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Original Research Article

Understanding the spatial distribution of hydrologic sensitive areas in the landscape using soil topographic index approach☆

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ABSTRACT

Maintaining healthy watershed is pivotal to ensure sustainability in water resources thereby improving the carrying capacity of the earth. Understanding and identifying the spatial variability of hydrologically sensitive areas (HSAs) in a watershed is an important step to prioritizing the landscape to maintain water sustainability with limited resources. A spatial technique known as Soil Topographic Index (STI) was used to identify HSAs in the landscape. This study was conducted in Clinton and Tewksbury Townships in New Jersey, United States. Three different scenarios (STI > =9, STI > =10, and STI > =11) were conducted to understand the spatial distribution of HSAs in the watershed. The following conclusions were derived from this study. Firstly, a more detail representation of HSAs in the watershed was observed when applying the STI technique with a fine scale light detection and ranging (LiDAR) digitial elevation model. Secondly, all three scenarios consistently identified perennial stream corridors as HSAs; therefore, it is important to protect perennial stream corridors through implementation of various land use controls. Thirdly, this study analyzes the land use pattern of HSAs under the three scenarios and identifies the HSAs for high intensity land uses such as agriculture and urban to be the high priority locations for implementing best management practices for water quality improvements. The procedures developed in this study can be applied to watersheds in other parts of the world with similar physiographic characteristics.

1. Introduction

Healthy Watersheds Initiative (HWI) is a new watershed program introduced by the United States Environmental Protection Agency (USEPA) in 2009. The program intended to protect water resources from contamination by identifying, conserving and protecting the highest quality watersheds and their intact components; and protecting the key watershed processes and habitat required for healthy aquatic ecosystems (USEPA, 2010). HWI acknowledges the dynamic characteristics of water and aquatic ecosystems and their interconnections with the landscape, and protects all integral hydrologic, geomorphic, and other processes as a whole interconnected system. HWI strategies call for prioritization in protection and restoration of healthy watersheds. However, these strategies should be cost-effective because of limited availability of funding and resources for protection and restoration. Protecting healthy watersheds provides numerous benefits including sufficient clean water to support healthy aquatic ecosystems, habitat for fish and wildlife, safe drinking water, and better human health. Moreover, it helps to reduce the vulnerability of water resources to future land use and climate change impacts because it would subsequently decrease the cost of adaptation (USEPA, 2011).

Land use changes have substantial impact on water resources which needs to be addressed carefully when implementing HWI. Rapid urbanization has altered the landscape during last three decades in the United States (USDA, 2015). One illustrative example of such changes is found in New Jersey which has the highest population density in the United States. During 1986–2007, the urban land use in New Jersey has increased by 26.8%, which is a massive 130,817 ha of land adding to the state's pre 1986 urban footprint, while the population has increased only by 14% to finally reach 8.5 million during the same time period (Hasse & Lathrop, 2010). During the same period, New Jersey lost 24% of its agricultural lands, 7% of its forest lands and 5% of its wetlands to urban development (Hasse & Lathrop, 2010). Land use changes greatly alter watershed hydrology, which leads to nonpoint source pollution that degrades water quality, breaks down the stream integrity, and causes public concerns on water chemistry and biotic health issues of streams (Qiu et al., 2014).

Urbanization changes the land uses in a watershed, which leads to water resource degradation, however, its impacts on water resources vary across different parts of the watershed. For example, urbanization

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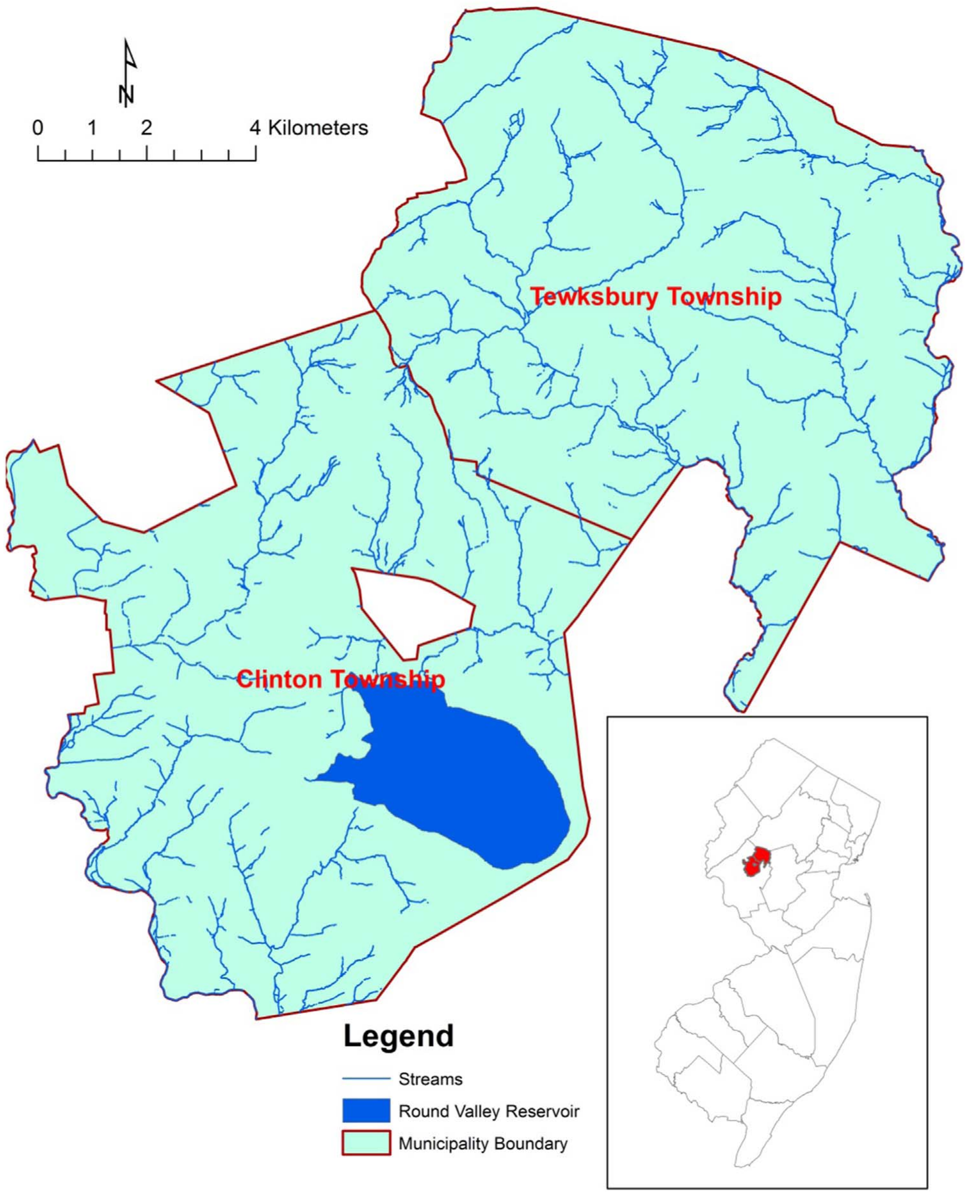

Fig. 1. Location of study area (Clinton and Tewksbury Townships) in New Jersey, US.

occurred close to the streams has far greater impact than away from the streams. To cope with the complicated hydrological interaction between streams and various parts of a watershed, researchers developed different techniques such as principal component analysis, positive matrix factorization, simple export coefficient modeling, statistical modeling (SPARROW), and physically based watershed modeling (SWAT) to identify critical source areas in the watershed that have most significant impacts on water quality in streams. However, most of these techniques require extensive input data as well as in-depth modeling knowledge. Therefore, we are proposing a simple terrain based approach that adopts the variable source area (VSA) hydrology concept to assess contributions of different parts of a watershed to runoff generation and identify these critical source areas. The term VSA usually attributed to Hewlett and Hibbert (1967) and is based on a saturation-excess hydrological process that explains how runoff is generated from relatively small saturated areas in a watershed (Hewlett, 1982). VSAs contribute to the increase or decrease of the saturation areas in a watershed and it varies with respect to change in time and storm intensity. While VSAs represent a dynamic pattern of saturated area actively contributing to runoff generation in a watershed during a storm event, hydrologically sensitive areas (HSAs) are defined as parts of VSAs which are more susceptible to produce runoff compared to other parts of watershed (Walter et al., 2000).

HSAs play a critical role in watershed hydrology, therefore, land uses inside HSAs have more dominant impacts on water quality than land uses in non-HSAs of a watershed. The concept of HSAs helps relate the watershed scale problems to various smaller areas in the watershed that potentially contribute water pollution. Identification of HSAs helps optimize the utilization of resources and provides a cost effective way to control pollutants transported by runoff into streams.

Considerable research has been using HSA approach to understand watershed hydrology and prioritize the watershed for water quality improvement. Soil Topographic Index(STI) is a terrain-based technique often used to quantify the runoff generation potential and define HSAs (Walter et al., 2002). Giri, Qiu, and Zhang (2016) used STI technique and HSA concept and created a regional scale model to understand the relationship between land uses and water quality in Northern New Jersey watersheds. They used STI value greater than equal to 10 to delineate HSAs in their study and analyzed the correlation between land uses and water quality. Anderson,