

Article

The Impact of Group- and Single-Tree-Selection Cuttings on Runoff and Sediment Yield in Mixed Broadleaved Forests, Northern Iran

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Abstract: Silvicultural treatment and the forest harvesting operations using different methods can lead to an increase in the production of runoff and sediment by changing the canopy and soil surface where they are conducted. In order to investigate this issue, sampling plots were established in the Namkhaneh district of the Kheyroud forest with three replications for every treatment: control stand and tree harvesting systems using single-selection cuttings and group-selection cuttings. The amount of runoff and sediment was collected and estimated from precipitation over a period of one year. Also, some soil physical properties such as bulk density, penetration resistance, sand, silt, and clay content, soil moisture, and soil organic matter were measured. The results showed that tree harvesting systems has a significant effect on runoff, the runoff coefficient, and sediment but the season (growing season and fall) and the combined effect of tree harvesting systems and the season have no significant effect on the runoff coefficient and sediment. The mean runoffs of each rainfall event for the control, single-tree, and group-selection treatments were 5.67, 8.42, and 10.28 mm, respectively, and the sediment amounts were 3.42, 6.70, and 11.82 gr/m², respectively. Furthermore, the total annual erosion amounts of the control, selection, and grouping treatments were 0.427, 0.838, and 2.178 t/ha, respectively. The bulk density, penetration resistance, and percentage of sand and silt were positively related and the percentages of clay and organic matter were negatively related with the amount of runoff and sediment. In the method of individual selection cuttings, the damage to the forest in terms of the amount of runoff and soil erosion was less than for the group-selection cuttings. Forest harvesting by the selection method (single-selection and group-selection) has caused different changes in the vegetation canopy. The final summary of our results could be the advice to predominantly use the single-selection method in high-slope stands.

Keywords: forest harvesting; single- and group-selection method; canopy cover; annual erosion; runoff and sediment



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1. Introduction

Forest ecosystems play an effective role in regulating and maintaining the water balance in watersheds, and the ecosystem's function of water supply and regulation by trees includes regulating seasonal water flows, providing water for various uses, and water purifying and storing. In forests, due to humus and organic matter in the soil, the amount of water absorption and infiltration is high [1]. The area of Hyrcanian forests in northern Iran is about 1.9 million ha, of which an area equal to 1.07 million ha has been exploited in the past decades. Disturbance in a forest's hydrological function leads to an increase in the

soil erosion intensity, the loss of topsoil, and a decrease in its water holding capacity [2–10]. Undisturbed forest areas usually have the least runoff and sediment production among all ecosystems due to the presence of tree and herbaceous cover, a litter layer, and tree remains. In this regard, the soil erosion rate in undisturbed forests has been reported in a range from 0.02 to 1.2 t/ha [11]. Forest harvesting operations which cut trees and remove vegetation from forest floor lead to an increase in the volume of surface runoff [12].

One of the key goals of sustainable forestry and agricultural management is to minimize soil erosion. Accordingly, the soil properties and vegetation are two important factors which influence soil erosion processes [6,7]. The study of the role of vegetation and soil physical properties on runoff and sediment yields in different land cover types (forest, monoculture plantation, and agroforestry) in China by Zhu et al. [13] showed that the runoffs in land with monoculture plantations are 33.2 and 2.6 times greater than those of forest and the agroforestry fields, respectively. Furthermore, the sedimentation rates in forest, monoculture plantation, and agroforestry systems are 0.041, 11.54, and 2.73 t/ha, respectively. This shows that the conversion of forests to other types of land cover leads to negative hydrological consequences (excessive runoff and sedimentation). The amounts of runoff and sedimentation are two important parameters related to soil erosion, which is considered as an important environmental problem related to natural hazards and forest management operations [14,15]. Vegetation evaporates part of the rain that it receives on the one hand and slowly transfers another portion to the earth's surface. At the same time, creating a barrier to the movement of water on the ground surface, it increases the penetration of water into the soil [5]. Therefore, land cover change has a profound effect on the water cycle. The reduction of vegetation cover due to forest harvesting generally increases the average surface runoff volume and overall water performance [16]. The removal of a certain number of trees in the stand as a consequence of exploitation induces a change in the crown layer of forest cover, reducing the amount of interception and increasing evaporation. It also increases the amount of throughfall on the ground [17,18]. In deciduous forest stands, trees experience two distinct periods, leafy and leafless periods, which have significant effects on hydrological characteristics such as interception, followed by runoff and sediment [19]. The average runoffs in plots with low, medium, and high traffic intensity in the leafless period were 95.5, 54.2, and 21.7% higher than the runoff values in the leafy period, respectively. The average yields of sediment in low-, medium-, and high-traffic treatments in the leafless period were 7.1, 5.1, and 3.3 times higher than the amount of sediment in the leafy period [19].

Soil erosion is affected by many factors, including the rainfall intensity, soil type, vegetation, soil moisture, and slope [20]. The dry bulk density, moisture content, and total porosity were affected considerably on skid trails by the slope and traffic frequency [8,10]. In harvested areas, the presence of foliage and litter on the forest floor is very important to prevent splash erosion, and somewhat to reduce runoff and particle movement to downslope [21]. In areas with steep slopes, the strength of the soil is weak, and heavy rains and high temperatures make the erosive soils more sensitive to the effects of machinery and the disturbance of vegetation [22–24]. The research of Akbarimehr and Naghdi [25] shows that the main variable affecting runoff and soil erosion is the slope. Bahadur [26] also stated that the highest amounts of runoff and soil loss come from plots with a steep slope. Runoff generally increases in forest watersheds in a short time after forest clear cutting, but it decreases in the long term due to the evapotranspiration increase with tree regrowth in the stand [27]. Etehad Abari et al. [28] studied the runoff and sediment changes following changes in some soil properties due to forest harvesting operations and they concluded that changes in the crown and plant cover have a significant effect on the amount of runoff and sediment. Furthermore, the percentage of clay and the soil bulk density have a significant positive correlation with the amount of runoff [1,5]. The percentage of sand, the pH, and organic matter have a significant negative correlation with the amount of runoff. It was also found that the variables of soil moisture percentage, sand percentage, and soil organic matter have a negative relationship, and the clay percentage and soil bulk density have

a significant positive correlation with the amount of sediment [28]. Soil compaction by changes in the soil properties is an important factor in soil losses. The amounts of soil sediment under the influence of harvesting operations in areas with a steep slope and for the control are estimated at 2.56 and 0.13 tons per ha per year, respectively [29].

Nowadays, sustainable forest management aims to reduce environmental degradation at all levels. In the Hyrcanian forests, due to the implementation of single-selection and group-selection harvesting systems as well as the creation of small and large patches caused by tree harvesting, it is necessary to evaluate changes in vegetation, soil properties, runoff, and sediment. The purpose of this is to reduce the effects of disturbance factors and improve the conditions of the forests. The objective of this study was to determine the effect of forest cover on sediment yield and runoff rates. In particular, the effects of the single-tree and group-selection methods were compared. Furthermore, since the studied forest is a deciduous forest, the effect of seasonal coverage due to the presence or absence of leaves was taken into consideration. The aim was, therefore, to have a better understanding of the factors that have a significant effect on sediment and runoff according to the hypothesis that forestry methods (single- and group-selection) and relative logging activities have an influence.

2. Materials and Methods

2.1. Site Description

This study was conducted in compartment 207 of the Namkhaneh district in the Kheyroud forest (Forest Research Station of University of Tehran). The studied area in the Hyrcanian forests is a remnant of the third ice age and belongs to the Upper Jurassic period. These forests have a high biodiversity and, on the other hand, are exposed to the use of local people and commercial harvesting. The annual rainfall in this area is 1380 mm. The rainiest months of the year are October and November, with averages of 273.6 mm, and July is the least rainy month of the year with 47.5 mm of rainfall. The average annual temperature is 16.1 °C. Parcel area is 49.7 ha with north-west aspect and the altitude is between 710 and 900 m above sea level. The soil type is brown forest, and the forest type is beech-hornbeam. In the Namkhaneh district, the average stem density and average growing stock of stands were 251 tree ha⁻¹ and 510.6 m³ ha⁻¹, respectively. The type of harvesting was done in the form of the selective method (single-tree selection method and group-selection method). Marked trees were felled and processed using a chainsaw, and the timber was extracted from stump to landing by a TAF E655 wheeled skidder. The operations of cutting and logging trees for both treatments were carried out in 2018.

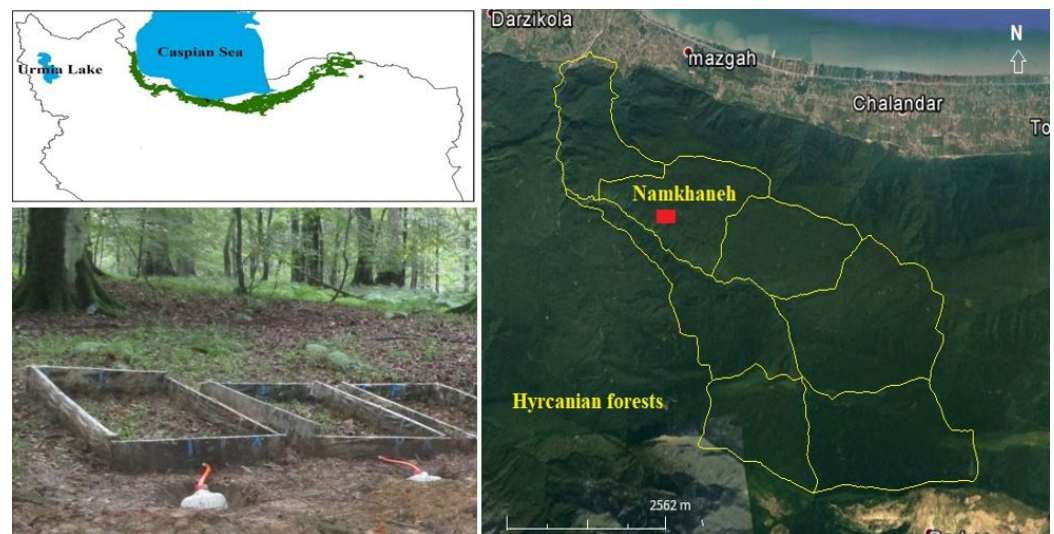
The natural rainfall of the region (not using the rain simulator) was used to determine the amount of runoff and sediment due to the application of the forestry method of selection cutting by groups or by single trees. The studied treatments included undisturbed forest (control), forest with single-tree harvest (single-selection), and forest with more than one tree harvest (group-selection). Also, considering the coverage of tree leaves during the research, the season was considered as another variable. The season factor was divided into two parts: growing season (with leaves, maximum herbaceous cover and litter) and non-growing season (no leaves, limited herbaceous cover and litter). The durations of the growing and non-growing seasons in Hyrcanian forests are 7 and 5 months, respectively. The characteristics of the undisturbed area and the two harvested areas with single-selection and group-selection methods are shown in Table 1.

Table 1. General characteristics of the Namkhaneh district under the investigated treatments.

Location	Features	Average Patch Area (m ²)	Average of Cover by Season				Soil Texture
			Tree Cover (%)		Grass Cover (%)		
			Fall	Growing	Fall	Growing	
Undisturbed (Control)	No disturbance, unharvested, existence of livestock in the field	0	30	85	4	26	Loamy clay
Single-selection cuttings	Low disturbance, effects of water conversion and transportation, existence of livestock in the field	100	10	50	12	65	Loamy clay
Group-selection cuttings	High disturbance, effects of water conversion and transportation, existence of livestock in the field	400	50	15	23	88	Loamy silt

2.2. Experimental Design

In order to determine the sampling location, areas with the same conditions (geographic direction, altitude, forest type) were selected and the plots of each treatment were randomly installed in areas with a 30% slope. Plots with dimensions of 2 m² with longer length in the slope direction and with 3 repetitions of the three treatments were designed [1,12,30]. The plots were enclosed using 25 cm-wide wooden planks so that the runoff would not leak out from the plots, allowing them to represent the actual amount of runoff. At the ends of these plots, a pipe is installed to direct the runoff flowing through the plots to the collection reservoir (Figure 1). Data collection was performed for one year, after each rainfall event from 26 September 2018 to 28 September 2019.

**Figure 1.** Study area and design of plots for measuring runoff and sediment.

2.2.1. Data Collection and Laboratory Analysis

During the research period, after each occurrence of rainfall, the amount of runoff per plot was measured by recording the volume of water in the reservoirs. After the rain stopped, several liters of water were collected from each plot and transported to the laboratory to measure the sediment concentration (g/L) using the water discharge method [31]. In this method, one liter of water and sediment sample is poured into the container, it is kept in a stationary state for 48 h, and then the water is slowly separated from the sediments. The sediments remaining in the container were washed, poured into pre-prepared and weighed foils, and dried in the oven at a temperature of 105 °C for 24 h [2]. By weighing the samples of containers (plates) with sediment and subtracting the weight of the original containers (plates), the sediment sample weight is calculated in g/L.

Then, by performing the necessary calculations, the total concentration of sediments in each rainfall was estimated at the scale of plots (m^2) and stand (ha).

To measure the amount of rainfall, six rain gauges were installed in the undisturbed area and in the harvesting areas for single-selection and grouping-selection methods. To determine the amount of runoff, the amount of water leaving the plots that was stored in the container during each precipitation event was measured. The runoff height was calculated by dividing the runoff volume by the plot area. By dividing the runoff height by the rainfall height, the runoff coefficient was calculated.

2.2.2. Soil Properties

Soil samples were taken from the 0–10 cm layer using metal cylinders with a length of 10 cm and a diameter of 5 cm in all plots. In order to reduce the error, three soil samples were randomly taken in each plot, the samples were mixed together and, at the end, a soil sample was collected from each plot. Soil samples were dried at 105°C for 24 h to calculate the soil moisture content and dry bulk density. The bulk density was calculated using Equation (1):

$$\text{BD} = \frac{\text{WD}}{\text{VC}} \quad (1)$$

where BD is the dry bulk density (g cm^{-3}), WD is the weight of the dry soil (g), and VC is the volume of the cylinder (cm^3).

Penetration resistance in the field was measured using a manual penetrometer (Eijkelkamp, 06.01.SA penetrometer, Giesbeek, The Netherlands) and soil texture was measured by hydrometric method in the laboratory. Soil penetration resistance in each plot was measured at the location of soil samples (3 sample locations) by applying vertical force to the penetrometer.

2.3. Statistical Analyses

The Kolmogorov–Smirnov test was used to test the normal distribution of the data. For homogeneity of variance test, Levene's test was used. The comparison of runoff rate, runoff coefficient, and sediment yield among treatments was done by two-way analysis of variance (ANOVA). If two-way analysis of variance between treatments was significant, Duncan's multiple range test was used to compare means. Pearson correlation test was also used to investigate the relationship between soil physical properties with runoff and sedimentation. Polynomial regression model was used to predict the relationship between runoff and sediment with rainfall. All statistical tests were performed using the SPSS 20 software package.

3. Results

3.1. Precipitation Events

Over the course of one year, 28 precipitation events were recorded, the highest amount of precipitation was recorded for event number 2 (250 mm) and the lowest amount was 7 mm on 13 December 2018 (Figure 2). In order to avoid errors in our data analysis, precipitation event number 2 was deleted due to excessive precipitation and an insufficient capacity of the collection container. Additionally, events number 22 and 23, in July 2019, were removed due to cracking of the ground due to lack of moisture, extreme water penetration into the ground, and the number of sunny days before the rain (very low runoff production). The total amounts of precipitation during the 25 recorded events in the field without harvesting (undisturbed control), with single-selection, and with group-selection were 871, 970, and 1057 mm per year, respectively (Figure 2).

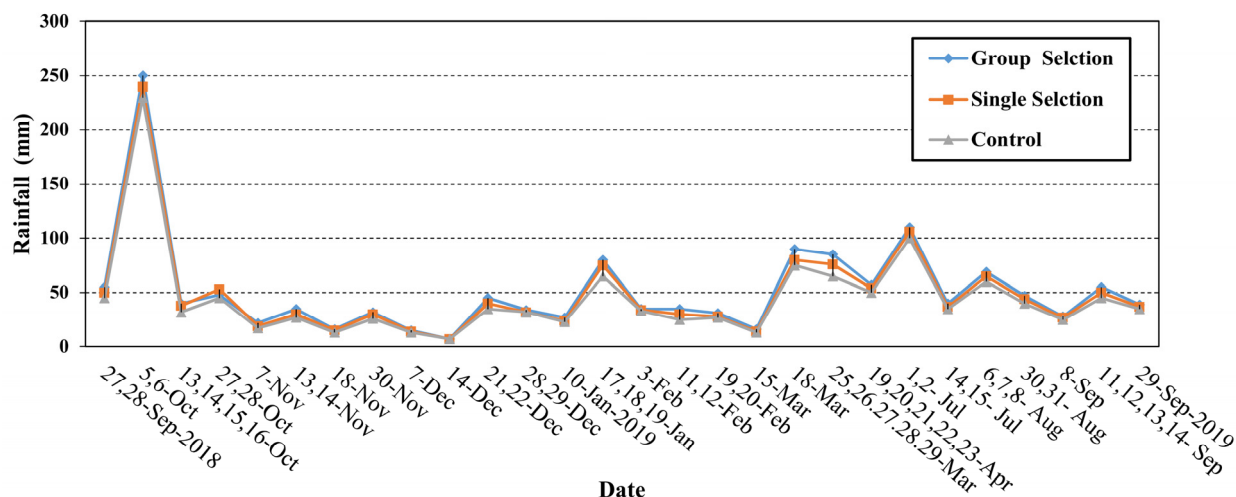


Figure 2. The amount of precipitation in each rainfall event in different treatments.

3.2. Effects of Stand Management and Season

The results of Table 2 showed that the lowest and highest average values of the bulk density, penetration resistance, percentage of sand, and silt were obtained in the undisturbed area and the area with group-selection harvesting. On the other hand, the percentages of clay, soil moisture, and soil organic matter were the highest and lowest in the undisturbed area and the area with group-selection harvesting, respectively. Also, the values of soil physical properties were significantly different between the undisturbed area and the areas with single-selection and group-selection harvesting (Table 2).

Table 2. Average ($\pm$ standard error) soil physical properties in each of the study areas (treatments).

Soil Properties	Control	Single-Selection	Group-Selection
Bulk density (g/cm^{-3})	1.2 ± 0.08^b	1.24 ± 0.10^{ab}	1.3 ± 0.09^a
Penetration resistance (MPa)	1.37 ± 0.07^c	1.43 ± 0.11^b	1.5 ± 0.12^a
Sand (%)	19 ± 3^c	22 ± 4.27^b	25 ± 2.47^a
Silt (%)	44 ± 5.96^b	48 ± 5.45^{ab}	51 ± 6.49^a
Clay (%)	27 ± 4.87^{ab}	30 ± 3.50^a	24 ± 6.06^b
Water Content (%)	27 ± 11.03^b	31 ± 7.85^a	28 ± 4.45^b
Organic Matter (%)	7.64 ± 0.82^a	5.24 ± 0.25^b	3.2 ± 0.44^c

Note: Different letters in a row indicate significant differences among soil physical property values ($p < 0.05$).

According to the results of Table 3, the bulk density, penetration resistance, and percentage of sand have a positive significant relationship, and the percentages of clay and organic matter have a significant negative relationship with the amount of runoff and sediment. The percentage of silt is not correlated with the runoff rate, while it has a significant positive correlation with the amount of sediment. The water content (moisture percentage) was not correlated with the amount of runoff and sediment (Table 3).

The results of the variance analysis of the studied treatments on the amount of runoff, runoff coefficient, and sediment showed that the tree harvesting system, the seasonal changes, and their interaction effects have a significant effect on the runoff and sediment, while only the effect of seasonal changes was significant on the runoff coefficient (Table 4).

Regression analysis showed that the runoff and sediment changes increased linearly in relation to the rainfall changes for the areas with different harvesting systems (Figures 3 and 4a). The increase in the runoff and sediment in relation to rainfall in the area with the group-selection harvesting is more intense compared to the other areas. Comparing the average runoff from rainfall events using Duncan's test showed that the lowest amounts of runoff and sediment were obtained in the control area (undisturbed) and the highest

amounts were obtained in the area with the group-selection harvesting (Figures 3 and 4a). Also, the amounts of runoff and sediment in all three areas have significant differences.

Table 3. Pearson correlation results between soil physical properties with runoff and sediment.

Soil Properties	Runoff		Sediment	
	R	p Value	R	p Value
Bulk density	0.68 *	0.043	0.72 *	0.028
Penetration resistance	0.82 **	0.006	0.82 **	0.006
Sand	0.71 *	0.031	0.68 *	0.045
Silt	0.61 ns	0.082	0.67 *	0.048
Clay	−0.78 **	0.012	−0.82 **	0.007
Water Content	−0.59 ns	0.092	−0.56 ns	0.116
Organic Matter	−0.84 **	0.005	−0.78 *	0.012

Note: *: $p < 0.05$; **: $p < 0.01$; ns: not significant.

Table 4. Variance analysis of the effect of the studied treatments on the amount of runoff, runoff coefficient, and sediment.

Variable	Source of Change	df	MS	F Value	p Value
Runoff	Tree harvesting system	2	103.520	12.441	0.000
	Change of season	1	138.390	17.036	0.000
	their interaction	2	4.854	0.598	0.012
Runoff coefficient	Tree harvesting system	2	0.069	3.835	0.113
	Change of season	1	0.069	3.835	0.026
	their interaction	2	0.003	0.141	0.869
Sediment	Tree harvesting system	2	425.854	10.214	0.005
	Change of season	1	49.640	5.826	0.000
	their interaction	2	11.639	0.762	0.024

p-values (<0.01 and <0.05) are given in bold.

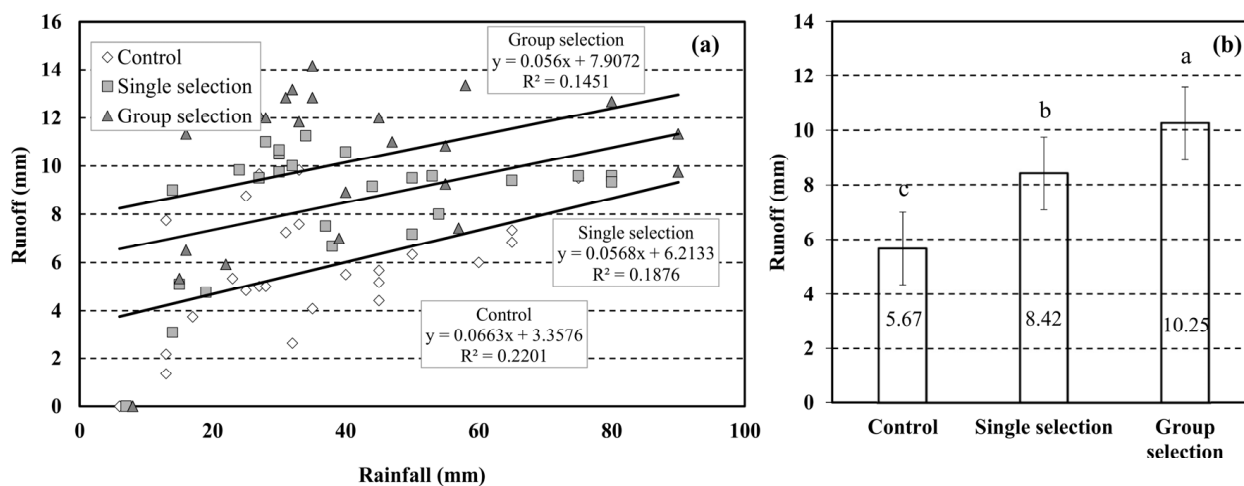


Figure 3. Relationship between rainfall and runoff in plots with different treatments (a), comparison of mean runoff in different treatments using Duncan's test (b). Different lowercase letters indicate significant differences by Duncan's test in B.

As the height of the runoff increases, the amount of sediment increases. The increase in the sediment rate due to the increase in runoff in the area with group-selection harvesting is the highest and, in the control area (undisturbed area), it is the lowest. For low runoff values, the amount of sediment has less differences between the studied treatments, and with increasing runoff, the differences in sediment values increase significantly (Figure 5). The total annual runoff values in the current study for the control treatments, single-selection

and group-selection harvesting were 148, 219, and 267 mm per year, respectively. Also, the amount of runoff in the growing season for all treatments was less than that for the fall season (Figure 6a). Also, the amount of erosion in the growing season for all treatments is less than that for the fall season (Figure 6b).

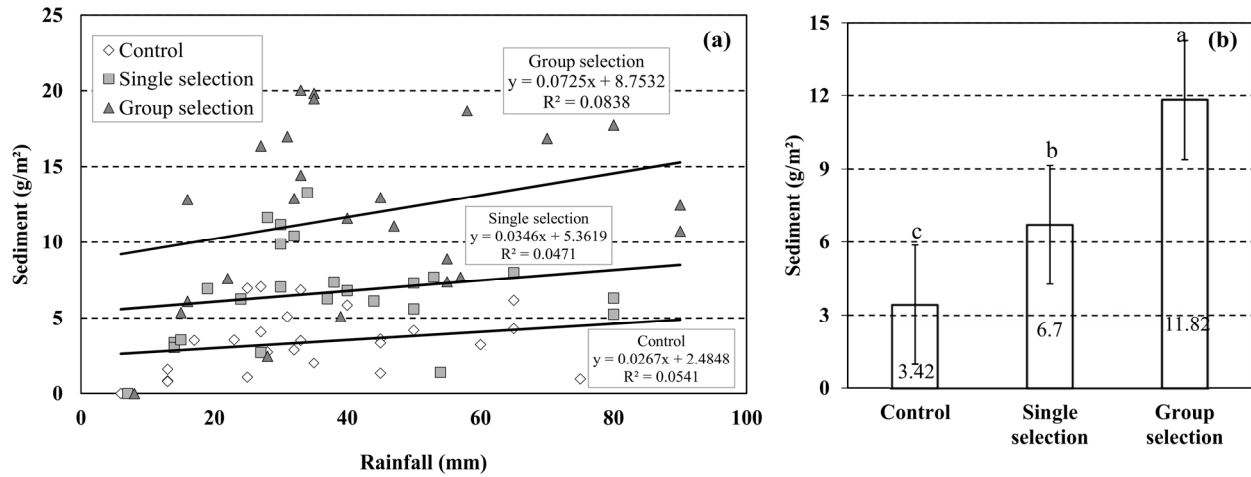


Figure 4. Relationship between rainfall and sediment in plots with different treatments (a), comparison of mean sediment in different treatments using Duncan's test (b). Different lowercase letters indicate significant differences by Duncan's test in B.

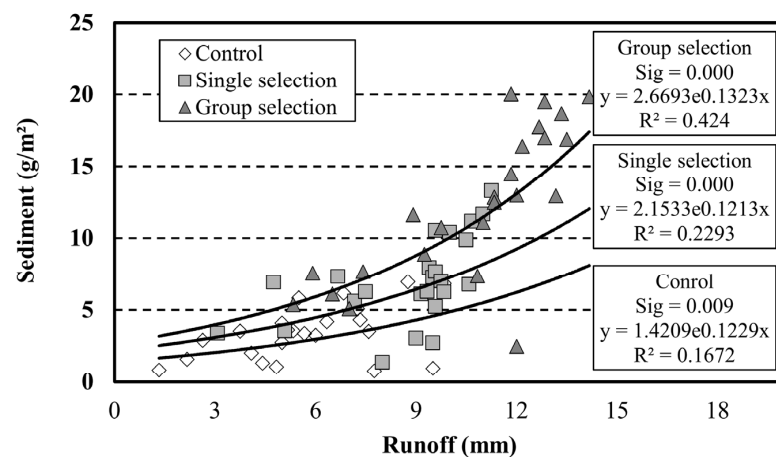


Figure 5. Relationship between runoff versus sediment in areas with different harvesting systems.

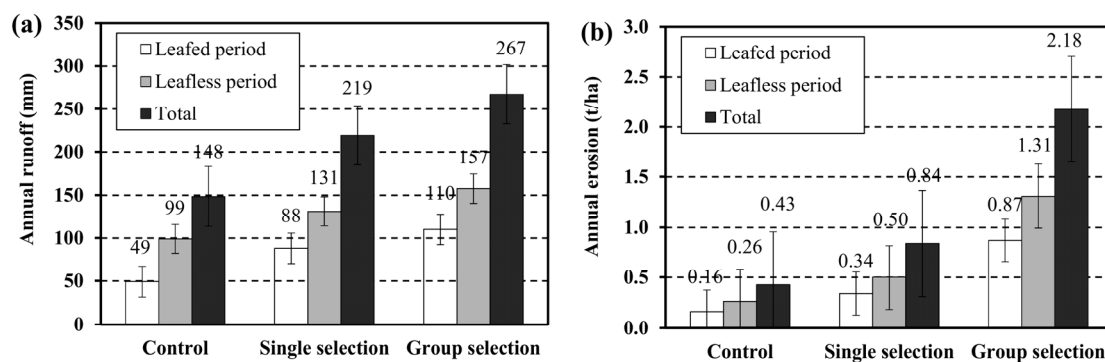


Figure 6. Annual runoff (a) and annual erosion (b) of rainfall in different treatments in the growing season (leafy period of trees) and autumn season (leafless period of trees).

4. Discussion

4.1. Precipitation Events

Change in forest hydrological characteristics are largely due to the effects of management and executive operations and, finally, the change in the type of land cover, because they can affect many components of the hydrological cycle [32,33]. Different factors such as the soil characteristics, vegetation type, and intensity and duration of rainfall affect the amount of infiltrating water in the soil or surface runoff [34,35]. With the increase in the amount of rainfall in each event, the amount of runoff and sediment increases, and the amount of runoff in each studied treatment was different due to the difference in the amount of rain that reached the soil and forest floor cover. According to the results, in the control area and the area with single-selection harvesting, the amounts of rainfall that reached the soil were 26% and 8% less, respectively, than in the area with group-selection harvesting. In areas with group-selection harvesting, due to lower densities of the canopy and litter, the amount of precipitation reaching the soil is higher, which increases the runoff and sediment rate. With the operation of tree harvesting and the resulting reduced forest cover, raindrops directly hit the soil; thus, the runoff volume also increases [27,36]. The curve of rainfall and runoff for the different treatments in Figure 3 is linear, and should be parabolic naturally [36]. This issue could be due to the fact that the rainfall intensity, which is an important factor in the amount of runoff, was not measured. The lack of measurement of the rainfall intensity and the lack of simultaneity of its measurement due to the distance of the plots in each of the three study areas represent the limitations of this study. Also, the rainfall of the recorded events varied from 1 h to 5 days.

4.2. Effects of Stand Management and Season

The soil physical properties (bulk density, penetration resistance, percentage of sand, silt, and clay, moisture content, and soil organic matter) are effective in determining the amount of soil erosion. Also, many studies showed that the amount of water infiltration is influenced by the soil physical properties [37]. The bulk density is known as an important factor determining the amount of soil loss due to its direct relationship with the penetration resistance [29].

Soil compaction is a factor in reducing properties such as the soil porosity, water infiltration, ventilation, and gas exchange [38,39]. In this study, the highest amount of runoff was observed in the group-selection harvesting treatment, in which the bulk density is the highest. This study is consistent with the research of Cleophas et al. [29], who stated that, with an increase in bulk density, which has a direct and positive relationship with penetration resistance [40,41], less water infiltrates into the soil. Also, with the increase in bulk density, the sediment rate increased, which is consistent with the research of Lotfalian et al. [42]. In the area with group-selection harvesting, due to the greater traffic of logging machines, and the litter layer with a low thickness and low moisture (open canopy and more light reaching the forest floor), the bulk density and penetration resistance increased, while the infiltration decreased [4,43,44], which ultimately led to an increase in runoff and sediment. In the control area (unharvested), the soil had a lower bulk density due to the presence of organic matter and more porosity, and as a result, the water penetration rate was higher [45,46].

Harvesting operations reduce the ability of water to penetrate into forest soils [47,48]. By increasing the percentage of sand in the soil, the amount of water infiltration increases, while increasing the percentage of clay and silt causes a decrease in water infiltration [23]. However, the results of this research are inconsistent with this assumption. In fact, the discrepancy may have been caused by the influence of other factors such as organic matter, the slope, and soil resistance to water infiltration. The increase in soil organic matter causes more water infiltration, and as a result, the rate of infiltration is higher and the amount of runoff and sediment is lower, which is consistent with the findings of the research by Etehadi Abari et al. [28].

Creating patches of different sizes in the forest affects the percentage of crown and herbaceous cover. Changing the vegetation cover (crown and herbaceous) causes a change in the number of raindrops reaching the soil, and ultimately the amount of runoff and sediment [35]. The results of this study showed that changes in the vegetation cover have a significant effect on the amount of runoff and sediment, which is consistent with the results of previous studies [28,29,48]. The relationship between the rainfall and sediment in the plots and the comparison of the mean sediment for the different treatments clearly show that, in the forest with group-selection harvesting of trees, due to the lower amount of canopy cover and vegetation, the average runoff was higher and the amount of sediment was greater. In the area with the group-selection harvesting, the amount of canopy cover was the lowest compared to the single-selection and control treatments; consequently, the amount of rainfall reaching the forest soil was greater [48] and, finally, the amount of runoff and sediment increased [49,50].

In the control area (unharvested), the vegetation cover causes part of the raindrops to be absorbed and evaporated by the canopy and not hit the soil surface [29], so the erosive power caused by the raindrops is reduced [48]. Furthermore, the presence of a greater litter layer on the forest floor leads to an increase in infiltration and a decrease in runoff [51,52]. Various studies have pointed out the role of organic materials in improving the physico-chemical and biological characteristics of forests and reducing the amount of runoff and erosion. For example, Salehi et al.'s research [53] showed that there is a positive relationship between the amount of soil organic matter and the weighted average diameter of soil grains, and that organic matter can improve the stability of soil grains and reduce the amount of sediment and soil erosion. Siegrist et al. [54] stated that organic matter in the soil increases the porosity and water-holding capacity of the soil and causes water to penetrate into the soil and decrease the volume of runoff. The leafiness and leaflessness of trees are also related to the amount of rain that reaches the soil [50]. Canopy interception affects the water level in forest ecosystems, and some of the rain is evaporated, returning to the atmosphere due to interception [6,55]. Leaf loss during the autumn period reduces the amount of interception, the canopy maintenance capacity, and the ratio of evaporation to the rain intensity during the rainy period [19,27]. Our study shows that the annual amount of runoff and erosion in the growing season, which is accompanied by the presence of leaves and herbaceous cover, was lower than in the fall season.

In the treatment with group-selection harvesting, with the increase in the amount of rainfall reaching the soil, the amount of sediment increased in direct relation with the runoff. In this treatment (group-selection harvesting), due to the open canopy, the erosive power caused by raindrops is greater, and also, due to the small quantity of litter on the floor, the amount of infiltration is lower; as a result, the amount of runoff and sediment is greater than for other treatments. The amount of sediment in this research is higher than that in the research of Etehadi Abari et al. [28]. One of the main reasons could be the difference in slope between our study and that of Etehadi Abari et al. [28]. The average slope in the present study was 30%, while in the study of Etehadi Abari et al. [28], the slope was 15%. The tendency for soil erosion is greater on slopes with higher grades [56,57]. Our findings showed that, with the increase in the harvesting rate and the consequent greater canopy opening, on average, the runoff and sediment increased, as reported also in Jourgholami et al. [19]. The rates of soil erosion in the control area, single-selection, and group-selection treatments were 0.864, 1.743, and 3.076 tons per ha per year, respectively, while, in the study by Cleophas et al. [29], in the unharvested and harvested area, were estimated at 0.13 and 2.56 tons per ha per year, respectively. These differences are due to the different slope and amount of annual rainfall.

5. Conclusions

Forest harvesting by selection cutting methods (single-selection and group-selection) has caused different changes in vegetation canopies. According to the results of this study, in the control area and the area with single-selection harvesting, the amount of rainfall

that reached the soil was less than in the area with group-selection harvesting. In the area where group-selection harvesting was carried out, due to lower amounts of canopy and litter, the amount of rainfall reaching the soil was higher, which increases the runoff and sediment rate. The soil physical properties are effective in the amount assessment of soil erosion. In the area with group-selection harvesting, due to more traffic of logging machines and increases in soil compaction, the amount of litter layer with a low thickness and low moisture (open canopy and more light reaching the forest floor), the bulk density, and the penetration resistance increased, while the infiltration decreased. Finally, this led to an increase in runoff and sediment. The leafiness and leaflessness of trees also affect the amount of rain reaching the soil surface and soil erosion. The annual amount of runoff and erosion in the growing season, which is accompanied by the presence of leaves and herbaceous cover, was less than in the fall season. Therefore, it is suggested to use the single-selection method on high slopes for forest harvesting. In this research, the studied areas were almost the same in terms of topography and other effective factors, but due to the influence of the slope and its direct and positive relationship with the amount of runoff and sediment, and in order to obtain more accurate results, it is deemed necessary to investigate further by conducting studies in different topographical conditions. Considering the existence of livestock in forest areas and the long-term natural regeneration of degraded areas caused by the group-selection method, it is necessary to accelerate the improvement of these areas by planting seedlings.

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