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Assessment of land use and land cover dynamics and its impact in direct runoff generation estimation using SCS CN method

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Abstract
The Madurai local planning authority, encompassing a land area of 726.34 sq. km, has encountered challenges of droughts and flash floods during the north–east monsoon season. These issues have arisen as a result of notable alterations in land use and the swift pace of urbanization. This comprehensive study aims to assess the effects of land use changes on direct runoff within the study area over a span of 40 years, from 1980 to 2020. This study attempted to understand the evolution of land use and land cover change in the Madurai LPA region over the past 2 decades and its corresponding impact on runoff generation. The study also predicted the trend of LULC in 2040. LANDSAT images from different years were acquired to create land use and land cover maps using ERDAS IMAGINE 9.1 and Arc GIS Version 10.1. Four hydrological soil groups were determined using data from the Madurai Atlas, and the surface runoff was calculated using the soil conservation service–curve number. The accuracy of the land use and land cover maps was evaluated using an error matrix and kappa index. LULC predictions for 2040 were made using the cellular automata and artificial neural network model. The analysis showed that agricultural land increased by 5.9% between 1980 and 2020, while forest cover decreased by 0.2% and urban settlements grew by 7.4% in the D hydrological soil group. The predicted land use for 2040 indicates that agricultural land will account for 54.1%, followed by 1% forest cover and 15.8% urban areas. The accuracy of the predicted land use map was validated using the 2020 map, with a 91% accuracy and a kappa coefficient of 0.8. The Madurai region has experienced a notable surge in urbanization, highlighting the urgency for effective flood management and the implementation of urban development strategies that prioritize the creation of green spaces and efficient storm water drainage systems.

Keywords Remote sensing · GIS · LULC prediction · Runoff analysis · SCS CN

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Introduction

Over the past 6 decades, there has been a significant evolution in global land use and land cover (LULC) change. According to Winkler et al. (2021), between 1960 and 2019, land use change impacted a staggering 32% of the world's land area, which is four times higher than the initial estimate. It is important to note that these changes are not uniform across the globe. The global north has witnessed afforestation and cropland abandonment practices, whereas the global south has experienced deforestation and agricultural expansion (Winkler et al. 2021). Land dynamics encompass the various alterations in the physical and biological attributes of land over time. This includes changes in land cover, utilization, and management practices (Pacheco et al. 2023). These changes are influenced by a multitude of factors, both natural and human-induced.

Climate change, urbanization, deforestation, agricultural expansion, and other land use transformations all play a role in shaping these dynamics (Bragagnolo et al. 2020; Gessesse et al. 2015). The impacts of land dynamics extend beyond the mere changes in land. They have far-reaching consequences on ecosystem services, such as water regulation, runoff, carbon sequestration, and biodiversity conservation. Additionally, they also affect social and economic systems, including livelihoods, food security, and overall human well-being (Bringezu et al. 2014; Etefa et al. 2018; Uriarte et al. 2011). Understanding and comprehending land dynamics is crucial in developing sustainable land management policies and practices that align with environmental and socio-economic objectives. By gaining insights into these dynamics, we can work towards a future where land is managed in a way that benefits both the planet and its inhabitants.

The varying patterns of land-use dynamics across different regions of the world necessitate a more contextual analysis to fully comprehend their impacts on various biophysical aspects, such as runoff and water regulation (Yuan et al. 2005). While there is a wealth of literature available on how land-use dynamics influence carbon emissions (Lam et al. 2021; Piabuo et al. 2023), there are also studies that specifically examine the effects of urbanization on landslides (Lehmann et al. 2019; Mugagga et al. 2012). Furthermore, a growing body of research has delved into the relationship between land-use change patterns and their effects on runoff, microclimate, soil erosion, sediment loads, land degradation, and biodiversity (Edokpayi et al. 2017). However, it is important to note that the connection between land-use and land-cover change and surface runoff is inherently complex, as it is influenced by regional physical characteristics such as size, topography, and soil types (Mewded et al. 2021).

The soil conservation service–curve number (SCS–CN) method is predominantly practiced for catchments all over the world for the estimation of direct runoff potential from rainfall as it is simple, requires less data, and has static assumptions (Hu et al. 2020; Moniruzzaman et al. 2020; Psomiadis et al. 2020). As SCS–CN does not require rigorous calibration like the other models, it can be applied to ungauged smaller watersheds where measured runoff data are unavailable (Zare et al. 2016).

The SCS–CN method was employed to calculate the surface runoff potential, which is a flexible empirical hydrological model with fewer calculation parameters and observation data (Ponce & Hawkins 1996). It is commonly used to estimate runoff at various spatial scales (Wang et al. 2012). Numerous studies have demonstrated that the SCS–CN model effectively determines surface runoff in highly urbanized areas with high runoff potential, even in very small watersheds. Moreover, it is applicable for areas with ungauged catchments where it is difficult to obtain the actual hydrological data (Ozdemir & Elbaşi 2015).

The study of changes in runoff characteristics resulting from human activities is of utmost importance in order to fully comprehend the effects of land use and land cover changes on hydrological processes worldwide (Shi et al. 2007). It is crucial to analyze the impact of past land use changes on runoff in order to accurately predict the future implications on runoff characteristics. Numerous studies have directly linked land use and land cover change (LULCC) to human endeavors (Xu et al. 2020), emphasizing the need for comprehensive discussion. Additionally, the impacts of climate change and LULCC on regional hydrological processes vary spatially (Yonaba et al. 2021). To fully grasp these impacts, it is essential to assess the optimal conditions of a specific region. While previous studies have attempted to consider the combined and individual effects of climate change and LULCC on regional hydrological processes, this study specifically aims to investigate the effect of climate change and LULCC on hydrological processes in a particular region. This approach will provide a deeper understanding of the mechanisms that influence these impacts.

This research paper delves into the realm of empirical research, specifically focusing on the intricate relationship between land use, land cover, and runoff. While valuable insights can be gained from various contexts, it is often challenging to find context-specific information. That is why this study has chosen the Madurai LPA region as its focal point. This region stands out due to its rich history of human settlement, rapid urbanization, dense population, and significant land-use changes. Understanding the impact of these factors on runoff is crucial for supporting agricultural systems, urban planning, and disaster risk management. Surprisingly, there is a dearth of recent empirical research in this locality. Therefore, this paper aims to bridge this gap and contribute to the existing literature by employing geospatial technology and remote sensing to identify land use and land cover (LULC) patterns in the Madurai LPA region. The study has set forth several objectives: 1. Creating comprehensive LULC maps for the Madurai LPA region using Landsat satellite imagery and evaluating the changes in land use and land cover from 1980 to 2020. 2. Forecasting future LULC maps for 2040 by analyzing the patterns of LULC transitions observed in previous periods. 3. Examining the impact of LULC changes on direct runoff generation and estimating the volume of runoff in the Madurai LPA region. By accomplishing these objectives, this research will not only fill the existing gap in empirical data but also provide valuable insights into the dynamics of land use, land cover, and runoff in the Madurai LPA region.