the simulated runoff values, and they all indicate the need of further modifications to the method (Cooley & Lane, 1982; Sharma, 1987; Hawkins, 1993; Bingner, 1996; Ponce & Hawkins, 1996; Mishra & Singh, 1999; Woodward et al., 2003; Jacobs & Srinivasan, 2005).

The SCN method has been also extensively used to estimate the runoff potential for designing and monitoring purposes in Ethiopia, due to the ease of use and low input data requirement (Dile et al., 2016). The method has been simply adapted to the catchments without any modification and calibration made on empirical values embedded the model. This is due to lack of data on spatial information on soil and hydrological characteristics and observed runoff events in most catchments of Ethiopia (Berhanu et al., 2013; Mekonnen et al., 2016). Different tools; however, can be easily adopted and spot based measurements can be taken for getting sufficient runoff data for model verification and reduction of the predictive uncertainties in rainfall-runoff models (Perrin et al., 2007; Seibert & Beven, 2009). As described earlier, knowledge of the spatial distribution and mapping of these data at the appropriate scale is also very important for planning and implementation of sustainable water development and watershed management strategies. Within the Ethiopian context an economy and landscape dominated by agriculture, this particularly important to assist in planning soil and water conservation management. Additionally the spatial data generated can also be used as input parameters while performing model verification tasks. This study therefore focused on mapping of the basic soil and hydrological characteristics of the catchment at a high resolution, and assessing the applicability of the SCN method for simulating the direct runoff in the targeted catchment.

## 2. Description of the study area

This study was conducted at Godigne catchment located in the territory of Tekeze river basin (see Fig. 1). The Tekeze river basin is among the 12 major river basins found in Ethiopia with an area of 68751 $km^2$. The catchment considered in this study is geographically located within the latitude ranges of 13°5′N to 13°8′N and longitude of 37°49'E to 37°53'E. The catchment covers a total area of about 21 $km^2$ and the elevation in the catchment ranges from 2600 to 3000 m above mean sea level. Physiographically, the catchment is divided into hills, pediments with the slope ranges from 0.2% to 50%. The average annual precipitation recorded in the last twenty years is approximately 1000 mm, of which about 90% of this rainfall is received from June to September (Zerfu, Endalkachew, Gizaw, & Zewdu, 2011).

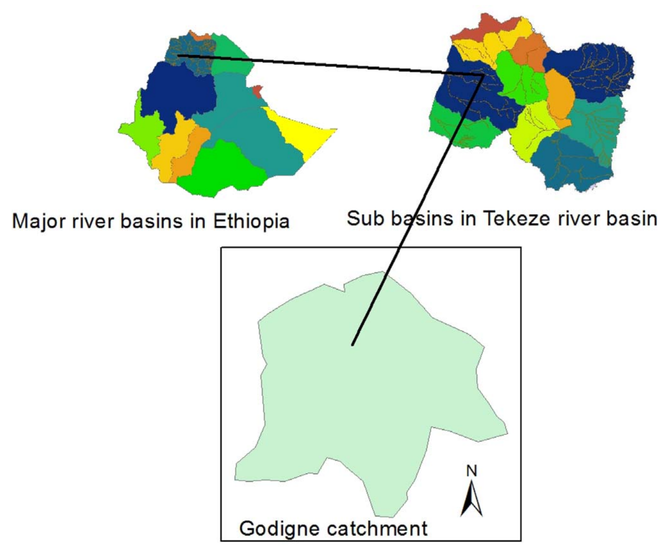


**Fig. 1.** Context of the study catchment a) 12 river basins of Ethiopia; b) sub-basins of the Tekeze, and c) the Godigne catchment study area.

## 3. Materials and methods

### 3.1. Generation of spatial soil database for the catchment

As described earlier, a detailed spatial database for soil and hydrological characteristics with high resolution at the local scale has the potential for providing a significant contribution to improve the process understanding in hydrological studies undertaken in a given catchment. In the absence of such information for the study region, a considerable effort was invested in this developing a high resolution soil database for the catchment.

#### 3.1.1. Soil texture

Soil texture describes the relative proportion of sand, silt and clay particles in a given soil sample and it is an indicator of basic soil physical properties (Brady & Weil, 1996). It is a basic parameter for studying the soil–water relation (Saxton, Rawls, Romberger, & Papendick, 1986) and hydraulic characteristics of the soils (Cosby, Hornberger, Clapp, & Ginn, 1984). It also provides basic information for undertaking the hydrological analysis in a given catchment, In this study, grids with 0.5 km intervals were first created in the catchment, and sampling points were then selected within these grids. About 29 soil samples were taken up to 50 cm depth using soil auger, and then analyzed for percentage of sand, silt and clay. The USDA textural classification triangle was used to define the textural class for each soil sample.

#### 3.1.2. Hydrological soil group

Soil conservation scientists classified generally all types of soils into four basic hydrological group categories (A, B, C and D) basically based on soil classification and infiltration (water transmission rates) (USDA, 1986). Considering their principal definition, soils with hydrological class of A normally have low runoff potential and high infiltration rates when thoroughly wetted, where as soils with hydrological class of D have mostly a high clay content with high runoff potential. Information on the soil–water characteristics such as the transmission(infiltration) rate is therefore a basic parameter in classifying and assigning the soil hydrological group. To attain soil infiltration rates in this study a double ring infiltrometer was used. The infiltration points were chosen at the point where the soil sampling points had been previously taken, and sites with no fractures and cracks were selected.