Catena 166 (2018) 220–228

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Changes in selected physical water quality characteristics after thinning in a forested watershed

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ARTICLE INFO

Keywords:
Forestry activities
Thinning
Selective cutting
Streamwater quality
Stream and air temperatures

ABSTRACT

Climate change is a natural phenomenon with far-reaching impacts. Due to global warming, forest vegetation patterns in the Mediterranean region can be affected and the extent of forested areas can be altered. The purpose of this study was to investigate the impact of slightly decreased forest density on physical water quality parameters by employing 18% thinning with a paired watershed methodology in a broadleaf forest ecosystem. After a 70-month monitoring period that started in December 2005, calibration equations were established between control and treatment watersheds for streamwater parameters including pH, color, turbidity, electrical conductivity (EC), suspended sediment concentration (SSC), water and air temperatures. After 18% standing timber volume was harvested from the treatment watershed, streamwater was also sampled for the same parameters in both watersheds during the 46-month treatment period between January 2012 and October 2015. Changes in the mean monthly values of streamwater parameters were determined as the differences between measured and estimated values derived from the calibration equations. Results showed that 18% forest thinning caused 7.3 μS cm^{-1} increase in the overall average monthly EC, 2.8 NTU in turbidity, 15.1 mg L^{-1} in SSC, 0.3 °C increase in the air temperature, and 1.2 °C in the maximum air temperature, whereas it caused 0.5 °C decrease in overall average monthly minimum temperature and 1.3C.P·U in overall mean monthly color. In contrast, forest harvest did not have significant impact on overall average monthly pH and streamwater temperature values. Results of 18% forest harvest indicated that even a small decrease in the forest cover can significantly affect selected physical water quality parameters and hence aquatic life in the forested watersheds.

1. Introduction

Forest ecosystems provide many benefits and services for human well-being, such as providing wood, clean air, recreation, nutrient cycling, preventing disturbance (flood and erosion) damage, and resilience to climate change (Amacher et al., 2014; Hanson et al., 2011; MEA, 2003, 2005; WRI, 2002). Due to soil characteristics, root systems, canopy cover, tree species and forest floor, forest ecosystems have been highlighted as the main contributors of water quality (Eisalou et al., 2013; Fiquepon et al., 2013; Makuch, 2008; Neary et al., 2009; Sun et al., 2004). Besides this vital role of forest ecosystems, forestry activities such as forest thinning, timber harvesting, site preparation and road construction are necessary in order to meet increasing public demand for forest resources. Forestry activities can cause decreases in the forest covered areas. The interactions between forestry activities and forest ecosystems becomes significant because they impact water quality and quantity in the watersheds. Much research has found that forestry management practices have different impacts on hydrologic processes, such as shortening the time of concentration, causing sedimentation, changing streamflow regimes and hence water yield and quality (Arvidson, 2006; Gökbulak et al., 2008; Grace III et al., 2006; Serengil et al., 2007b). These impacts mainly can be attributed to the decrease and alteration of forest cover that affect forest soil and the amount of precipitation reaching the soil surface. On the other hand, the impacts of forestry activities depend on intensity of forestry practices. For example, some research has found that the minimum amount of timber harvest should be at least 20% of the forest cover in order to detect a change in streamflow (Bosch and Hewlett, 1982). In order to examine the effect of timber harvest on watershed hydrology, the paired watershed approach is commonly used worldwide (Binkley and Brown, 1993; Brown et al., 2005; Gökbulak et al., 2016; Neary, 2016; Stednick, 1996). The main goals of paired watershed approach are to examine the effects of forestry activities on watershed hydrology in small scale watersheds and provide management options for large scale watersheds. A number of studies carried out worldwide focused on the relationship between forest harvest and water yield. These studies

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https://doi.org/10.1016/j.catena.2018.04.010
Received 3 November 2017; Received in revised form 2 April 2018; Accepted 6 April 2018
Available online 13 April 2018
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found that water yield generally increases after intensive timber harvest, such as clearcutting. On the other hand, increases in the water yield after timber removal can deteriorate water quality (Gökbulak et al., 2017; NRC, 2008). Although Neary (2016) mentioned that many paired watershed research projects were expanded to investigate the effects of forestry activities on the chemical water quality parameters and nutrient cycling, as in Hornbeck et al. (1997), Bäumler and Zech (1999), Grace III et al. (2006), and Serengil et al. (2007a), studies that examined the effects of timber harvest on physical water quality parameters including pH, electrical conductivity, color, and turbidity have been limited compared to the studies of stream chemistry and water yield. In fact, physical water quality parameters are important water characteristics because the changes in these parameters can indicate the impacts of forestry activities on water quality and hence aquatic life in an easy and practical way compared to other chemical water characteristics. Therefore, physical water quality characteristics can be used as an indicator for recovery of disturbed forested watersheds. In other words, some undesirable characteristics of water can be seen or understood by monitoring some water characteristics such as color, turbidity, stream water temperature, and suspended sediment concentration. Also, some parameters like turbidity and total suspended sediment concentration are interrelated (Davies-Colley and Smith, 2001) and can be considered as an indicator of each other (Bilotta and Brazier, 2008). In this case, high suspended sediment concentration or high turbidity values can be considered as an indication of degradation in potable water quality (Binkley and Brown, 1993). Likewise, EC is also an important physical water quality parameter (Miller et al., 1988) investigated in some paired watershed studies (Ensign and Mallin, 2001; Gökbulak et al., 2008) because it indicates pollution of streamwater with a sudden alteration of vegetation cover (Fondriest Environmental Inc., 2014). Various land use types have significantly different effects on the EC in the streamwater (Bowden et al., 2015; Brauman et al., 2007; Haidary et al., 2013; Serengil, 2003; Tong and Chen, 2002). In general, agriculture and urban areas are the most effective land use types that increase EC in streamwater compared to the other land use types. For instance, Haidary et al. (2013) found a significantly positive relationship between EC and intensity of urban areas but negative relationship for the intensity of forest areas. Similiarly, Bowden et al. (2015) found a higher EC value (1216 $\mu S\,cm^{-1}$) and pH value (9.9) in agricultural and urban areas, respectively. Due to forestry management activities such as thinning, harvesting or clearcuttig, water quality parameters may show different variation depending on the intensity of tree removal, climatic conditions and watershed characteristics (Bäumler and Zech, 1999; Gökbulak et al., 2008; Reuss et al., 1997; Wang et al., 2006). Moreover, forest management activities can also alter the air and streamwater temperatures in the watersheds. Air and streamwater temperatures are important climatic parameters and play a vital role in biological, hydrological and chemical processes in water and soil (Johson and Jones, 2000). In general, removal of forest canopy mostly causes changes in the maximum and minimum air temperatures by influencing the intensity of light distribution, solar radiation, amount of rainfall reaching the soil surface, humidity and wind velocity and therefore, microclimatic conditions in the forested watersheds (Aussenac, 2000). Despite much research into the hydrologic consequences of forestry management activities worldwide, there is a need for more studies conducted under different ecological conditions to understand fully the interactions between water quality and forestry management activities and to determine a threshold level for water quality. This issue is important due to clean water scarcity around the world that results from population increase, land degradation and rapid urbanization, all of which are occurring in Turkey as well. On the other hand, global warming is a real and ongoing phenomenon and the Mediterranean region, including Turkey, is among the most vulnarable regions in the world (Giorgi, 2006; IPCC, 2007; Solomou et al., 2017). Due to global warming, forest cover is expected to shrink or be replaced with herbaceous vegetation cover around the world (Howard, 2012; Hufnagel and Garamvölgyi, 2014; Zeydanlı et al., 2010). The impact of forest cover reduction or vegetation cover change is not well documented in the Mediterranean region. Therefore, the objective of this study was to determine how physical water quality parameters change due to a decrease in forest cover resulting from management activities. In order to investigate the impact of this decrease in forest cover on physical water quality characteristics including pH, electrical conductivity, color, turbidity, suspended sediment concentration, streamwater and air temperatures, 18% of standing timber volume was harvested and the effects on physical water quality parameters were examined by using a paired watershed methodology. Results of this study may help decision makers and forest managers to make projections about the influence of a decrease in the tree density in the context of water quality in the fresh water producing forested watersheds.

2. Material and methods

2.1. Study site

This study was conducted in Belgrad Forest, which is the home of 7 reservoirs providing freshwater to Istanbul (41° 13′ 00″ - 41° 14′ 13″ N, 28° 54′ 53″ - 28° 56′ 37″ E). The two experimental watersheds, W-I (control) and W-IV (treatment), were 1400 m apart (Fig. 1) and a paired watershed methodology, which requires at least two watersheds, was used to investigate the effects of the treatment in the study. The selected watersheds are part of a long-term experimental watershed research project initiated in 1978 to determine the principles of forest management in the fresh water producing watersheds in Istanbul (Balcı et al., 1986). To date, these experimental watersheds have been studied in other research of the relationship between sylvicultural treatments and streamflow and nutrient flow (Gökbulak et al., 2008, 2016; Özyuvaci et al., 2004; Serengil et al., 2007a, 2007b) (Table 1).

The watersheds have similar ecological conditions such as climate, soil, vegetation and topography. According to the Tornthwaite classification method, the watersheds have a humid, mesothermal and oceanic climate with moderate water deficit in the summer months (Özyuvacı, 1999). Average annual precipitation is about 1129 mm and mostly falls in the winter months. Mean annual temperature is about 12.3 °C and varies from 4.2 °C in February to 21.7 °C in August (Özhan et al., 2008). The parent materials in the experimental watersheds are the carboniferous clay schists, neogene loamy and gravelly deposits. Moderately deep to deep soils have high erodibility potential with loamy clay texture and medium to high permeability rates. The forest ecosystem in the watersheds have a crown closure of about 75–100% and mull type forest floor with an average depth of 5–6 cm (Özhan et al., 2010). Dominant vegetation cover in the study site is forest mainly composed of *Quercus petraea* (Mattuschka) Liebl, *Quercus frainetto* Ten., *Quercus cerris* L., and *Fagus orientalis* Lipsky (Yaltırık, 1966). The experimental watersheds also have similar slope and drainage density values. The treatment watershed (W-IV) has an area of 77.5 ha with an average slope of 14.0% and drainage density of 3.8 $km\,km^{-2}$ while the control watershed (W-I) has an area of 71.9 ha with a mean slope of 10.0% and drainage density of 3.6 $km\,km^{-2}$.

2.2. Methods

Two watersheds were selected as a control (W-I) and treatment (W-IV) and monitored for both streamflow and selected physical water quality characteristics between December 2005 and October 2011 for a calibration period of 6 years. During the calibration period, water grab samples were collected from the streams of both watersheds close to outlets just above the V-notch weirs on a weekly basis and analyzed for pH, electrical conductivity (EC), color, turbidity and suspended sediment concentration (SSC) on the same day of collection. EC and pH were analyzed by using WTW Multiline P4 universal meter, color with Hellige aqua tester, turbidity with Hellige turbidimeter and SSC was

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