Acidity (pH) and Electrical Conductivity Changes in Runoff Water from Ditches of Paved and Unpaved Forest Roads

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Abstract

Temporal acidity (pH) and electrical conductivity (EC) changes in runoff water determined through sediment traps established on unpaved (UPFR) and paved forest road (PFR) ditches and in an undisturbed (UA) forest land. Research was carried out one year with monthly samplings from November 2009 to October 2010. In runoff water, pH was changed between 5.15 pH and 7.32 pH, and EC was between 58.35 ġS/cm and 198.09 ġS/cm. Both EC and pH of runoff water showed significant variations among experiment sites and months. Runoff EC and pH sourced from PFR showed a significant relationship in regressions with same parameters of precipitation indicating that EC and pH of runoff sourced from paved forest road were related directly to precipitation chemistry. However, to indicate a definite trend or difference is difficult despite significant differences among road types and sampling times.

Key words: EC, erosion, road pavement, salinity, sediment

Introduction

Adequate understanding of road erosion and sediment delivery processes is essential to develop cost-effective land management decisions (Fu et al. 2010). The connection of road ditches and culverts with stream networks accelerates the flow of runoff that quickly reaches channels, in hydrological perspective. Also this can create rapid flow peaks and higher total discharges (Arnáez et al. 2004). Sediment delivered to streams from roads causes to many problematic effects on water quality and aquatic life (Alekseevskiy et al. 2008, Parsakhoo et al. 2009). Forest roads have long been admitted as the main and relatively consistent source of surface water pollutants within managed forest catchments. Forest roads affect severely hydrological processes by: intercepting sub-surface flow, intercepting rainfall directly on the road, beginning surface runoff by causing a relatively impermeable surface soil, concentrating overland flow on roads and in adjacent roadside drainage channels (Megahan et al. 2001; Arnaez et al. 2004). In addition, the direct connection of roads with surface waters at stream crossings further increases the potential for pollution of off-site waters (Lane and Sheridan 2002). Forest roads cause to extremely low infiltration rates and forest roads are consequently main sources of runoff compared to other land uses (Forsyth et al. 2006, Jordán and Martínez-Zavala 2008, Jordán-López et al. 2009, Foltz et al. 2009) as a result of the direct influence of rain and the turbulence of runoff (Arnáez et al. 2004). Unpaved forest roads can cause significantly local alterations to soil properties, impact the water movement through hill slopes, intercept surface and subsurface water flows, create surface flow in areas far from established channels, and they are big sediment source in forested watersheds (Martínez-Zavala et al. 2008). However, there are few published data that directly link water quality with measured erosional characteristics of roads (Lane and Sheridan 2002). Additionally, the significance of roads as agents of runoff and sediment has not been adequately recognized and these processes are rarely measured (Martínez-Zavala et al. 2008). Acidity (pH) and electrical conductivity (EC) are the main parameters on water quality of ecosystems and both are the most commonly measured water quality variables. Electrical conductivity and pH are important indicators of water quality, and need to be understood and predictable within and beyond the range of observed field data in managing, planning and regulating specific operations. Stream acidity or pH has been adopted as a general indicator of the resilience of watersheds and streams against soil acidification in general. Continuous monitoring of stream pH could – at least in principle – reveal much about the acid buffering (Chi 2008). Also, EC is useful indicator of total dissolved solids in water, and is commonly used to estimate relative ion load contributions of precipitation and subsurface water in stream hydrographs. In general, in-stream EC depends on the total of all geochemical ion inputs (Chi 2008).

The main aims of this study were: to determine temporal changes in acidity (pH) and electrical conductivity of runoff waters accumulated front of sediment traps located on forest road ditches and differences among unpaved (UPFR), paved (PFR) forest roads and undisturbed area (UA) in Istanbul Belgrad Forest, Turkey.

Matetial and Methods

Study site

Research area is located between latitude of 41°10' 90"-41° 11' 20" N and longitude of 28° 15' 40"-29° 10' 00" E in Istanbul-Turkey. The mean annual precipitation is 1,074 mm while the mean annual temperature is 13°C. The study area was comprised of a dominant sessile oak (*Quercus petraea* L.) forest with a canopy cover of 0.8, an average tree diameter of 15 cm, an average tree height of 16 m, and a stand density of 3,200 trees ha^{-1}. The average altitude of the site is 140 m and the slope is 4-7 % with a north-northeast aspect. Soil texture is clay loam, dispersion ratios of soil samples changed between 25-47 % including erosive soils class, permeability class of soils determined as moderate-moderate slow (Kartaloglu 2011). Chemical properties of top soil in experiment site were pH = 5.8, EC = 40.6 and no calcium carbonate reaction (lime free, $CaCO_3$ = 0.00) (Ozturna 2013).

Precipitation

To determine the monthly precipitation, four precipitation collectors established and their average was calculated as mean monthly precipitation. Precipitation was maximum (133.02 mm) on January 2010 and was minimum (9.48 mm) on August 2010. Monthly rainy days were ranged from 2 days (August 2010) to 16 days (January 2010) in annual observation. Total cumulative annual precipitation was 635.45 mm and total number of rainy days was 109 in a year. Mean monthly precipitation was calculated as 52.96 mm and mean number of rainy days was 9 days per month (Figure 1) (Kartaloglu 2011). Also pH and EC of precipitation were given on Figure 1.

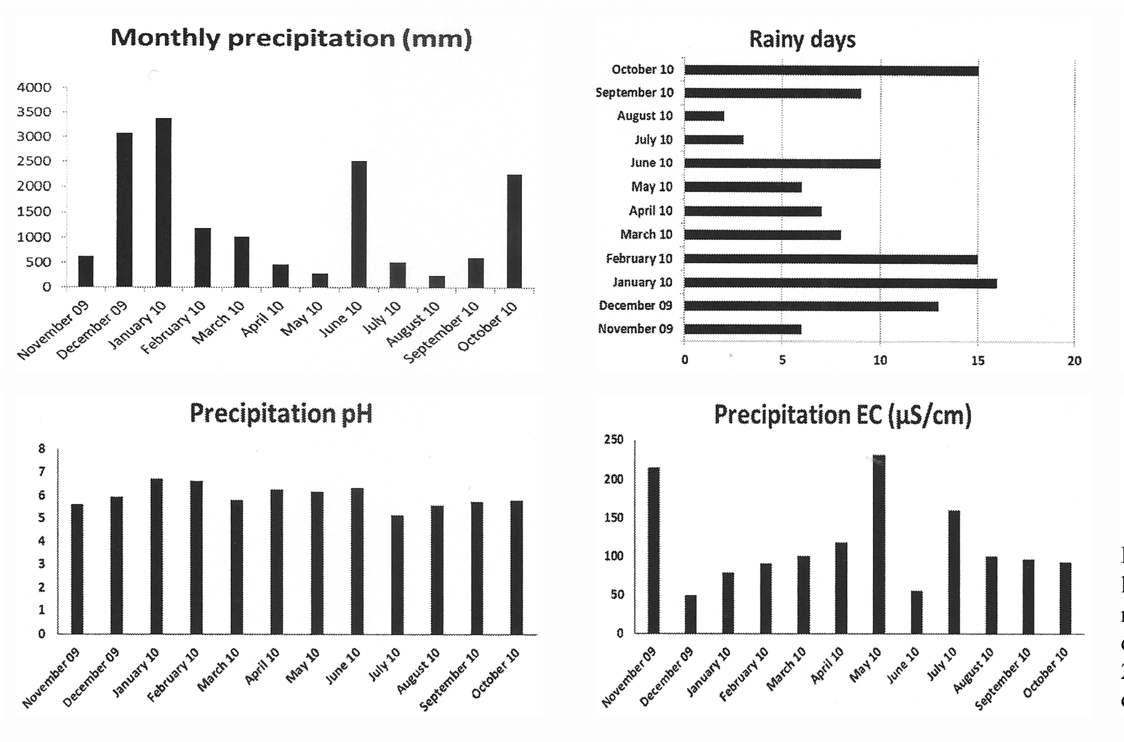

Figure 1. Monthly precipitation, number of rainy days (Kartaloglu, 2011), EC and pH of precipitation

Forest road properties in research area

The unpaved and paved forest roads were selected 100 m long. The unpaved (UPFR) and paved forest roads (PFR) width is 4.0 m, longitudinal slope is 4-7% and transverse slope is 2-5%. Road ditch width is 1.0 m and was covered with vegetation. UPFR and PFR cut slope has been vegetated, 0.5-1.0 m high, 1:3 slope, no recently graded. Estimated age of roads is 35. Pavement material on paved road is crushed stone with thickness in 25 cm and one time graded after constructed. Traffic density is 1-5 vehicles per day and vehicle types are 2×4, 4×4, truck, tractor and tractor-trailer. The forest roads passes through the stand in a north-south direction and has been used to logging and transporting in forest area. But, there are no logging and harvesting activities in area, recently. (Kartaloglu 2011).

Collection of runoff water via sediment traps and laboratory analysis

Study was conducted between November 2009 to October 2010 (12 months). Ribbed iron sticks of 1.2 cm in diameter and 1.3 m high and plastic geotextile materials are used in research to establish sediment traps. Sediment traps located on forest road ditch at 10 m intervals and located randomly on undisturbed areas (UA), where were at least 30 m away from the forest road where there was no direct road impact (at least one tree length away from the forest road edge). Total of 24 sediment traps, 4 on undisturbed area, 10 on unpaved forest road ditch and 10 on paved forest road ditch have been established. Each sediment trap collected sediment from 20 m^2 areas on forest roads (total 200 m^2). Each sediment traps on undisturbed area collected sediment from 50 m^2 areas (Kartaloglu 2011). Samples of runoff water were collected manually in front of each established sediment traps and precipitation samples from collectors were collected with sterile glass samplers monthly. Runoff water samples possible includes very less portion of clay particles because they were collected after completely stagnancy of runoff and after sedimentation of particles bigger than clay. Water samples were analyzed on the same day of sample collection for acidity with Hanna pH meter (HI 221 model, microprocessor pH meter) and for electrical conductivity using WTW-Inolab (cond level 1) electrical conductivity meter according to user guidelines of the measurement equipment.

Statistical analysis

Montly and annual tested data of pH and EC of the sites were compared with ANOVA. For significant results Duncan mean seperation test was performed at 0.05 significance level. SPSS software was used for all the statistical analysis (SPSS 2003). In addition, suitable regression models for pH and EC were used to evaluate the significant relationships between sites and precipitation.

Results

Acidity (pH)

Comparisons of monthly mean acidity values among experiment sites show significant differences in each month, except November 2009 and December 2009 (Table 1). Annual mean acidity values (pH) were: 6.14 on PFR, 6.39 on UPFR and 6.27 on UA, experiment sites did not show significant differences on mean annual values of acidity (Table 1). The lowest monthly mean acidity (pH) values were determined as 5.15 (July 2010) on PFR, 5.92 (September and November 2010) on UPFR and 5.79 (July 2010) on UA. On the other hand, the highest acidity (pH) values determined as 6.81 (February 2010) on PFR, 7.32 (March 2010) on UPFR and 7.01 (October 2010) on UA. The comparison of monthly mean acidity levels of water in each experiment sites show significant differences among months. Describing a definite trend or fluctuation in a season of year is difficult despite significant differences among mean monthly acidity values of water.

Table 1. Mean monthly runoff water pH and statistical comparison of sites in each month

Months	Acidity (pH)			P-values
	PFR	UPFR	UA	
November 2009	6.03 ^{a} ± 0.17	5.92 ^{a} ± 0.05	6.04 ^{a} ± 0.03	0.282
December 2009	6.01 ^{a} ± 0.22	5.97 ^{a} ± 0.05	6.24 ^{a} ± 0.49	0.179
January 2010	6.19 ^{b} ± 0.19	6.43 ^{c} ± 0.15	5.93 ^{a} ± 0.10	0.000
February 2010	6.81 ^{b} ± 0.31	6.45 ^{a} ± 0.05	6.44 ^{a} ± 0.17	0.003
March 2010	6.43 ^{a} ± 0.08	7.32 ^{b} ± 0.17	6.40 ^{a} ± 0.12	0.000
April 2010	6.63 ^{a} ± 0.04	6.68 ^{b} ± 0.01	6.81 ^{c} ± 0.008	0.000
May 2010	6.41 ^{a} ± 0.03	6.48 ^{b} ± 0.02	6.50 ^{b} ± 0.07	0.001
June 2010	6.00 ^{a} ± 0.08	6.23 ^{b} ± 0.07	6.21 ^{b} ± 0.11	0.000
July 2010	5.15 ^{a} ± 0.28	6.18 ^{c} ± 0.03	5.79 ^{b} ± 0.374	0.000
August 2010	5.74 ^{a} ± 0.09	6.53 ^{b} ± 0.52	5.89 ^{a} ± 0.08	0.000
September 2010	5.78 ^{a} ± 0.03	5.92 ^{ab} ± 0.18	6.01 ^{b} ± 0.26	0.047
October 2010	6.61 ^{a} ± 0.20	6.58 ^{a} ± 0.24	7.01 ^{b} ± 0.09	0.006
Annual mean	6.27 ^{a} ± 0.46	6.14 ^{a} ± 0.39	6.39 ^{a} ± 0.37	0.370

UA: Undisturbed area, PFR: Paved forest road, UPFR: Unpaved forest road,
Within rows followed by the same letter are not statistically different at 0.05 significance level. (±) Standart deviation.

Electrical conductivity

Significantly differences on mean monthly EC values of runoff water were determined among experiment sites in the most of observation period except four months (February 2010, May 2010, September 2010 and October 2010) (Table 2). There is no extremely high EC levels of runoff waters in all experiment sites and sampling times depending likely on local soil and organic matter properties of research area. Monthly EC varied between 63.09 µS/cm (October 2010) and 198.09 µS/cm

(May 2010) on PFR, 65.67 µS/cm (October 2010) and 196.96 µS/cm (May 2010) on UPFR and 58.35 µS/cm (October 2010) and 198.67 µS/cm (May 2010) on UA. Interestingly, among months, the highest monthly mean EC values were on May 2010, and the lowest values were determined on October 2010 in all experiment sites (Table 3). Monthly mean EC values of each experiment sites changed significantly among months (Table 3). Annual mean EC values were determined as 103.54 µS/cm on PFR, 121.14 µS/cm on UPFR and 109.14 µS/cm on UA, without statistically significant differences among experiment sites (Table 2).

Table 2. Mean monthly electrical conductivity of runoff water and statistical comparison of sites in each month

Months	Electrical Conductivity (µS/cm)			P-values
	PFR	UPFR	UA	
November 2009	90.19 ^{a} ± 2.38	101.92 ^{b} ± 2.20	87.62 ^{a} ± 2.90	0.000
December 2009	91.38 ^{a} ± 3.49	102.74 ^{b} ± 3.35	99.67 ^{b} ± 3.88	0.000
January 2010	83.23 ^{a} ± 3.73	93.86 ^{b} ± 4.81	94.35 ^{b} ± 3.98	0.000
February 2010	97.93 ^{a} ± 18.49	89.76 ^{a} ± 4.80	94.62 ^{a} ± 4.74	0.367
March 2010	107.92 ^{a} ± 2.14	196.60 ^{c} ± 43.46	157.37 ^{b} ± 4.11	0.000
April 2010	161.61 ^{c} ± 2.46	153.18 ^{a} ± 1.30	157.07 ^{b} ± 1.70	0.000
May 2010	198.09 ^{a} ± 1.57	196.96 ^{a} ± 3.31	198.67 ^{a} ± 1.30	0.424
June 2010	68.33 ^{a} ± 1.50	84.17 ^{c} ± 2.77	76.82 ^{b} ± 10.49	0.000
July 2010	85.85 ^{a} ± 19.95	142.06 ^{b} ± 28.78	100.95 ^{a} ± 3.67	0.000
August 2010	99.57 ^{a} ± 2.44	136.89 ^{b} ± 23.66	99.97 ^{a} ± 2.99	0.000
September 2010	95.32 ^{a} ± 2.37	89.93 ^{a} ± 9.50	84.27 ^{a} ± 14.04	0.089
October 2010	63.09 ^{a} ± 13.20	65.67 ^{a} ± 10.97	58.35 ^{a} ± 1.99	0.553
Annual mean	109.14 ^{a} ± 38.58	103.54 ^{a} ± 43.70	121.14 ^{a} ± 40.69	0.567

UA: Undisturbed area, PFR: Paved forest road, UPFR: Unpaved forest road,
Within rows followed by the same letter are not statistically different at 0.05 significance level. (±) Standart deviation.

Table 3. Statistical comparison of mean monthly electrical conductivity and pH of runoff water

Months	Acidity (pH)			Electrical Conductivity (µS/cm)		
	PFR	UPFR	UA	PFR	UPFR	UA
November 2009	c	a	abc	bc	c	cd
December 2009	c	a	bcd	bcd	c	e
January 2010	d	c	ab	b	bc	de
February 2010	g	c	d	cd	bc	de
March 2010	e	e	cd	e	f	f
April 2010	f	d	ef	f	e	f
May 2010	e	c	de	g	f	g
June 2010	c	b	bcd	a	b	b
July 2010	a	b	a	b	de	e
August 2010	b	cd	ab	d	d	e
September 2010	b	a	ab	cd	bc	bc
October 2010	f	cd	f	a	a	a
P-values	0.000	0.000	0.000	0.000	0.000	0.000

UA: Undisturbed area, PFR: Paved forest road, UPFR: Unpaved forest road,
Within columns followed by the same letter are not statistically different at 0.05 significance level.

Regression Models

The regression models with p values of lower than 0.05 are given on Table 4. Only EC and pH of paved forest road showed a significant relationship with the same parameters of precipitation. These results demonstrated that EC and pH of runoff sourced from paved forest road were related directly to chemical characteristics of precipitation. Paved material cause to direct flow of runoff to road ditches without mixing other particulates or materials, and it reflects directly the chemistry of precipitation. Rainfall fluctuations are also possibly high effective on pH and EC of runoff water effecting runoff chemically and quantitatively in experiment site. Many researches indicated the importance of chemistry and deposition of precipitation (Tuncel and Ungör 1995, Gülsoy et al. 1999, Okay et al. 2002, Akkoyunlu and Tayanç 2003). On the other hand, runoff water from unpaved forest road and even from undisturbed area likely include many particulates, solutions and materials which are dissolved or mixed from soil, forest floor, wet or bulk deposition and weathering etc., can be more effective on runoff water chemistry than precipitation.

Table 4. Significant (p < 0.05) regression models

(PFR-EC) $y = 59.839 + X_1{}^{*}\ 0.378$		(X_1 = precipitation EC)	
$R^2 = 0.32$	$S_e = 33.37$	$F = 4.70$	*
(PFR-pH) $y = 59.839 + X_1{}^{*}\ 0.378$		(X_1 = precipitation pH)	
$R^2 = 0.45$	$S_e = 0.36$	$F = 8.31$	**

S_e: standard error, *: p 0.01-0.05, ** : p 0.01-0.001, PFR: paved forest road

Many researches described that temporal changes of effects caused from roads by erosion, runoff and sediment indicating different possible reasons. For example, seasonal measurements show that soil losses by road erosion are greater in winter when the soil is wet (Parsakhoo et al. 2009, Martínez-Zavala et al. 2008). Possibly more sediment and runoff water occurs in rainy periods despite we did not measure runoff amount on research site (Kartaloglu 2011). Also, plant covers or higher organic matter concentration of soil can decrease the influence of seasonal changes (Martínez-Zavala et al. 2008). UPFR and PFR cut slope has been vegetated, protecting plant cover and forest floor on roadside slopes and road ditches give different effects on runoff in research area. Arnįez et al. (2004) emphasized the important effect of freeze-thaw process during the winter and spring on road erosion. Snowfall can also be effective on erosion processes. Snow cover, especially when prolonged, decrease erosion (Fu et al. 2010). Unfortunately, we did not measure snow cover and snowy days in experiment. In general, decreased evapotranspiration contributes mostly to base flow, increasing stream discharge in all seasons. Impacts on evapotranspiration, stream flow and soil properties depend on various factors related to the original forest and soil type, and the land use history (Cuo et al. 2008). As mentioned above, studies of the hydrological effects of roads have produced a range of results (Cuo et al. 2008). Erosion on a forest road can be determined by infiltration, splash of raindrop, concentrated flow and plant cover (Foltz et al. 2009). The influences impacting erosion from roads also contain intensity and duration of rainfall, snowfall, properties of surface materials, the hydraulic characteristics of the road surface (topsoil, subsoil, road gravel), road slope, traffic and vehicles, construction and maintenance, and the contributing road surface (Fu et al. 2010; Sheridan et al. 2008; Lane and Sheridan 2002). Unpaved road surfaces have usually slow infiltration rates due to soil compaction, which cause to greater level of infiltration excess overland flow (Fu et al. 2010). The existence of a large organic residue within the roadside drains is likely to have influenced the organic carbon concentrations in surface runoff (Forsyth et al. 2006), which can be more effective on acidity and electrical conductivity of runoff water. In addition, suspended particles in runoff have more significant influence on chemical characteristics of runoff water, as described by Katari and Tauxe (2000), clay sized minerals in water act as colloidal particles, which displace a surface charge, and this charge is influenced by the mineralogy of the particles as well as the acidity and electrolyte composition of the water. These authors underlined the following three mechanisms to acquire the charge of solid particle surfaces: 1) chemical reactions at the surface, 2) isomorphous replacement of ions within the solid crystal lattice, and 3) adsorption of surfactant ions (Katari and Tauxe 2000). In addition, Atkinson et al. (2007) indicated the other important reaction that fate of metals released from sediments is influenced by water parameters such as the pH, salinity, dissolved oxygen and suspended particles. Also, the main physical characteristic of the road surface can increase movement of discharged material (Jordịn-López et al. 2009). As mentioned above, sediment amount and sediment characteristics have importantly effects on runoff chemistry. In research area, total sediment production of UPFR was 1.96 times higher than to PFR and 12 times higher than UA. Monthly sediment production on UPFR is significantly higher than the PFR and UA for each month. (Kartaloglu 2011). These changes are possibly particular effects of runoff chemistry in experiment. In addition, related to aim of study that there are many effective factors on acidity and electrical conductivity of runoff water described by Chi (2008):

• Water acidity (pH) is affected by numerous factors, especially the content of some of the components (carbon dioxide, bicarbonates and carbonates). Acidity may changes daily and be in very closely correlation with fluctuations in solar radiation and water temperature. On the other hand, biogeochemical hydrologic changes also influence pH and chemistry of water (Chi 2008).

• Electrical conductivity indicates the water existence to conduct electricity. Salts, as they dissolved in water, break into positively and negatively charged ions, which then conduct the current. Calcium, sodium, potassium and magnesium are the main positively charged ions in stream water. Salt accumulations lead to higher electrical conductivities. In addition, soil mineralization affects electrical conductivity. Evaporation is another impact, evaporation of water increases ion concentrations in water. Water temperature is also important factor due to the effects on water evaporation (Chi 2008).

Conclusions

As seen on these explanations there are many factors, which have influence on chemical characteristics especially on the acidity and electrical conductivity of runoff water depending on site specific characteristics of the research area. The research area is under deciduous forest canopy cover, and it has rich organic matter especially in autumn months when litterfall occurs, also other site specific factors such as edaphic, microclimate and forest roads can be effective on the results. It can be stated that, besides many complicated effective factors on acidity and electrical conductivity of runoff water, low traffic intensity, forest canopy cover and site characteristics manipulate achieved results. Results on the paved roads demonstrated that EC and pH of runoff were highly related to chemistry of precipitation concluding that paved road material may prevent mixing of other particulates or materials with precipitation. However, in future, more experiments including more factors such as chemical characteristics of soil and sediment, runoff chemistry, mineralization of soil and organic matter, rainfall chemistry and seasonal changes in these factors can be able to gain detailed results.

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