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Analysis of changes in stream water chemistry following logging practices in north of Iran (Darabkola forest)

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Abstract: Forest management practices such as road construction and harvesting may substantially alter the quality of water. The main concern of this investigation was to consider the influence of passed time from logging operation on stream water quality parameters. Six Stream crossings (culverts) with two logging treatments were implemented in three replications on permanent haul roads for this study. Water samples were collected in bottles. All the samples were kept cold and analyzed for total suspended solids (TSS), NO_3^- and PO_4^{-3}. T–test results showed that the PO_4^{-3} and NO_3^- concentrations of stream water from logging treatment had significantly higher concentrations ($p<0.05$). Also, results of correlation analysis of parcel characteristics in logging treatments showed that only NO_3^- concentration was significantly correlated with stocking volume (R=0.738). Logging has resulted in some decline in water quality by decreasing tree uptake and increasing litter deposition. A much longer time span for monitoring program is recommended to see what happened with the recovery from felling on the stream water quality.

Keywords: Logging, nutrient, stream water, total suspended solid

İran'ın kuzeyinde sürütme uygulamalarının dere suyu kimyasında yarattığı değişiklikler analizi (Darabkola ormanı örneği)

Özet: Yol yapımı ve sürütme gibi orman yönetimi uygulamaları büyük ölçüde suyun kalitesini değiştirebilir. Bu araştırmanın ana bakış açısı, sürütme faaliyetleriyle geçirilen zamanın akarsu su kalite parametreleri üzerine etkisidir. Altı adet menfez, bu çalışma için kalıcı mesafeli yollarda üç tekrarlamalı olarak uygulanmıştır. Su örnekleri şişelenerek toplanmıştır. Bütün örnekler soğuk muhafaza edilerek; toplam askıda katı madde (AKM), NO_3^- ve PO_4^{-3} için analiz edilmiştir. T-testi sonuçları NO_3^- ve PO_4^{-3} konsantrasyonlarının anlamlı derecede yüksek değerlerde ($p <0.05$) olduğunu gösterdi. Ayrıca, parsel özelliklerinin korelasyon analizi sonuçları sadece No_3^- konsantrasyonunun önemli ölçüde stoklama hacmi (R = 0.738) ile ilişkili olduğunu göstermiştir. Ağaçların alandan kesilerek uzaklaştırılması ayrıca çöp birikimi de arttırarak su kalitesinde bazı düşüşe neden olmuştur. İzleme programları için çok daha uzun bir zaman aralığının bırakılması, su kalitesi üzerindeki etkisini görme açısından tavsiye edilmektedir.

Anahtar Kelimeler: Sürütme, besin maddesi, dere suyu, toplam askıda katı madde

1. INTRODUCTION

Ground water quality has become an important water resources issue due to the rapid increase of pollution from upland to lowland, and too much use of fertilizers (Joarder et al., 2008). It is unfortunate that most of natural water bodies are gradually becoming degraded to a great extent due to rapid progress of industrialization and population explosion (Maqbool et al., 2012). Forests and woodlands have been relied

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upon as sources of water since the development of civilizations throughout the world (Neary and Koestner, 2012). It is well accepted that in comparison to watersheds with other land uses, watersheds with natural forests almost always provide higher water quality with less sediment and fewer pollutants (Singh and Mishra, 2014).

Stream water quality is a function of a variety of parameters, including temperature, sediment load, inorganic chemistry, and toxic metals and organic compounds. Also, forest management practices, such as road construction and harvesting may substantially alter the quality of water draining from forested watersheds (Binkley and Brown, 1993). The initial impacts of forest harvesting are the increment in the amount water reaching the soil surface due to reduce interception by a forest canopy. Therefore, more suspended sediment enters to the stream and adversely affect other hydrological parameters (Marryana et al., 2007). The destruction of protective vegetation and compaction of the soil surface that is associated with timber harvesting procedures reduces soil permeability to water, increasing erosive surface runoff. Following timber harvesting, the amount of dissolved nutrients leached from organic debris into the soil and thence to the stream via subsurface flows increases (Campbell and Doeg, 1989).

Changes in stream water chemistry are more difficult to prevent. Such changes include increased concentrations of nutrients which persist for 3–5 years or even longer. Hydrological losses of nutrients are small in magnitude relative to the nutrient capital removed in harvested products (Wang et al., 2006). Forest harvesting and associated operations have been shown to affect the quality of stream water, principally through additional sediment supply to drainage systems. Additionally, roads are essential elements of forest harvesting infrastructure, but can play an important and continual role in supplying sediment into streams (Cornish, 2001). Suspended sediment leads to loss of ecological integrity (Palmer–Felgate et al., 2013).

Water quality parameters can be classified according to 1) physicochemical basic parameters (temperature, pH, dissolved organic matter, etc.) and nutrients, 2) micro pollutants, including metals, pesticides and pharmaceuticals and 3) biological parameters with pathogens microorganisms, cyanobacteria and water quality proxies (Delpla et al., 2009). Poor water quality in many areas across the globe has been attributed to anthropogenic nitrogen and phosphorus additions to surface waters (Mc Daniel and David, 2009). Nitrogen and phosphorus are of particular concern as an excess of either nutrient can lead to eutrophication of water systems (Palmer–Felgate et al., 2013). The chemical composition of water in high mountain streams and changes therein are determined primarily by natural factors (Zelazny et al., 2011). However, land surface characteristics influence on water dynamics, evapotranspiration, interception, infiltration and watershed characteristics affect the quality of water bodies (Bhat et al., 2006; Maqbool et al., 2012). But the impact of changes in density or other such parameters of the forest cover on stream water quality has not really been evaluated (Singh and Mishra, 2014).

Determination of water quality is essential for assessing its suitability for various purposes like drinking, domestic, agricultural and industrial uses (Thilagavathi et al., 2012). The development of natural resources is based on maintaining the fragile ecosystem balance between the productivity functions and conservation practices through monitoring and identification of problem area. The assessment of water resources requires the monitoring of the current situation and reach to plan for future development (Yusif et al., 2013).

With regard to that forest play important roles in natural ecosystems and have been relied as sources of water; and also by attention to that forest management practices such as logging and road construction may alter the quality of stream water through affecting leaching or surface runoff (consequently lead to delivery of sediment associated nutrients to streams), hence it is necessary to evaluate the stream water quality relation to logging practices. The main concern of this investigation concentrated on answering three questions:

I. What is the relative influence of passed time from logging operation on stream water?
II. How is the contribution of TSS to NO_3^- and PO_4^{-3} losses from forest logging operation?
III. How is the contribution of TSS to NO_3^- and PO_4^{-3} losses from parcel characteristics that is overlooked to sampling stations?

2. MATERIALS AND METHOD

The study area is located in district 1 of Darabkola forest. Darabkola forest with an area of 2612 ha is located in watershed number 74, southeast of Sari, Mazandaran province, Iran. The latitude, longitude ranges of this forest are 36° 33′ 20″ to 36° 33′ 30″ N, 52°14′40″ to 52°31′33″ E. The altitude of study area starts from 180 m and continues till about 874 m above sea level. Mean annual air temperature is 16.7°C. The region receives 983.8 mm of precipitation annually. The main woody species in Darabkola are *Fagus orientalis Lipsky*, *Ulmus glabra Huds*, *Acer velatinum Bioss*, *Carpinus betulus*, *Parrotia persica* and *Alnus glatinosa L*. The logging is done using a method of selecting individual trees. The Darabkola forestry project has a total road length of 50 kilometers. The general road aspects are northern and northwestern. The average slope of field is about 40% (5–70%). Other characteristics of the study area are shown in Table / Tablo 1.

Table 1. Characteristics of study area
Tablo 1. Çalışma alanı özellikleri

Characteristic	Description
Soil texture	Clay loam–Silty clay
Time since road construction	30 years
Silvicultural system	Single tree selection
Form of timber extraction	Short log
Wood extraction method	Ground based skidding
Slope of roadbed	Less than 10%
Diameter of culverts	100 cm
Gradient of cut slope	Less than 20 %

Water quality monitoring has been undertaken for stream water. Stream crossings (culverts) were implemented in three replications consisted of cement pipes on permanent haul roads for this study. Two logging states of stream crossing identified for study: 1) logging treatment (less than 3 years after logging and under hauling of harvesting extraction machines), 2) unlogging treatment (more than 3 years after logging and no hauling of harvesting extraction machines). The sampling season was in the spring of 2014. Water samples were collected after tree harvesting. Samples were collected manually. During sampling, water samples were carefully collected in order to limit disturbance of the stream. Stream water samples were collected at 6 stream crossings (Figure / Şekil 1).

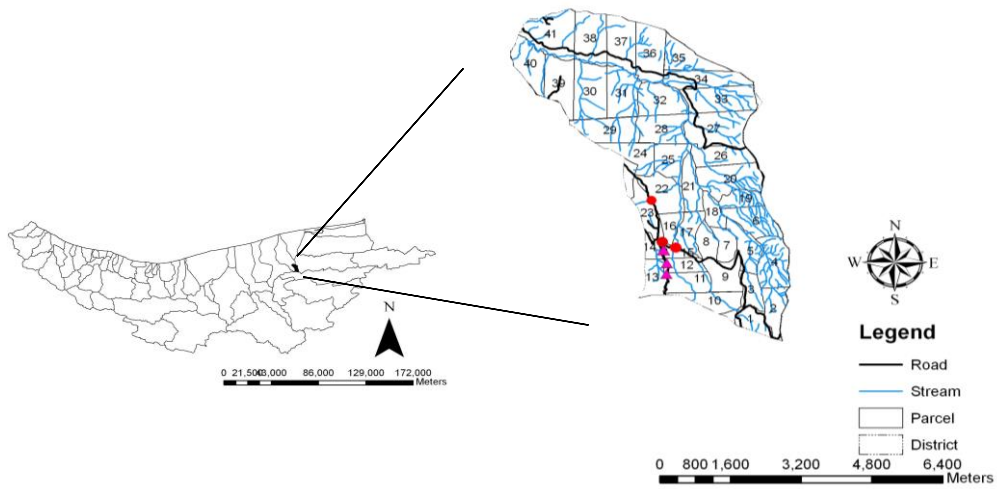

Figure 1. Study area
Şekil 1. Çalışma alanı

Water samples were collected in bottles. Bottles were rinsed with sample water prior to collection. Stream water samples were labeled, kept cool in an ice box, transported to the water laboratory. All the samples were kept cold at 4 °c in refrigerator and analyzed for TSS, NO_3^- and PO_4^{-3}.

For nutrient analyses the stream water was filtered through a 0.45 µm membrane filter. After filtration, NO_3^- and PO_4^{-3} was measured by ion chromatography (Metrohm, 882 Compact IC plus, Switzerland). A water sample was injected into a stream of sodium carbonate–sodium bicarbonate eluent. Anionic separator column and constant flow rate were applied in this study; detection was based on conductivity. For measuring the amount of TSS in each of water samples, crucibles were dried in an oven for approximately 2 hours at 105°C and then placed in a desiccator to cool for 10 minutes. Immediately after cooling the crucibles were weighted. Next, each water sample was shaken, placed in a crucible and dried in an oven. Then, crucibles were removed with a glove and placed in the desiccator for 15 minutes. After cooling, each crucible was weighted with the sediment and the weight was recorded. TSS was determined by using the following formula:

$$TSS(mg/L) = \frac{Secondweight - initialweight}{Amountofsample} \times 100$$ (Akan et al., 2010)

T–test was performed at 5% level of significance to test whether mean values of water quality parameters differ between two logging treatments. The Pearson correlation coefficients were calculated to examine the significance of the relationships among water quality parameters. Also, Pearson correlation analysis was performed to identify the relationships among parcel characteristics and the water quality parameters. The parcel characteristics that are overlooked to sampling station are summarized in Table / Tablo 2. Data were analyzed using statistical package for the social sciences for windows SPSS 13.

Table 2. Characteristics of upper parcels of sampling stations
Tablo 2. Örnekleme istasyonlarıdaki üst parsellerin özellikleri

Parcel number	Logging condition	Parcel area(ha)	Stocking volume(m^3)	Tree density(N/ha)
23	Log	52	306.81	173
15	Log	19	250.28	215
15	Log	19	250.28	215
14	Unlog	25	206.80	146
13	Unlog	50	260.76	141
13	Unlog	50	260.76	141

3. RESULTS AND DISCUSSION

Water quality was evaluated through TSS, PO_4^{-3} and NO_3^- concentrations. As can be observed in Table / Tablo 3, the TSS, PO_4^{-3} and NO_3^- concentrations of stream water are lower in unlogging treatments. Traffic of harvesting extraction machine associated with selective cutting (logging treatment) produced 8.08% more TSS, 66.66% more PO_4^{-3} and 85.17% more NO_3^- concentrations than unlogging treatment.

Table 3. Mean value, standard deviation and variation of parameter concentrations of streams
Tablo 3. Ortalama değer, standart sapma ve akarsu parametre konsantrasyonlarının değişimi

Parameter	Logging		Unlogging		
	Mean (mg/l)	Std. Deviation	Mean (mg/l)	Std. Deviation	Variation (%)
TSS	0.099	0.067	0.091	0.034	8.08
Po_4^{-3}	0.027	0.024	0.009	0.006	66.66
NO_3^-	2.313	1.946	0.343	0.187	85.17

The measurements were conducted out according to the difference among the logging states of sampling stations. In the case of the PO_4^{-3} and NO_3^- concentrations of stream water, logging treatment had significantly higher concentrations than unlogging treatment; but significant difference among treatments of TSS concentration was not found (Table / Tablo 4).

Table 4. Results of T–Test of stream crossing water quality
Tablo 4. Su kalitesinin T-testi sonuçları

Parameter	df	F	t	Sig(2–tailed)
TSS	16	2.668	0.054	0.958
Po_4^{-3}	16	3.261	2.240	0.040
NO_3^-	16	29.571	3.022	0.008

Also, when considering the concentration of nutrients by TSS, a positive relation was found between parameters in unlogging treatments; there was a positive relation to TSS and NO_3^- concentration in logging treatment, too. Regarding the results, there was not a same trend in relation between PO_4^{-3}, NO_3^- and TSS, PO_4^{-3} concentration of treatments. The results of Pearson correlation analysis are shown in Table / Tablo 5. The results of T–test analysis of parcel characteristics in logging treatments are shown in Table / Tablo 6. The results showed that only tree density had significant differences between parcels of two logging treatments; however stocking volume and tree density of parcels under logging treatment had higher level than unlogging treatment. The results of Pearson correlation analysis of parcel characteristics and water quality parameters are shown in Table / Tablo 7. While the under study parcels vary in area, stocking volume and tree density, only NO_3^- concentration was significantly correlated to stocking volume characteristic. Also, except the relationship between tree density and TSS concentration, all parcel characteristics and water quality parameters had positive correlations.

Table 5. Pearson correlation among parameters of stream water (n=9)
Tablo 5. Dere suyu parametreleri arasındaki Pearson korelasyonu (n = 9)

Parameters	Logging		Unlogging	
	R	Sig(2–tailed)	R	Sig(2–tailed)
TSS, Po_4^{-3}	–0.263	0.495	0.093	0.811
TSS, NO_3^-	0.291	0.448	0.420	0.261
Po_4^{-3}, NO_3^-	0.720	0.029	–0.056	0.887

Table 6. Results of T–test of parcel characteristics of two logging treatments
Tablo 6. İki bakım kesimine ait parseldeki özelliklere ait T-testi sonuçları

	t	df	Sig(2–tailed)
Parcel area	–1.691	16	0.110
Stocking volume	2.023	16	0.060
Tree density	8.275	16	0.000

Table 7. Pearson correlation analysis of parcel characteristics and water quality parameters (n = 18)
Tablo 7. Parsel özellikleri ve su kalite parametrelerinin Pearson korelasyon analizi (n = 18)

	Parcel area	Stocking volume	Tree density
TSS	0.217	0.244	–0.097
PO_4^{-3}	0.304	0.688	0.222
NO_3^-	0.301	0.738	0.215

Disturbances are a normal part of forest landscapes that may alter water chemistry. Although, Streams in forest have very low nutrient levels, reflecting the ability of forest systems to trap and retain nutrients, but study results showed that stream NO_3^-, PO_4^{-3} and TSS concentrations in the unlogging treatment were lower than logging treatment. Variations in stream water about NO_3^- and PO_4^{-3} concentrations were relatively high according to results of Table 3. A comparison of stream water from logging and unlogging treatment in Darabkola indicated that logging effect were significant for NO_3^- (p=0.008) and Po_4^{-3} concentrations (p=0.04) according to Table / Tablo 4. Statistically significant differences among logging treatments confirmed that felling (less than 3 years after felling) and transport of extraction machines could increase NO_3^- and PO_4^{-3} concentrations in stream water considerably.

As Neal et al., (2004) in their study indicated that there is a large increase in NO_3^- concentration with felling; the release of NO_3^- peaks in the first two years and declines thereafter. Also, Tetzlaff et al., (2007) stated that the initial felling results in a four years period of elevated concentrations of NO_3^- in stream waters. However, there was a much more subdued response in the NO_3^- variations which have been attributed to differences in harvesting practices which involved felling smaller areas and removing the harvested brush. Although, Campbell and Doeg (1989) concluded that the NO_3^- concentration was 41–fold higher during the first year and 56–fold higher during the second year, than in a similar undisturbed catchment. Löfgren et al., (2014) and Tetzlaff et al., (2007) concluded that clear cuts are well known to result in increased N concentration in soil water and surface waters, increased runoff, fine sediment mobilization and increased nutrient leaching. But Wang et al., (2006) stated that after harvesting, the NO_3^- concentration increased sharply for a short time.

Consumption of phosphorous does not appear to affect human health, but high phosphorous levels in the water can have dramatic effects on aquatic life. However, Millard and Pinheiro Santos (2008) stated concentrations of over 0.03 mg/l can provoke excessive plant growth, increase demand of oxygen and reduce fish stock. As Binkley et al., (2004) stated that forest harvesting may alter the stream water chemistry, but the effects should not be consistent. Furthermore, they stated that forest harvesting appeared to have little effect on concentration of PO_4^{-3}. It is obvious; the result of the current study (about the effect of logging on nutrients) is in accordance with previous researches.

Increased sediment movement into streams is a major environmental concern in managed forest catchments; however, it occurs naturally without human associated disturbances. Sediment increases by forest harvesting are the largest and most visible water quality impacts on water supply. After the trees fell down, rainfall reaches the nearest streams because of no filtering by the trees (Marryanna et al., 2007). The concentration of TSS was lower in unlogging treatment because the trees help in preventing erosion by intercepting rainfall directly and protecting the soil surface. Also, the root will act as a filter to minimize the sediment entering the stream. In humid temperate climates typical of the Darabkola region, a cover of vegetation dissipates the erosive force of falling rain drops. Also, the roots of vegetation bind soil particles together and impart strength to the soil. As it seems, smaller cutting area and bare soil is covered by vegetation following harvesting to the extent that resulted in water quality recovery related to TSS concentration. Furthermore, the degree which sediment impairs the quality of water supplies after forest harvesting is highly variable and depend on such factors as soil, climate, topography, ground cover, watershed condition, the type of harvesting equipment used, and transportation system. As, Neary and Koestner (2012) concluded that soil disturbance and sediment movement can be significantly reduced by use of low ground pressure and wide–track harvesting equipment. Moreover, wash–off of sediment from the road surface during use of forestry traffic, have been responsible for damaging the water environment. Increasing in soil disturbance and water movement caused by timber harvesting extraction operation result in increasing stream sediment and nutrients. The present study results showed that subdued cutting (select cutting) could help in lowering the entrance of suspended sediments to stream, too.

The correlations established an account for variability in TSS and nutrients, and could constitute an important database for assessing the TSS amounts to nutrients. Although the Pearson correlation results provide an evidence of a positive correlation between TSS, NO_3^- and Po_4^{-3} (except for TSS and Po_4^{-3} in logging area) (Table 5). The results of TSS and nutrient relation are in accordance with previous studies (Sthiannopkao et al., 2007; Wall et al., 2013; Gilmer et al., 2012). However, Bhat et al., (2006) stated that the natural characteristics of watershed and soil type influenced only conductivity and pH. But some relationships between characteristics of under study area and water chemistry are likely to be direct effect. The results of Bhat et al., (2006) showed a positive correlation between area, total phosphorus and area, TSS. Also, Schaefer et al., (2000) concluded that for small scales, potassium, NO_3^- and ammonium are temporarily (1–3 years) released to soil and stream water. Singh and Mishra (2014) concluded that old and dense forests help to keep streams clean and high water quality by promoting soils that provide natural filtration and cover that minimize soil erosion and sediment runoff. On one hand, forest ecosystems are fundamental for providing and maintaining water resources. But according to study of Wahyuningrum and Pramono (2013) forest may act as the source of chemical elements resulting from the decomposition of litter. The correlation of tree density and TSS concentration result is in accordance with Singh and Mishra (2014). Study area characteristics appeared to be a determinant of water quality parameters, at least tree density and stocking volume for TSS and nutrient concentrations.

It seems, the researches of forest engineering focused on damage to forest soil, involve the determination of soil compaction by wheels and skidded load, measuring damage of physical soil characteristics like Lotfalian and Bahmani (2011), Agherkakli et al., (2010) and Najafi et al., (2009). But the physical damaging influence of machine work can consequently degrade stream water quality. Based on the logging effect on water quality, this study showed that after logging, forest floor and intercepting of rainfall by forest canopy decreased. Hence, the rate of water runoff and soil washing increased from surrounding of logging area. So that, 3 years after logging, nutrient uptake reduced, litter decomposition left more available nutrients for soil and lead to more transportation of nutrients to stream. Logging affects the nutrients in three ways; it stops the uptake of nutrients, converts living non merchantable tree tissue into slash, and it often increases soil erosion. Increased nutrient losses in the stream can be expected until the uptake of nutrients in vegetation is again in balance with the mineralization of nutrients by decomposition (more than 3 years after logging) and soil erosion losses subsides. Furthermore, rainfall is more intense on the road than in the interior forest, which can cause more damage to the soil and water. On the one hand, various water quality parameters can be explained in terms of logging and road effects on canopy that influence evapotranspiration, runoff and soil characteristics. By attention to that no road building, skidding or timber removal occurred in unlogging stations and skidding was common method of select cutting extraction used in study area which has been caused damage to stream waters; it could be resulted that during logging, the forest floor and mineral soil are disturbed or rutted by trucks and skidders to varying degrees and influenced stream water quality. Because of the skidder and truck passes, the top soil is obviously vibrated more and consequently exposed to more disturbances compared to gentle trails. Trucks are essential for transport of logs that require a network of forest roads. The decrease of total porosity and increase of bulk density on the road surface may be associated with passes of log extraction machines during logging on road surface; especially where roads are near to streams (like a stream crossing), excavated material that is on hillside reach the stream. Nutrients are also lost from the forest as soil transported to streams. So the combination of forest roads and logging on the ground is responsible for the increase in stream TSS, NO_3^- and Po_4^{-3} concentrations. Also, by increasing the area, stocking volume and tree density, the nutrient concentration will be increased, although tree density could help in decreasing the movement of sediment from the soil surface by using of roots and canopy.

There is evidence that logging producing a significant, short term adverse impact on the quality of water in streams such as higher NO_3^- and Po_4^{-3} concentrations. The main sources of water quality deterioration are associated with tree cutting, log extraction, and road construction. It could be concluded that sediment and nutrient in stream water results of decreasing tree uptake, forestry traffic and transporting of logs from the forest. In terms of the ground waters, logging has resulted in some decline in water quality by decreasing tree uptake and increasing litter deposition. Suspended solids were consistently higher in the logged catchment during the 3–year period. Hence, forest management activities that expose mineral soil have the potential to increase suspended solids and deliver nutrients to streams. The most important strategy to limit soil disturbances is to avoid traffic whenever the weather condition is not appropriate. Extraction operations should be planned and performed when soil condition is dry so as to minimize soil disturbance and water pollution. Although, availability of good forest cover within the parcel may be attributed to low sediment transport from logging area. Characteristics of the study area may be useful predicators of surface water chemistry; correlation results can provide useful information, but care should be exercised when applying relations to surface water in basins with different characteristics. Future research relative to forest logging should concentrate on the cumulative effects of changes in the physical, chemical and biological quality of water in managed forest, before, during and after logging.

However, a much longer time span for monitoring program is necessary to see what happened with the recovery from felling on the stream water quality. Some of the aspects of logging that require future research include:

– Comparison of selection versus clear–felled cutting

– Evaluation of different traffic intensity on water quality

– Comparison of the effects of logging on water quality in various watersheds

REFERENCES (KAYNAKLAR)

Agherkakli, B., Najafi, A., Sadeghi, S.H., 2010. Ground based operation effects on soil disturbance by steel tracked skidder in a steep slope of forest. *Journal of Forest Science* 56 (4): 278-284.

Akan, J.C., Abdulrahman, F.L., Yusuf, E., 2010. Physical and chemical parameters in abattoir wastewater sample, Maiduguri Metropolis, Nigeria. *The Pacific Journal of Science and Technology* 11 (1):640–648.

Bhat, S., Jacobs, J.M., Hatfield, K., Prenger, J., 2006. Relationships between stream water chemistry and military land use in forested watersheds in Fort Benning, Georgia. *Ecological Indicators* 6:458–466, doi:10.1016/j.ecolind.2005.06.005.

Binkley, D., Ice, G.G., Kaye, J., Williams, C.A., 2004. Nitrogen and phosphorus concentrations in forest streams of the United States. *Journal of the American Water Resources Association* 40 (5): 1277–1291.

Binkley, D., Brown, T.C., 1993. Forest practices as nonpoint sources of pollution in North America. *Water Resources Bulletin* 29 (5):729–740.

Campbell, I.C., Doeg, T.J., 1989. Impacts of timber harvesting and production on streams: a review. *Austrian Journal of Marine and Freshwater Research* 40: 519–539.

Cornish, P.M., 2001. The effects of roading, harvesting and forest regeneration on stream water turbidity levels in a moist eucalypt forest. *Forest Ecology and Management* 152:293–312.

Delpla, I., Junge, A.V., Baures, E., Clement, M., Thomas, O., 2009. Impacts of climate change on surface water quality in relation to drinking water production. *Environmental International* 35:1225–1233, doi:10.1016/j.envint.2009.07.001.

Gilmer, A.M., Rosado–Berrios, C.A., Bouldin, J.L., 2012. Establishing baseline nutrient and sediment input in the lower Cache river watershed, AR. *Journal of the Arkansas Academy of Science* 66: 62–66.

Joarder, M.A.M., Raihan, F., Alam, J.B., Hasanuzzaman, S., 2008. Regression analysis of ground water quality data of Sunamganj district, Bangladesh. *International Journal of Environmental Research* 2 (3): 291–296.

Löfgren, S., Fröberg, M., Yu, J., Nisell, J., Ranneby, B., 2014. Water chemistry in 179 randomly selected Swedish headwater streams related to forest production, clear–felling and climate. *Environmental monitoring assessment* 186:8907–8928, doi:10.1007/s10661–014–4054–5.

Lotfalian, M., Bahmani, H., 2011. Effects of ground based skidding system on soil compaction and herbaceous species in a hyrcanian forest. *European Journal of Science Research* 61 (4):601-606.

Mc Daniel, M.D., David, M.B., 2009. Relationships between sediments and water column phosphorus in lllinois streams. *Journal of Environmental quality* 38: 607–617, doi:10.2134/jeq2008.0094.

Marryana, L., Siti Aisah, S., Saiful Iskandar, K., 2007. Water quality response to clear felling trees for forest plantation esTablelelishment at Bukit Tarek F.R., Selan G.R. *Journal of Physical Science* 18 (1):33–45.

Maqbool, F., Malik, A.H., Bhatti, Z.A., Pervez, A., Suleman, M., 2012. Application of regression model on stream water quality parameters. *Pakistanian Journal of Agricultural Science* 49 (1):95–100.

Millard, P., Pinheiro Santos, N.D., 2008. A spatial–statistical approach for modeling the effect of non–point source pollution on different water quality parameters in the Velhas river watershed–Brazil. *Journal of Environmental Management* 86:158–170, doi:10.1016/j.jenvman.2006.12.009.

Najafi, A., Solgi, A., Sadeghi, S.H., 2009. Soil disturbance following four wheel rubber skidder logging on the steep trail in the north mountainous forest of Iran. *Soil and Tillage Research* 103 (1): 165–169, doi:10.1016/j.still.2008.10.003.

Neal, C., Reynolds, B., Neal, M., Wickham, H., Hill, L., Williams, B., 2004. The impact of conifer harvesting on stream water quality: the Afon Hafren, mid–wales. *Hydrology and Earth System Sciences* 8 (3): 503–520.

Neary, D.G., Koestner, K.A., 2012. Forest bioenergy feedstock harvesting effects on water supply. *Wires Energy Environment* 1:270–284, doi:10.1002/wene.26.

Palmer–Felgate, E.J., Acreman, M.C., Verhoeven, J.T., Scholz, M., Maltby, E., Stratford, C.J., Newman, J., Miller, J., Coughlin, D., 2013. How effective are reedbeds, ponds, restored and constructed wetlands at retaining nitrogen, phosphorus and suspended sediment from agricultural pollution in England?. *Environmental Evidence* 2 (1):1–6.

Schaefer, D.A., McDowell, W.H., Scatena, F.N., Asbury, C.E., 2000. Effects of hurricane disturbance on stream water concentrations and fluxes in eight tropical forest watersheds of the Luquillo experimental forest, Puerto Rico. *Journal of Tropical Ecology* 16:189–207.

Singh, S., Mishra, A., 2014. Spatiotemporal analysis of the effects of forest covers on stream water quality in Western Ghats of peninsular India. *Journal of Hydrology* 519:214–224, doi:10.1016/j.jhydrol.2014.07.009.

Sthiannopkao, S., Takizawa, S., Wirojanagud, W., 2007. Assessment of seasonal variations of surface water quality in the Phong watershed, Thailand. *Thammasat International Journal of Science Technology*12 (4):36–43.

Tetzlaff, D., Malcolm, I.A., Soulsby, C., 2007. Influence of forestry, environmental change and climate variability on the hydrology, hydrochemistry and residence times of upland catchments. *Journal of Hydrology* 346:93–111, doi:10.1016/j.jhydrol.2007.08.016.

Thilagavathi, R., Chidambaram, S., Prasanna, M.V., Thivya, C., Singaraja, C., 2012. A study on ground water geochemistry and water quality in layered aquifers system of Pondicherry region, Southeast India. *Applied water science* 2:253–269, doi:10.1007/s13201-012.

Wahyuningrum, N., Pramono, I.B., 2013. The potential of forest buffer to prevent stream from water pollutants: a case study in Grojokan Sewa sub–watershed, Karanganyar district, central Java. *Journal of Forestry Research* 10 (2): 101–109.

Wall, G.J., Bos, A.W., Marshall, A.H., 1996. The relationship between phosphorus and suspended sediment loads in Ontario watersheds. *Journal of Soil and Water Conservation* 51(6): 504–507.

Wang, X., Burns, D.A., Yanai, R.D., Briggs, R.D., Germain, R.H., 2006. Changes in stream chemistry and nutrient export following a partial harvest in the castill mountain, New York, USA. *Forest Ecology and Management* 223:103–112, doi:10.1016/j.foreco.2005.10.060.

Yusif, M., El Abd, E.S., Baraka, A., 2013. Assessment of water resources in some drainage basins, north western coast, Egypt. *Applied water science* 3:439–452, doi:10.1007/s13201–013–0093–2.

Zelazny, M., Astel, A., Wolanin, A., Malek, S., 2011. Spatiotemporal dynamics of spring and stream water chemistry in a high–mountain area. *Environmental Pollution* 159:1048–1057, doi:10.1016/j.envpol.2010.11.021.