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Relationship between water yield and water quality in broadleaf forested watersheds

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Abstract: Forest ecosystems provide fresh water with best quality in sustainable manner but they consume huge amount of water. Researchers apply different forestry practices to increase water yield by minimizing water loss through evapotranspiration and maximizing amount of rainwater reaching soil surface in the watersheds. Studies showed that water yield and nutrient losses increase after clear cutting. High nutrient concentrations in the streamwater cause deterioration in the water quality. Therefore, objectives of this study were to investigate relationship between amount of annual streamflow and nutrient outflux and quantify nutrient losses in three oak-beech mixed forest covered watersheds. The experimental watersheds were located in Istanbul with sizes of 77.4 ha, 71.9 ha, and 17.5 ha. Water samples were collected from the streams of the watersheds on weekly basis and analyzed for pH, electrical conductivity (EC), total suspended sediment (TSS), chloride (Cl^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), total nitrogen (TN), sodium (Na^+), potassium (K^+), iron (Fe^{3+}), aluminum (Al^{3+}), ammonium nitrogen (NH_4^+ - N), and sulfate $(SO_4)^{2-}$. Regression equations were developed between annual water yields and nutrient outfluxes. Results showed that there were significant relationships between annual water yield and nutrient outflux except for pH and EC and these parameters showed increase with the increase in the streamflow discharge. This means that if the water yield increases after timber harvest then water quality can be deteriorated in the watersheds.

Key words: Water yield, water quality, forestry activities, nutrient flux

1. INTRODUCTION

Water has a vital importance in human life and there is also an increasing demand for the water resources worldwide due to population growth and industrial developments. On the other hand, forest covered watersheds provide fresh water with the best quality compared to other land use types (Neary et al., 2009). Forest cover in the watersheds also cause decreases in the streamflow (Zhang et al., 2014) because of great interception and transpiration capacities (Özhan et al., 2010). Water quality and quantity in a forested watershed are influenced by watershed characteristics, climate, and forest cover. Among these factors, forest cover is the only factor that can be modified to increase water yield in the watersheds due to their enormous transpiration and interception losses. Therefore, a number of studies have been carried out around the world to investigate the effects of forest harvest on water yield (Swank et al., 2001; Özyuvacı et al., 2004; Dung et al., 2012). In general, these studies showed that forest harvest can increase water yield depending on harvest intensity. For instance, Bosch and Hewlett (1982) and Stednick (1996) stated that at least 20 % of the forest cover in a watershed must be harvested in order to perceive an increase in the water yield whereas Sahin and Hall (1996) claimed that a minimum of 10 % forest cover removal would be sufficient to significantly increase the water yield in their review papers. On the other hand, there is also a potential increase in nutrient losses from the watersheds together with streamflow after timber harvest. In fact, Reuss et al. (1997) found significant increases in both streamflow and nutrient export from the watershed after the treatment in Colorado. Stednick (2000) reviewed the studies about effects of forest harvest on water yield and quality and reported that nutrient discharges from the forest cover harvested watersheds were significantly greater than those from the forest cover untouched ones. Similar results were also reported in other studies (Bäumler and Zech, 1999; Wang et al., 2006). In general, it can be concluded from all these studies that forest harvest can increase water yield and nutrient losses from the watersheds depending on the harvest intensity and amount of precipitation. In the long run, high nutrient loads in the streamflow due to tree removal can result in poor water quality and productivity losses in the soils of watersheds.

In Turkey, forest-water relations have been received attention since late 1970s (Özyuvaci, 1976; Özhan, 1977) but studies investigating impacts of forest harvest on streamflow quantity and quality are limited (Balci et al., 1986; Özyuvaci et al., 2004; Serengil et al., 2007a,b; Gökbulak et al., 2008a,b). Therefore, objectives of this study were to examine the relationship between streamflow discharge and nutrient outflux and quantify amount of nutrient export in three forested watersheds.

2. MATERIAL AND METHODS

2.1 Study area

Three experimental watersheds with similar elevation, slope, drainage density, and ecological conditions in Belgrad Forest of Istanbul were selected for this study (41°13′00″ – 41°14′13″ N, 28°54′25″ – 28°56′37″ E) (Table 1). The sizes of the watersheds are 71.9 ha for W-I, 77.5 ha for W-IV, and 17.5 ha for W-V. All watersheds have second-order streams that flow into a dam supplying drinking water for Istanbul city. Thickness of the forest floor and crown closure were similar among the watersheds and varied from 4 to 6 cm and from 74 % to 100 %, respectively. Dominant parent materials in the area are carboniferous clay schists and Neogene loamy, gravelly deposits. The soil type is Vertic Xerochrept (USDA, 1994) and soil texture is sandy clay loam and sandy loam. Average annual precipitation is around 1129 mm and mostly falls between October and April. Mean annual temperature is about 12.3 °C and changes from 4.2 °C in February to 21.7 °C in August (Özhan et al., 2008). The study area has a subhumid Mediterranean climate with mild-rainy winter and hot-dry summer months. Dominant trees are mostly oak [*Quercus petraea* (Mattuschka) Liebl. and *Q. frainetto* Ten.] and beech (*Fagus orientalis* Lipsky) species with low proportions of other tree species such as *Q. cerris* L., *Alnus glutinosa* L., *Carpinus betulus* L., *Acer trautvetteri* Med., *Acer campestre* L., *Castanea sativa* Mill., and *Ulmus campestris* L.

Table 1. Some characteristics of experimental watersheds.

Watershed characteristics	Watershed - I	Watershed - IV	Watershed - V
Area (ha)	71.9	77.5	17.5
Mean elevation (m)	140.3	123.5	128.7
Mean slope (%)	10	14	13
Form factor	1	0.7	0.6
Drainage density (km/km^2)	3.60	3.80	3.60
Stream density (number of streams/km^2)	0.14	0.13	0.18
Road density (m/ha)	12.93	12.36	0.00
Slope of main stream channel (%)	3	5	6
Elevation range (m)	99-170	97-190	98-170

2.2 Data collection and analysis

Three neighboring watersheds were selected with similar vegetation, soil, topography, elevation, slope, geology, and aspect and monitored for streamflow and nutrient outflow since late 1979.

Stream stages were recorded in 90° and 120° concrete sharp-crested V-notch weirs instrumented with automatic water stage height recording systems at the outlets of the watersheds. Stream discharge was estimated by using the following formula:

$$Q = C \times H^n \quad (1)$$

where Q = the runoff (m^3/s), H = the depth of the water column above the bottom of the V-notch in meter, n = a coefficient taken as 2.48, and C= a constant and changes in relation to the angle of the notch and unit of the measurement (Özhan et al., 2010). Precipitation was measured with an automatic tipping-bucket type rain gauge installed near the watersheds. Streamwater grab samples were collected from the watersheds on weekly basis and analyzed usually at the same day of collection for pH, EC, TSS, Cl^-, Fe^{3+}, Al^{3+}, TN, NH_4^+-N, Ca^{2+}, Mg^{2+}, K^+, Na^+, and SO_4^{2-}according to the standard methods of APHA–AWWA–WEF (1998). The pH and EC measurements were made according to the methods 4500-HB and 2510 B, respectively with the WTW Multiline P4 Universal Meter (WTW, Weilheim, Germany). Concentration of TSS was determined by evaporation procedure performed on 500 ml stream water samples. Concentrations of Fe^{3+}, Al^{3+}, and $(SO_4)^{2-}$ were measured by using UV visible spectrophotometer. TN, Ca^{2+}, and Mg^{2+} were determined with titration method, and NH_4^+-N, K^+, and Na^+ were measured with ion selective electrode method. Average annual export for each chemical parameter was estimated by multiplying mean annual concentration of each nutrient with the mean annual streamflow. Simple linear regression equations were developed between mean annual streamflow and water characteristics to determine relationship between streamflow and water quality parameters and results were evaluated at α level of 0.05 (Zar, 1996).

3. RESULTS

All experimental watersheds had similar trends for mean annual outflow of ions, pH, EC and TSS. Average annual exports of chemical parameters, along with pH, EC, and TSS were also given in Tables 2 and 3. Mean annual pH value was 7.31 and varied between 7.14 and 7.48. Mean annual EC of the streamwater was 262 µS/cm and varied from 205 to 332 µS/cm (Tables 2 and 3). The watersheds had similar TSS discharge and changed between 5024.4 and 6253.8 kg/ha/yr. The watersheds had statistically similar ion fluxes with the same order and the trend (Table 2). The order of ion flux was in descending order of $Cl^- > (SO_4)^{2-} > Ca^{2+} > Na^+ > Mg^{2+} > K^+ >$ TN $> Fe^{3+} > NH_4^+$-N $> Al^{3+}$. Cl^- (1146.4 kg/ha/yr) and $(SO_4)^{2-}$ (743.6 kg/ha/yr) were dominant ions in the streamwater and mean annual losses of the cations were lower than the anions. On the other hand, Cl^- had the highest mean annual outflow (1146.4 kg/ha) whereas Al^{3+} had the lowest outflow (3.6 kg/ha) from the watersheds (Table 3). Among the cations, streamwater had a higher calcium load compared to other cations (Table 3) and showed changes from 486.2 to 741.4 kg/ha (Table 2).

Table 2. Annual values (mean ± SEM) of streamwater quality parameters.

Parameters	Experimental watersheds		
	W-I	W-IV	W-V
pH	7.42 ± 0.06	7.14 ± 0.09	7.48 ± 0.07
EC (µS/cm)	298 ± 8.44	205 ± 6.59	332 ± 12.70
TSS (kg/ha/yr)	6253.8 ± 870.6	5482.3 ± 711.0	5024.4 ± 1063.4
Cl^- (kg/ha/yr)	1104.0 ± 156.3	1180.4 ± 154.3	1173.0 ± 244.8
Ca^{2+} (kg/ha/yr)	741.4 ± 105.7	530.0 ± 60.4	486.2 ± 96.9
Mg^{2+} (kg/ha/yr)	309.3 ± 50.9	271.4 ± 42.4	282.6 ± 57.2
TN (kg/ha/yr)	133.2 ± 49.1	40.7 ± 17.7	22.0 ± 12.9
Na^+ (kg/ha/yr)	328.5 ± 56.0	378.1 ± 56.5	311.4 ± 89.2
K^+ (kg/ha/yr)	163.4 ± 67.6	47.0 ± 7.0	28.7 ± 5.2
Fe^{3+} (kg/ha/yr)	28.9 ± 6.9	23.9 ± 5.0	20.8 ± 4.8
Al^{3+} (kg/ha/yr)	4.0 ± 1.6	4.0 ± 1.4	2.7 ± 2.0
NH_4^+-N (kg/ha/yr)	8.1 ± 1.9	7.0 ±1.8	4.9 ± 0.8
$(SO_4)^{2-}$ (kg/ha/yr)	893.0 ± 186.0	684.4 ± 120.2	630.8 ± 119.2

Simple linear regression equations showed that there was a statistically significant relationship between mean annual streamflow and mean annual outflow of the parameters except for pH and Al^{3+}. Streamwater had almost a neutral character with a pH value of 7.3 and it did not have a significant relation with amount of annual streamflow (Table 3). Al^{3+} load in the streamwater was the lowest compared to those of other chemicals and it did not have a significant relationship with streamflow. Among the water quality parameters, significantly high correlation coefficients greater than 80 % were found between streamflow and TSS, Cl^-, Ca^{2+}, NH_4^+-N, and Fe^{3+} while low correlation coefficients smaller than 80 % were determined between streamflow and EC, Mg^{2+}, TN, Na^+, K^+, and $(SO_4)^{2-}$ (Table 3).

Table 3. Regression equations and correlation coefficients for the relationship between mean annual streamflow (m^3/ha/yr) and streamwater quality parameters.

Parameters	**Regression equations**	**Correlation coefficient (*r*)**	**Mean values (mean ± SEM)**
pH	Y = 7.24 + 3E-05*X	r = 0.12^{ns}	7.31 ± 0.05 (n = 67)
EC (µS/cm)	Y = 289.61 - 0.01*X	r = 0.31*	262 ± 7.95 (n = 67)
TSS (kg/ha/yr)	Y = 387.92 + 2.24*X	r = 0.94***	5754.8 ± 503.6 (n = 67)
Cl^- (kg/ha/yr)	Y = 108.46 + 0.44*X	r = 0.96***	1146.4 ± 99.1 (n = 65)
Ca^{2+} (kg/ha/yr)	Y = 103.57 + 0.21*X	r = 0.82***	616.9 ± 55.7 (n = 66)
Mg^{2+} (kg/ha/yr)	Y = 39.51 + 0.10*X	r = 0.75***	289.6 ± 29.4 (n = 66)
TN (kg/ha/yr)	Y = 8.42 + 0.03*X	r = 0.26*	78.9 ± 23.4 (n = 64)
Na^+ (kg/ha/yr)	Y = 32.95 + 0.13*X	r = 0.80***	347.7 ± 36.1 (n = 60)
K^+ (kg/ha/yr)	Y = - 63.33 + 0.06*X	r = 0.48***	95.0 ± 30.2 (n = 60)
Fe^{3+} (kg/ha/yr)	Y = - 2.37 + 0.01*X	r = 0.93***	25.0 ± 3.4 (n = 35)
Al^{3+} (kg/ha/yr)	Y = 2.14 + 0.001*X	r = 0.19^{ns}	3.6 ± 0.9 (n = 31)
NH_4^+ - N (kg/ha/yr)	Y = - 0.144 + 0.003*X	r = 0.85***	6.8 ± 1.0 (n = 28)
$(SO_4)^{2-}$ (kg/ha/yr)	Y = 176.80 + 0.23*X	r = 0.79***	743.6 ± 85.8 (n = 28)

** Significant at α level of 0.05, ** 0.001, and *** 0.0001*
^{ns} Nonsignificant

4. DISCUSSION

Significantly high correlation coefficients were found between annual stream discharge and mean annual nutrient and sediment losses (Table 3). Thus, annual streamflow affected nutrient outflux and hence water quality as found in other studies (Balcı et al., 1986; Lewis, 1998; Serengil et al., 2007b). High correlation coefficients between stream discharge and nutrient losses can be considered as an indication of how forestry practices can influence water quality in the forested watersheds. In general, nutrient concentrations in the waters coming from forested watersheds are lower than those coming from other land use types (Ryan, 2000; Gravelle et al., 2009) but nutrient loads of waters from forest covered watersheds can be increased after timber harvest. In fact, several studies already have shown that intensive timber harvest practices can increase runoff in the watersheds and result in nutrient losses from the forest soil and deterioration in water quality. For example, Bäumler and Zech (1999), Swank et al. (2001) and Wang et al. (2006) found that nutrient export increased in relation to increases in the stream discharge after timber harvest. All these studies showed that forest harvest practices can be used as a tool to increase water yield but they can also have an adverse impact on water quality due to nutrient and sediment losses, and leaching. Thus, nutrient and sediment losses can be detrimental to quality of potable streamwater. For instance, Burns and Murdoch (2005) found that NO_3^- concentration increased more than 1400 μmol/L after clearcut and its concentration can deteriorate water quality in the streams and cause mortality of aquatic lives like brook trout (Baldigo et al., 2005). Similarly, increased concentration of chemicals in the streamflows can create problems such as eutrophication. In some places around the world like in Portland, streamwater from forested watersheds can be used without filtering (Neary et al., 2009) but the waters from forest areas can be polluted by excessive phosphorus and nitrogen concentrations as a result of intensive timber harvest (Gravelle et al., 2009; Tremblay et al., 2009). Therefore, impact of timber harvest must be evaluated before harvest activities are applied in watersheds because water is a valuable commodity without alternative.

5. CONCLUSION

The study examined the relationship between mean annual streamflow and outflow of some chemical water quality parameters showed that there were high correlations between streamflow and nutrient losses in the watersheds. This means that application of forest harvest to increase water yield is also detrimental to water quality and hence aquatic lives in forested watersheds. Purification of polluted water resources can affect sustainability of domestic water supply and increase cost of treatment and then water consumption. Additionally, leaching of nutrients from forest soils after timber harvest can affect productivity of forest soils and influence sustainability of forest ecosystems in the long term. Therefore, timber harvest programs and water management policies should be well developed and pros and cons of timber harvest especially in fresh water producing watersheds should be taken into account before actions.

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