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Benchmarking land use change impacts on direct runoff in ungauged urban watersheds

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ABSTRACT

This paper describes the results of benchmark testing of land use change impact on direct runoff using Soil Conservation Service-Curve Number (SCS-CN) model in two ungauged neighbouring urban watersheds (Çınar and Kadıyakuplu) in Istanbul, Turkey. To examine this impact, the model was applied to daily rainfall data using three different dated (1982, 1996 and 2012) hydrological soil groups and land use of the two ungauged urban watersheds. Finally, the impact of land use change and model performance were evaluated with the rainfall-runoff regression, the coefficient of determination and the NSE test using benchmark runoff data based on 1982 land use conditions. The results of the analysis indicate that the changing of land use types from natural surfaces to impervious surfaces has a significant impact on surface runoff. Additionally, remarkable spatial variations of the land use changes and their impact on the runoff in 1996 and 2012 were more detected in the Çınar watershed compared with the Kadıyakuplu watershed. The planning decision on land use of the watersheds, has vital role in these differences. The results of this research also reveal that change to intensive land use in urban watersheds has a significantly larger impact on runoff generation than those rainfall.

1. Introduction

Urban flood events are increasing in frequency and severity as a consequence of: (1) reduced infiltration capacity due to increasing impervious surfaces; (2) increased construction in flood prone areas due to population growth; (3) the possible amplification of rainfall intensity due to climate change; (4) sea level rise which threatens coastal development and (5) poorly engineered flood control infrastructure (Hsu et al., 2000; Brown et al., 2007; Mason et al., 2003; Gallegos et al., 2009). These factors will contribute to an increase in urban flood risk in the future, and as a result, an understanding of and improved modelling for urban flooding have been identified as a research priority (Wheater, 2002).

Land use and its change have significant impact on the nature of the runoff and related hydrological characteristics of a watershed. This runoff process is especially vital in urban areas due to the increase in impervious surfaces. Land use changes can affect runoff generation and flow patterns by altering hydrological factors such as interception, infiltration and evaporation and thus causes changes in the frequency and intensity of surface runoff and flooding (Weng, 2001; Ali et al., 2011). Therefore, a better understanding and assessment of land use change impacts on the watershed hydrologic process, is of great importance for predicting flood potential and the mitigation of hazard, and has become a crucial issue for the planning, management, and sustainable development of the watershed (Vorosmarty et al., 2000; Defries and Eshleman, 2004; Wang et al., 2007; Chen et al., 2009).

The impact of land use on runoff has been documented in the literature from different perspectives, including the analysis of runoff changes in response to land use changes, the prediction of runoff for future climatic and land use conditions, and the study of the spatial variability of urbanization and its effect on runoff generation, among others (Tang et al., 2005; Burns et al., 2005; Bari et al., 2005; Lin et al., 2007; Chen et al., 2009; Gholami et al., 2010; Ali et al., 2011; Zhang et al., 2012). In most of the studies, past and present land use conditions are used as input to event-scale hydrological models to determine the watershed's hydrological response to observed or hypothetical rainstorms (De Roo et al., 2003; Camorani et al., 2005; Olivera and DeFee, 2007). All these models are generally calibrated and validated with observed data in the watersheds studied. However, many river catchments are ungauged for stream flow data even in urban areas.

The Soil Conversation Service-Curve Number (SCS-CN) method (SCS, 1956, 1964, 1971, 1985, 1993) is one of the most popular methods for computing the direct surface runoff for given rainfall

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events from small agricultural, forest and urban watersheds. Many researchers have used Remote Sensing and Geographic Information Systems (GIS) techniques, and also their combination, to elucidate the effects of land use change on runoff using the SCS model (Nayak and Jaiswal, 2003; Zhan and Huang, 2004; Ozdemir, 2007). Some more attempts to apply hydrological models to investigate the impact of land use change are reported in De Roo et al. (2001), Wehmeyer and Weirich (2010), Nayak and Narulkar (2011) and Nayak et al. (2012). In most of the studies, the SCS-CN method was applied to a rural watershed to compute direct runoff, but its application on urban watersheds is limited (e.g. Tsihrintzis and Hamid, 1997; Chung et al., 2010).

The purpose of the present study is to use the SCS model, which fully considers physiographic heterogeneity (e.g. topography, soil, and land use), to determine the rainfall-runoff relationships in different dated land uses of two small ungauged urban watersheds, namely the Çınar and Kadıyakuplu streams in the upstream of the Ayamama River, Istanbul-Turkey. The land use change of the Çınar Stream watershed has occurred intensively in last 20 years, whereas the land use of the Kadıyakuplu Stream watershed has remained more stable depending on army usage. A comparison and determination of land use and how its changes impact on direct runoff in these two urban watersheds has been made to examine the differences between the watersheds.

2. Material and methods

2.1. Study area

This study was conducted in the two main upstream watersheds of the Ayamama River basin in Başakşehir county of Istanbul (Turkey). The Çınar and Kadıyakuplu streams watersheds are neighbours and they lie between 28°47′30″–28°51′10″E longitude and 41°4′10″–41°8′20″N latitude (Fig. 1). The Çınar watershed is 9.33 km^2 in size and the elevation of the watershed ranges from 45 to 221 m above sea level (asl). The Kadıyakuplu watershed has a total area of 17.4 km^2 and its elevation varies from 50 to 216 m asl. Both watersheds contribute their surface waters to the main Ayamama River which flows to the Marmara Sea.

Geologically, both watersheds are mainly covered by the same type of lithological unit called the Thrace formation. These Palaeozoic rocks consist of coastal shallow-marine clastics and carbonates, deep marine shales and limestones, deep-marine cherts and flysch constitutes the basement formation of the area (Oktay et al., 2002). According to the Florya meteorological station data, the average annual precipitation is 650 mm, more than 60% of which occurs during the months from October to February. The maximum and the minimum temperatures are 38.5 °C in August and −10 °C in February respectively. The mean relative humidity is about 72.7%, but varies from 53.3% in June to 86.8% in December. In most parts of the study area, the topsoil is Cambisol with sandy loam and medium to fine texture form, but the distribution of the soil can be seen only in the Kadıyakuplu and the north of the Çınar watershed where there is no urbanization. Both watersheds are inside of Başakşehir County in Istanbul Metropolitan area (Fig. 1) and this region is one of the urban expansion areas in Istanbul. However, only the Kadıyakuplu watershed restricted this expansion due to current usage.

As increasing human activity downstream of the Ayamama River results in greater flood damage, the floods themselves, in turn, increase in size and frequency due to human activities in the upstream section of the river system. Therefore, flooding has frequently occurred on the Ayamama River in the last 30 years. However, the largest event occurred on September 9, 2009. During this flood, more than 30 people were killed and economic damage of about $350 million was determined.

2.2. Data sources

In this study, a variety of data including topographic and soil maps at the scale of 1:25,000, different dated land use maps obtained from 1982 and 1996 aerial photos (produced by Istanbul

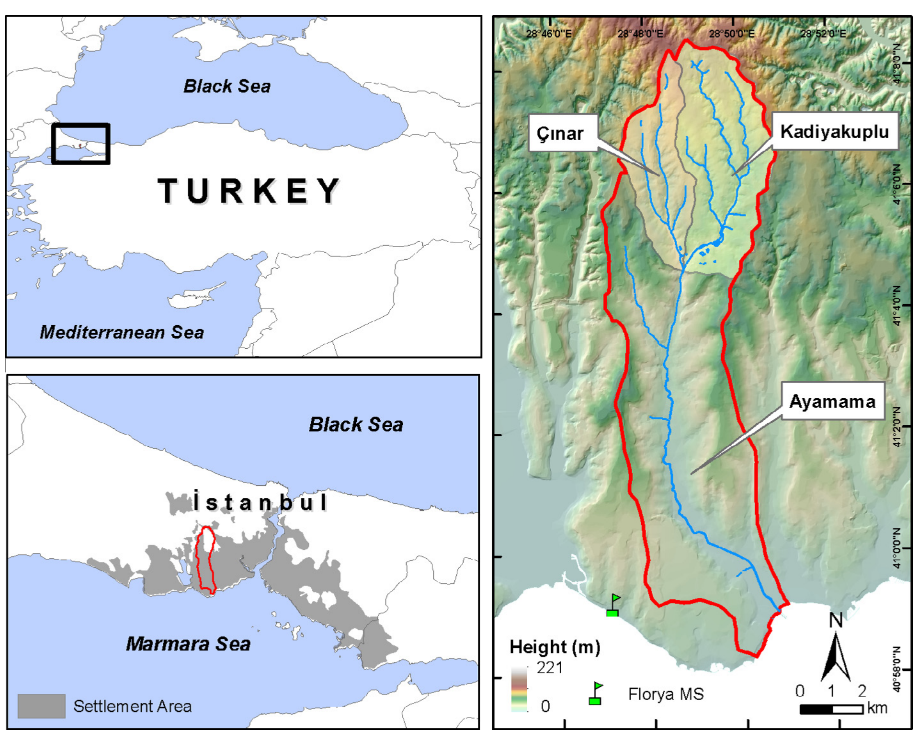

Fig. 1. Location of the study area.