J. Agr. Sci. Tech. (2019) Vol. 21(Suppl.): 1843-1858

Spatial and Temporal Variability of Throughfall under a Natural *Fagus orientalis* Stand in the Hyrcanian Forests, North of Iran

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ABSTRACT

The spatial and temporal heterogeneity of throughfall (*TF*) have important ecological impacts in forest ecosystems. The aim of this study was to quantify spatio-temporal variability of *TF* and to evaluate the effects of canopy traits and gross rainfall (*GR*) characteristics on *TF* at the event scale. Event-based measurements were carried out from September 2015 to October 2017 during the leafed-out period in a natural uneven-aged beech (*Fagus orientalis* L.) stand located in the Hyrcanian forest of Iran. Leaf area index (*LAI*) and canopy openness of the stand were 6 m^2 m^{-2} and 6.2%, respectively. Tree density in the studied plot was 188 tree ha^{-1} and the basal area (BA) was 51 m^2 ha^{-1}. During the measurement period, 25 rainfall events occurred (total rainfall= 784.8 mm). We observed variability of *TF* under the beech trees canopy in different *GR* classes (< 15, 15-30, 30-50 and > 50 mm). Increases in rainfall depth and intensity were associated with an increase in *TF* depth and decrease in *TF* variability. We found that rainfall depth along with the intensity were the most influential factors on the *TF* depth, spatial variability as well as time stability. Knowledge of the spatial persistence and variability of *TF* would help managers to optimize the management of these stands in terms of soil water and nutrition availability.

Keywords: Beech stand, Canopy trait, Ecohydrology, Gross rainfall, Tree density.

INTRODUCTION

Considerable quantities of precipitation transfer from the canopy to the ground through throughfall (*TF*) (Levia and Frost, 2006, Carlyle-Moses *et al*., 2004). The redistribution of gross rainfall *GR* as a result of interactions with the forest canopy creates a high spatial and temporal input of *TF* (Johnson and Lehmann, 2006, Zimmermann *et al*., 2008, Muzylo *et al*., 2009, Macinnis-Ng *et al*., 2012). *TF* spatial variability subsequently affects soil moisture variability and the spatial pattern of solute concentration and deposition on the forest floor (Zimmermann *et al*., 2007). Hence, understanding the heterogeneous patterns of *TF* beneath forests is critically important to ecological processes of canopy, ecohydrology, and biogeochemistry cycling in forest ecosystems (Keim *et al*., 2005).

Primary factors affecting the quantity of *TF* are species composition (Bouten *et al*., 1992, Lilienfein and Wilcke, 2004), meteorological conditions (Irome and Huber, 2002), season (Henderson *et al*., 1977), and canopy cover (Zirlewagen and Von Wilpert, 2001, Morris *et al*., 2003, Pypker *et al*., 2011). The impact of canopy cover on *TF* distribution in forest stands varies between stand types (Kimmins, 1973, Carlyle-Moses *et al*., 2004, Holwerda *et al*., 2006). In addition, rainfall magnitude,

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[DOR: 20.1001.1.16807073.2019.21.7.17.8]

duration, intensity as well as wind speed and direction, can affect spatial and temporal variability of *TF* at the forest floor (Vrugt *et al*., 2003, Levia and Frost, 2006, Staelens *et al*., 2006). Although numerous studies have focused on the spatial variability of *TF* in coniferous, broadleaved or mixed stands and tropical rain forests (e.g. Raat *et al*., 2002, Loescher *et al*., 2002, Konishi *et al*., 2006, Zimmermann *et al*., 2008, Huitao *et al*., 2012, Nanko *et al*., 2011, Klos *et al*., 2014, He *et al*., 2014, Fan *et al*., 2015), little information is available about *TF* patterns in deciduous broadleaved forests (Carlyle-Moses *et al*., 2004, Staelens *et al*., 2006, André *et al*., 2011, Kowalska *et al*., 2016).

The global average surface temperature has increased over the 20th century by about 0.6°C (Houghton *et al*., 1990). Over the next 20 years, climate change is predicted to reduce rainfall and increase the severity of droughts in the north and west of Iran (Alvankar *et al*., 2017). Oriental beech (*Fagus orientalis* Lipsky) forests are the dominant tree between 700 and 1,500 m elevation in Hyrcanian forests in the north of Iran with standing volumes of up to 800 m^3 ha^{-1} (Oladi *et al*., 2017). Air humidity is high and fog is frequent in this elevation band (Sagheb Talebi *et al*., 2014, Oladi *et al*., 2017). Climate change will likely alter *GR* characteristics and the phenology of trees thereby changing *TF* variability. To our knowledge, there has been no research quantifying the spatial variability of *TF* in oriental beech stands. To optimize the management of these natural beech stands, a better understanding of the mechanisms that control the spatial *TF* variability is required. In addition, a better understanding would help future investigators design better *TF* sampling strategies based on different *GR* characteristics and canopy cover behaviors. We hypothesized that: (i) The spatio-temporal variability of *TF* in natural beech stand is relatively high and, (ii) *TF* variability patterns are affected by canopy and rainfall characteristics. The objective of this study was: (i) To understand and quantify the variability of spatial *TF* under a natural *F. orientalis* stand in the Caspian forests of northern Iran, (ii) To examine the temporal stability of spatial *TF* patterns, and, (iii) To determine which measured canopy and rainfall characteristics are best correlated to *TF* variability.

MATERIALS AND METHODS

Study Site

The study was conducted in the Kheyrud forest research station of the University of Tehran, located in the central part of the Caspian forests, Mazandaran province, Iran (36° 35' N, 51° 37' E) (Figure 1). Due to lack of meteorological stations inside the Caspian forests, we reported the meteorological data recorded by Kojur (36° 38ˈN, 51° 73ˈE, elevation 1,550 m asl) and Nowshahr (36° 39ˈ N, 51° 30ˈ, elevation -21 m asl) synoptic meteorological stations. Based on Kojur records, from 2006 to 2017, mean annual precipitation was 325 mm and mean annual relative humidity and air temperature were 60% and 12.8°C, respectively. Minimum and maximum monthly air temperatures were 1.5 (January) and 22°C (August). The prevailing wind direction is from the north (42%) and northeast (37%). When from the north, the 3-hr-average wind speed is 4.5 m s^{-1}. Moreover, Nowshahr Station, located approximately 22 km away from the study plot, reports mean yearly precipitation±*SD* is 1,291±184 mm and mean air temperature is 16.4°C (1977-2015). The region has a temperate mountainous climate that is affected by changing elevation (1400 to 3000 m) and distance from the Caspian Sea. Fog plays a important role in providing moisture to vegetation in this region (Garstecki, 2017). The study area experiences a short, warm, temperate and extremely humid summer that is marked by heavy fog for 4-8 hours per day during leaf-out seasons (Authors' observations). The winter is long, cold with freezing temperatures.

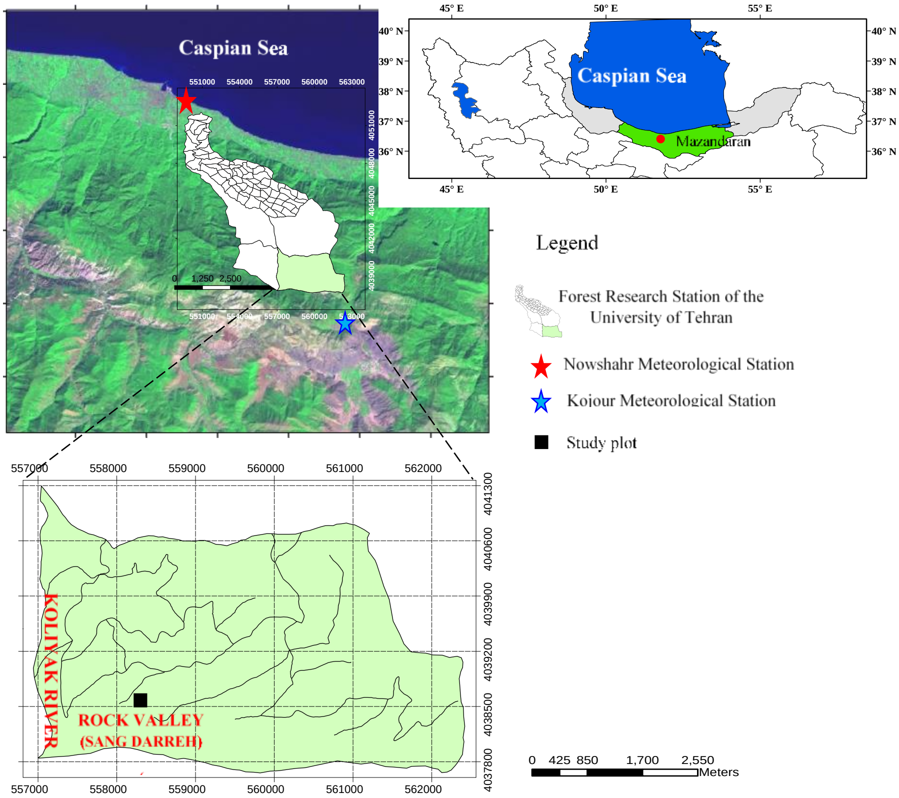

Figure 1. Location of the research area in the forest research station of the University of Tehran in northern Iran, (red circle in Iran's map). Black square refers to the study plot and stars show the locations of the nearest weather stations (Kojur and Nowshahr) (left upper Figure is Landsat data downloaded from USGS.gov).

Field measurements were carried out inside a 4,900 m^2 plot (36° 29' N, 51° 39' E, 1,476 m asl). Mean angle of the west-facing slope of the site ranged between 20 and 25%. The plot was dominated by an uneven aged stand of oriental beech trees with loamy nutrient rich soil. The stands are comprised of virgin forests that have not been harvested. About 10% of the understory was covered by *Ilex spinigera*, *Euphorbia helioscopia*, *Asperula odorata*, *Primula heterochroma*, *Sanicula europaea*, and *Viola odorata*, while the remaining area was bare ground. Tree density was 188 tree ha^{-1} with a basal area *BA* of 51 m^2 ha^{-1}. Mean tree height and diameter at breast height *DBH* were 29.5 m and 51.2 cm, respectively. Maximum and minimum height were 52.1 and 5.2 m, and for *DBH*, 138.4 and 10.5 cm, respectively. Prevailing wind direction during the measurement period was south and southwest.

Data Collection and Sampling Frame

Event-based *GR* and throughfall (*TF*) measurements were carried out continuously during the leafed-out seasons (from May to November) when the leaves are fully developed, for two years (September 2015 to October 2017). In this study, *GR* is defined as the rainfall entering the top of the canopy, *TF* is the portion that reaches 35 cm above the ground through canopy gaps without colliding with the vegetation (free *TF*) or via water dripping from the leaves, branches and stems (released *TF*) (Dunkerley, 2000, Levia and Frost, 2003, Levia *et al*., 2017).

Each precipitation event was measured eight hours after the end of rainfall,

[DOR: 20.1001.1.16807073.2019.21.7.17.8]

however, nighttime rainfalls were measured in the morning after sunrise (Carlyle-Moses *et al*., 2004). When the rain occurred over consecutive days, the rainfall was considered as an individual rainfall event (He *et al*., 2014). The duration of each rainfall event was calculated as the time between the first and last recorded measurement of an event. *GR* was measured using 10 manual rain-collectors located in a clearing area less than 100 m from the border of the study plot. *GR* manual rain-collectors were set 130 cm above the ground to prevent water drop splash from the ground and were wrapped in aluminum foil to minimize evaporation from increased radiation absorption. Manual *TF* rain-collectors (n= 122) were established under the canopy in a 70×70 m square plot (Figure 2). All low shrubs, grass, ferns, and herbs within 70 cm of a collector were removed. Manual *TF* rain-collectors were set 35 cm above the ground to reduce entry of splash water and *TF* rain-collectors were emptied prior to the rainfall event. The rain-collectors used for measuring both *GR* and *TF* had an orifice of 132.7 cm^2 (13 cm in diameter) and a height of 20 cm.

TF sampling points were distributed in a stratified simple random sampling design under the canopy to assess spatial distribution of *TF*. This method is more advantageous than grid and simple random sampling designs for spatial predictions because the stratified simple random sampling design provides more even distribution of sampling locations and produces unbiased estimates of the spatial mean (Zimmermann and Zimmermann, 2014). The 4,900 m^2 study plot was divided into 49 subplots, 10×10 m and two *TF* sampling points were then selected randomly in each subplot (Figure 2). In addition, we randomly sampled an additional 24 points within the study plot. These 24 sampling points were placed in a random direction, 0.5 m away from the *TF* sampling points already established in the subplot (Figure 2).

Leaf Area Index (*LAI*) and Canopy Openness

Leaf area index *LAI* and canopy openness (%) of the study plot were measured by Digital Hemispherical Photography (DHP, Canon EOS 6D digital camera with a 180°

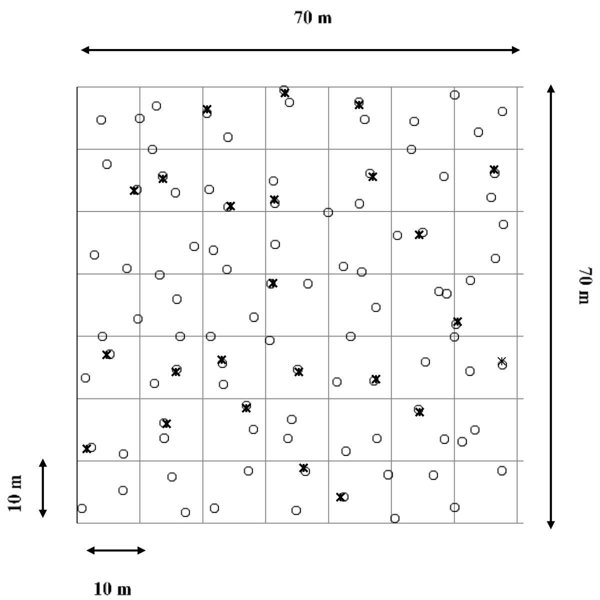

Figure 2. Throughfall *TF* sampling layout. The study plot was divided into 49 subplots; open circles in each subplot indicate *TF* sampling point. Crosses show the additional 24 sampling points.

fish-eye lens: Canon EF 8-15 mm f/4L). To determine the *LAI* and canopy openness, hemispherical photographs were taken vertically above each of the 122 *TF* rain-collector locations (Llorens and Gallart, 2000, Staelens *et al*., 2006) during cloudy sky conditions monthly during the leaf-out seasons, over the study period. The camera was mounted on a leveled tripod approximately 1.3 m above the ground (Liu *et al*., 2015). Digital photographs were processed with Gap Light Analyzer software version 2.0 to extract the value of *LAI* and canopy openness (Frazer *et al*., 1999).

Data Processing

Time stability of *TF* spatial patterns was evaluated by standardizing the *TF* rain-collector amount for each *GR* event using the method proposed by Keim *et al*., (2005). The method was a modified equation of Raat *et al*. (2002), and Vachaud *et al*. (1985), so that the variance at the sampling point quantified the stability of high or low *TF* areas:

$$\tilde{\delta}_{i,E} = \left(\delta_{i,E} - \bar{\delta}_E\right)(s\delta_E)^{-1}, \qquad (1)$$

Where, $\tilde{\delta}_{i,E}$ and $\delta_{i,E}$ are the normalized variable and variable at sampling point *i* of rainfall event E, respectively. $\bar{\delta}_E$ is the mean and $s\delta_E$ is the standard deviation of the variables for all sampling points in the *GR* event. We used Equation (2) to analyze the time stability of *TF* spatial patterns but replaced $\bar{\delta}_E$ with the median of δ_E , $M\delta_E$, and $s\delta_E$ with the Median absolute deviation (MAD) of δ_E, $MAD\delta_E$ as Equation (2) (Zimmermann *et al*., 2007):

$$\tilde{\delta}_{i,E} = \left(\delta_{i,E} - M\delta_E\right)(MAD\delta_E)^{-1}, \qquad (2)$$

The median and *MAD* were used because *TF* often does not exhibit a normal distribution at the rainfall event scale, and to control the influence of outliers on the dataset.

Statistical Analysis

The variability of *TF* was indicated by the spatial coefficient of variation (*CV*, %) described by a series of studies (Seiler and Matzner, 1995, Ratt *et al*., 2002, Staelens *et al*., 2006). The most appropriate correlation analysis (Pearson or Spearman) based on data distribution was performed to test the relationship between *TF* amount, *TF*%, $CV\%_{TF}$ and rainfall characteristics. Before statistical calculations, normal distribution was assessed using skewness and kurtosis, and the Kolmogorov–Smirnov statistic was used to test the normality of data. The points with *TF* depth more than 100 percent (hotspot points) for each *GR* class were detected using Getis Ord Hot-spot analysis in Arc GIS 10.2 at three significant levels (α= 0.10, 0.05 and 0.01) and using an Inverse-Distance spatial relationship concept (Getis and Ord, 1992). Data statistical analyses were carried out using statistical software IBM SPSS Statistics Version 25.0 and Microsoft Excel 2013.

RESULTS

Rainfall Characteristics

From September 2015 to October 2017, 25 rainfall events were measured with a cumulative rainfall of 784.8 mm (CV= 63.2%). The rainfall events were divided into four *GR* classes: < 15, 15-30, 30-50 and > 50 mm. There were 3, 12, 5, and 5 rainfall event at each rainfall class, respectively, which accounted for 2.9, 34.1, 21.7, and 41.3% of total rainfall events, respectively (Figure 3). Fifteen rainfall events (37.6%) were less than 30 mm (295.4 mm cumulatively) and the remaining (62.5%) exceeded 30 mm (490.6 mm cumulatively). Rainfall events ranging from 15 to 30 mm were the most frequent (48% of total events) and accounted for 34.1% of the cumulative rainfall during the study period. Small rainfall events (< 15 mm) were infrequent (12% frequency) and contributed only 2.9% of the total cumulative rainfall. Five large storms (> 50mm) were recorded but they accounted for 41.3% of the cumulative rainfall (Figure 3). In addition, rainfall

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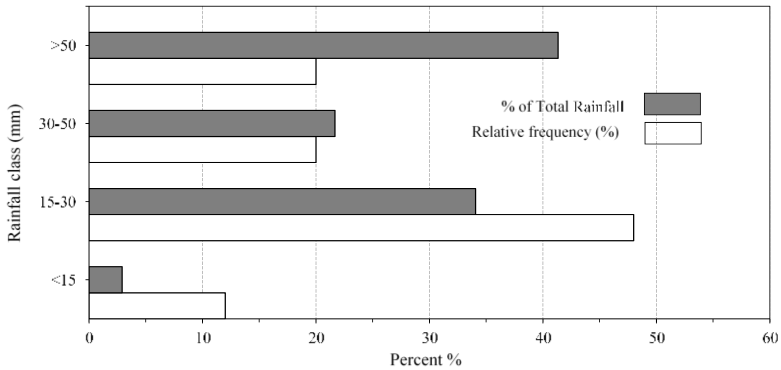

Figure 3. Relative frequency of rainfall events for four rainfall classes (white bars) and relative contribution of each rainfall class to the total rainfall amount (grey bars) during the study period from September 2015 to October 2017.

events ranging 15-30 and 30-50 mm were more common in the summer (67 and 60%, respectively) and rainfall events more than 50 mm and lower than 15 mm were more frequent in the fall (100%) and spring (67%), respectively. The average rainfall intensity for *GR* classes of < 15, 15-30, 30-50 and > 50 mm was 0.4, 0.7, 1.1 and 2.1 mm h^{-1}, respectively.

Canopy Characteristics (*LAI* and Canopy Openness)

The mean *LAI* and canopy openness of the study plot measured vertically above each *TF* rain-collector during the leaf-out period on summer were 6 m^2 m^{-2} (CV%= 13.7) and 6.2% (CV%= 20.2), respectively. Spring had the mean *LAI* and canopy openness of 5 m^2 m^{-2} (CV%= 14.5) and 7.6% (CV%= 17.7), respectively. The canopy parameters value in the fall were 4.5 m^2 m^{-2} (*LAI*) (CV%= 14.1) and 7.9% (canopy openness) (CV%= 18.2). There was significant difference between *LAI* during the summer and both the spring and fall (independent t-test, t= 9.65, P< 0.001).

Spatial Variability of *TF* in Relation to Rainfall Characteristics

The mean *TF* depth derived from 122 rain-collectors was strongly correlated with *GR* (r^2= 0.98, P< 0.01) (Figure 4-a) and significantly correlated with event-based mean rainfall intensity (P< 0.01), although this correlation was weak (r^2= 0.3) (Figure 4-d). In contrast, the correlation with rainfall duration was weak and not significant (P=0.08) (Figure 4-g). Generally, *TF* depth increased with increasing *GR* depth and rainfall intensity (Figures 4-a, -d, and -g). The relationship between *TF*% and *GR*, rainfall intensity and rainfall duration was not significant (P> 0.05) (Figures 4-b, -e, and -h). There was a significant correlation between spatial variability of *TF* ($CV\%_{TF}$) with *GR* depth (P< 0.01) (Figure 4-c) and rainfall intensity (P< 0.01) (Figure 4-f), whereas the correlation with rainfall duration was weak and not significant (P= 0.6) (Figure 4-i). Generally, $CV\%_{TF}$ decreased and then stabilized with increasing *GR* depth and rainfall intensity (Figures 4-c and -f).

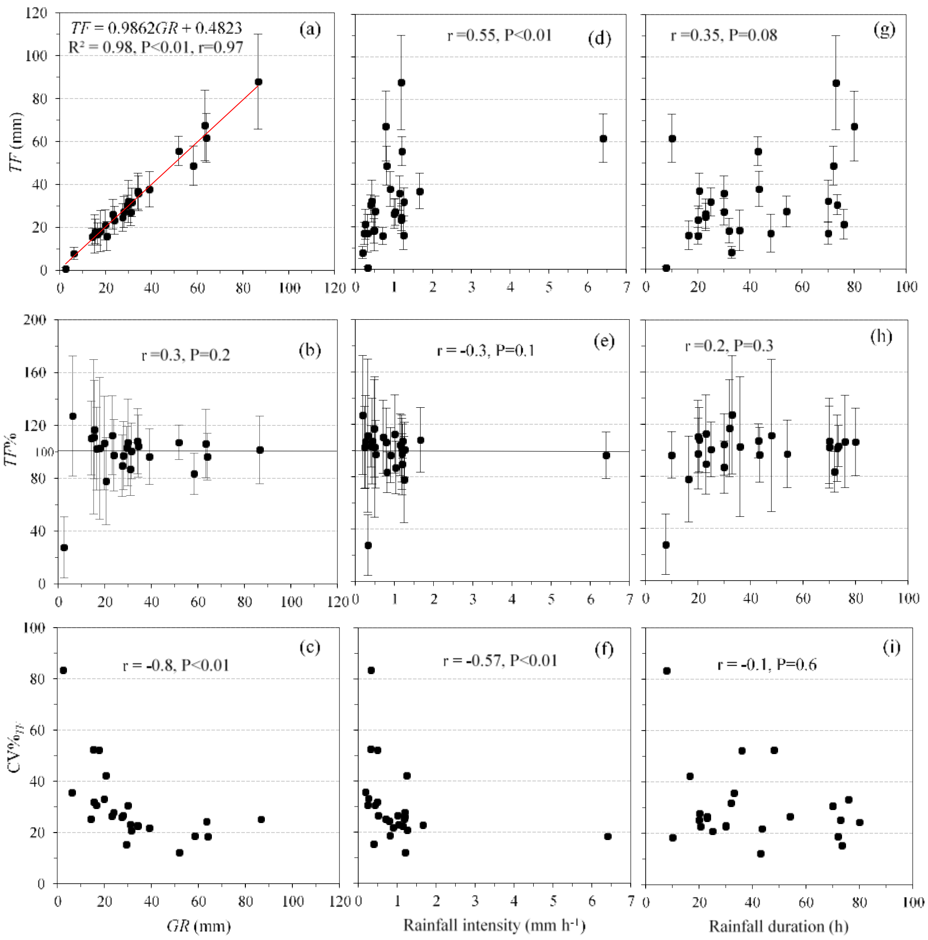

Figure 4. The correlation between mean values of throughfall (*TF*), *TF%*, $CV\%_{TF}$ with (a, b, c) gross rainfall (*GR*) amount, (d, e, f) rainfall intensity, (g, h, i) and rainfall durtion for individual rainfall events. Bars indicate ±standard error.

$CV\%_{TF}$ for each *GR* class was highest (48.1%) when the *GR* amount was lower than 15 mm (< 15 mm), and decreased to 33, 22.2 and 19.8% for *GR* classes of 15-30, 30-50 and > 50 mm, respectively (Table 1). The points with *TF* depth more than 100 percent (hotspot points) were highest for *GR* classes 15-30 and 30-50 mm and lowest for *GR* classes < 15 and > 50 mm (Table 1) that were more concentrated on the center of plot for all *GR* classes (Figure 5) where the large *DBH* trees were more frequent than the other parts of the study plot.

Temporal Persistence of Spatial Variability of *TF*

Time stability normalized *TF* plots indicate persistence of drier and wetter sampling points in the study area (Figure 6). Time stability plots using normalized *TF* were divided into four *GR* classes based on 20 mm thresholds. Each of these thresholds contained the same number rainfall events. Mean normalized *TF* for *GR* classes < 20, 20-30, 30-50, > 50 mm were significantly different from zero for 48, 42, 22 and 19% of the *TF* rain-collectors, respectively (t-test; α= 0.05), thus *TF* at individual sampling positions were not randomly distributed over time. With greater *GR*, the water flow paths in the canopy changed. For example, collector 103 had smaller *TF* with smaller *GR* but it received greater *TF* when the *GR* was larger (Figure 6). In contrast, collector 3 had greater *TF* when *GR*< 20 mm but it had much smaller *TF* in *GR* classes 20-30, 30-50 and > mm 50 (Figure 6).

Table 1. Mean, Standard deviation *SD*, Coefficient of variation of throughfall ($CV\%_{TF}$) and rainfall intensity for 122 *TF* rain-collectors for different gross rainfall *GR* classes.

GR classes (mm)	< 15	15-30	30-50	>50
Mean (mm)	7.6	22.3	34	64.9
SD (mm)	2.4	7.1	7.5	13.2
$CV\%_{TF}$	48.1	33	22.2	19.8
Rainfall intensity (mm h^{-1})	0.4	0.7	1.1	2.1
No of Hotspot point	5	12	9	5

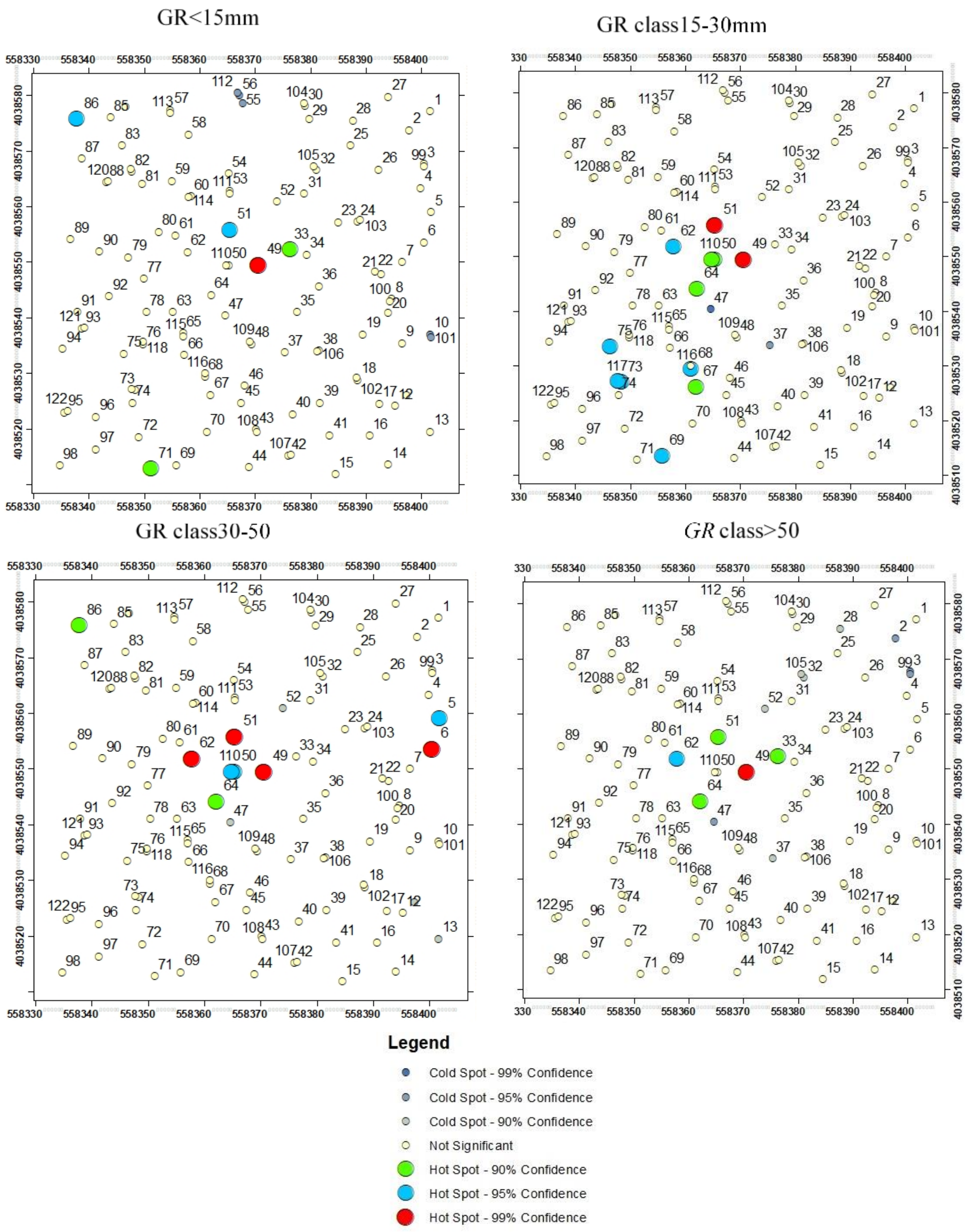

Figure 5. Spatial distribution of hotspot points under the oriental beech canopy for *GR* classes. Red, green and blue squares are hotspot points at three significant levels.

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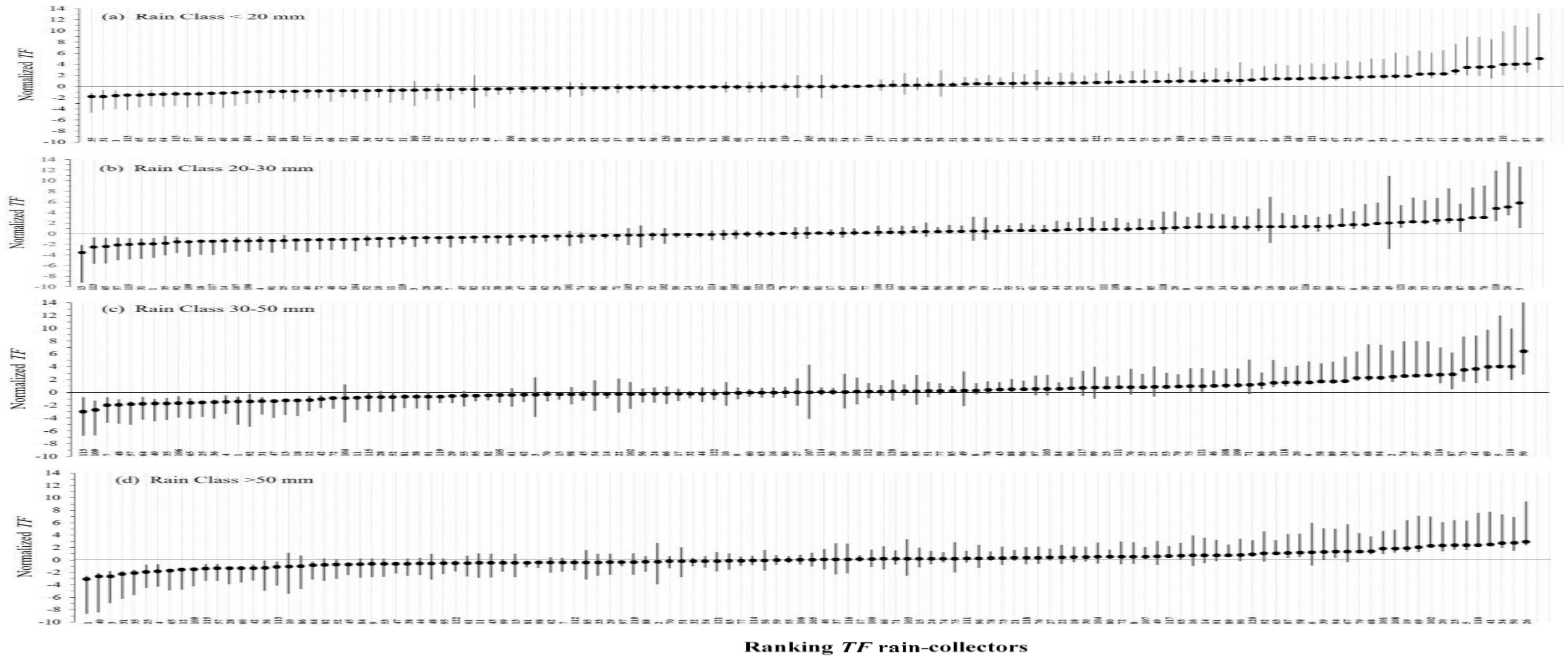

Figure 6. Time stability plots for normalized throughfall (*TF*) water amount to zero median in gross rainfall (*GR*) classes (a) < 20 mm (events 7, 8, 12, 13, 15, 17, 18, 19), (b) 20-30 mm (events 4,5,6,16,20,21,25), (c) 30-50 mm (events 1, 2, 9, 10, 11), and (d) > 50 mm (events 3, 14, 22, 23, 24). Each dot represents one *TF* rain-collector plotted along the horizontal axis and ranked by their means. Bars indicate 95% confidence intervals. Bars of for each data point indicate the stability of *TF* rain-collectors. data points with bars that do not overlap with the median line (horizontal line at zero) are extreme persistent whereas data points with bars that intersect the median line are general persistent (Zimmermann *et al*., 2008)

DISCUSSION

Spatial Variability of *TF*

The increase of *TF* production with increasing rainfall depth may result from longer periods when the canopy is saturated, thereby increasing the amount of rainwater falling to the ground as *TF* (Carlyle-Moses *et al*., 2004). For smaller rainfall events, the interaction of rainwater with forest canopy likely restricts *TF* to free *TF* (without contacting the canopy). Released *TF* (dripping from leaves and branches) becomes dominant when *GR* is larger than the canopy saturation point (Zhang *et al*., 2016, Gash, 1979). Similar to past research (Loustau *et al*., 1992, Zhan *et al*., 2007, Huitao *et al*., 2012, Fathizadeh *et al*., 2014, Fan *et al*., 2015), the variability of *TF* ($CV\%_{TF}$) decreased with increasing *GR* (Figure 4-c).

Past work on the relationship between spatial variability of *TF* (as *CV*%) and cumulative rainfall suggests that larger rainfall events would have a more homogenous redistribution of rainfall (e.g., Loustau *et al*., 1992, Huitao *et al*., 2012, Li *et al*., 2013, Carlyle-Moses *et al*., 2004, Fan *et al*., 2015). In addition, the lower variability of *TF* for large *GR* may be attributed, in part, to a greater *GR* intensity that saturates the canopy in a short time (Zhan *et al*., 2007). Typically, as rainfall intensity increases, the CV of *TF* initially declines and then stabilizes (Zhang *et al*., 2016).

In the present study, the $CV\%_{TF}$ of *GR* events < 15 mm was highest and for *GR* events > 50 mm was lowest. Both *GR* events > 50 and < 15 mm were more frequent in fall season with fairly similar *LAI*. It shows that the impact of canopy characteristics (e.g. spatial variability of canopy storage) is more diverse among different rainfall regimes. When the canopy is fully saturated for higher *GR*, both free *TF* and released *TF* participate in *TF* production with lower variability.

Input points producing hotspots were more common for *GR* classes 15-30 and 30-50 mm, whereas they decreased in *GR* classes < 15 and > 50 mm. Our results showed that 67% of rainfall event from 15 to 30 mm and 60% of rainfall event from 30 to 50 mm occurred in summer. On the other hand, 100% of rainfall events larger than 50 mm and 67% of rainfall smaller than 15 mm occurred in the fall. Therefore, the hotspots were likely related to both changes in rainfall and canopy characteristics. Yousefi *et al*. (2018) reported that hotspots were more frequent in leaf-out period compared with leaf-off condition. Hotspots in forest ecosystem that are dependent on *TF* tend to enhance drainage to the forest floor (Coenders-Gerrits *et al*., 2013, Hopp and McDonnell, 2011). Hence, the whole leaves and branches of the canopy may direct rainfall downward to allow for easy drainage of the *TF* during fully leafed conditions.

Time Stability of *TF* Spatial Variability

Mean normalized *TF* for 55% of the *TF* rain-collectors in the present study were significantly different from zero, thereby indicating high *TF* heterogeneity during the leafed period. Zimmermann *et al*. (2007) reported 68% *TF* heterogeneity in a tropical montane forest in Ecuador. Keim *et al*. (2005) showed 31-46% of collectors represented mean normalized *TF* different than zero in two conifer stands and one deciduous stand at leafed and leafless periods in the Pacific Northwest, USA. We found that the percent of *TF* rain-collectors with mean normalized *TF* different from zero was highest for *GR* class < 20 mm (48%) and lowest for *GR* class > 50 mm (19%), indicating *TF* heterogeneity decreases with increase in rainfall, supporting the claim of lower *TF* variability ($CV\%_{TF}$) for large rainfall events. Gómez *et al*. (2002) reported that the distribution of *TF* for large *GR* events were consistent, while there was no consistency of *TF* distribution in the smaller *GR* events under

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individual olive trees. Time stability plots indicated the switching of wet and dry collectors with changing *GR* class (e.g. collectors 3 and 103) might result from a change in the *TF* flow path. Therefore, changing *GR* under climate change or different seasons can affect *TF* flow path under the canopy.

Our results indicate that there was high temporal stability and low spatial variability of *TF* for high *GR* classes. The decrease in temporal stability and lower spatial variability suggests that canopy characteristics are less important as *GR* increases. Robson *et al*. (1994) suggested the effect of event size was possibly as important as variation in canopy structure characteristics on the stability of the *TF* spatial pattern. However, we found that fully developed canopy cover were more effective in creating hotspots of *TF* than different *GR* depth.

Changing climate has significantly altered *GR* characteristics around the globe (Huntington, 2006). Climate-change-induced effects on *TF* variability are especially important to forest ecosystems in the north of Iran. These forests have steep mountain slopes that are sensitive to soil erosion when water is locally in excess and forest regeneration partially depends on *TF* inputs (Akbarzadeh *et al*., 2016). Changing precipitation patterns may affect the spatial variability of *TF* and, therefore, affect ecological processes throughout a forest stand (Manderscheid and Matzner, 1995, Raat *et al*., 2002). Indeed, the spatial heterogeneity of *TF* may improve the calculations of percolation fluxes and the downward movement of water through the soil, in these beech stands (Beier, 1993). Generally, studies on the spatial and temporal variability of *TF* and its associated driving factors will increase our understanding of hydrologic and biogeochemical cycles of forest ecosystems that will permit better stewardship of forest and water resources (Levia and Frost, 2006). *TF* is an important water source for trees. A changing climate and/or tree harvesting may lead to changing *TF* distributions, ultimately altering the spatial distribution of water input to the soil. Therefore, fully understanding the spatial distribution of rainfall within forests under different *GR* depth helps the managers to optimize the management of these stands in terms of soil water and nutrition availability. Also, this study would help future investigators to design sampling strategies of *TF* based on different rainfall regimes by taking a look at canopy in these natural beech stands under similar climate conditions.

CONCLUSIONS

The spatial variability and temporal stability of *TF* as well as its correlation with rainfall characteristics and canopy traits were analyzed under a natural beech stand. In terms of rainfall characteristics, the spatial variability of *TF* tended to be high for the *GR* size class lower than 15 mm and decreased with increasing *GR*. During larger rainfall events, the canopy was fully saturated, resulting in decreasing of spatial variability of *TF*. The size and the variability of *TF* were more correlated to rainfall intensity and the size of *GR*. Based on time stability plots, the observed spatial variability was temporally stable for each *GR* class and temporal stability increased with increasing *GR*. The number of hotspots decreased for the highest and lowest *GR* classes (> 50 and < 15 mm, respectively) that were more frequent rainfall events in the fall and spring season when the *LAI* was lower. This indicates that the vertical and horizontal structures of forest canopy when fully developed in the summer season (when *GR* ranged between 15-50 mm) create stable water flow paths in the canopies that generate more persistently wet and dry areas in this forest. The present study suggests that spatial variability and time stability of *TF* were more related to rainfall characteristics than canopy traits. The canopy characteristics appears to play an important role in transferring water flow path to the

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ground when the canopy is fully developed in the beech stand, creating input points as hotspots of *TF* in different *GR* classes. This research could help the forest managers to optimize the management of these stands in terms of soil water and nutrition availability. The outcome of this research would assist future investigators to better sampling design strategies under different water input affected by climate change or in various seasons in these natural beech stands under similar climatic conditions.

ACKNOWLEDGEMENTS

This research was financially supported by the Iran National Science Foundation (INSF), Grant No. 95850072. The authors would like to thank Reza Olad Marzban, Kheyrud forest guard, for his assistance in field measurement. Special thanks go to Dr. Vahid Etemad, for preparing necessary data related to Kheyrud forest research station. We are grateful to Hamid Soofi Mariv for arranging the map of the research area.

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تغییرات زمانی و مکانی تاج بارش توده راش (*Fagus orientalis* Lipsky) خالص در جنگل‌های هیرکانی شمال ایران

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چکیده

تغییرات زمانی و مکانی تاج بارش در بوم‌سازگان‌های جنگلی مفاهیم بوم‌شناسی مهمی دارد. در این پژوهش تغییرپذیری مکانی و زمانی تاج بارش و نیز اثرات تاج‌پوشش و خصوصیات باران بر تغییرات تاج‌بارش ارزیابی شدند. نمونه‌برداری‌های باران و تاج بارش از مهر ۱۳۹۴ تا مهر ۱۳۹۶ در زمان رشد کامل برگ درختان تا قبل از شروع خزان برگها در توده طبیعی راش (*Fagus orientalis*) خالص واقع در سری بهاربن جنگل آموزشی پژوهشی دانشکده منابع طبیعی دانشگاه تهران (جنگل خیرود) انجام شد. میانگین شاخص سطح برگ توده (*LAI*) و درصد روشنه تاج پوشش در فصل برگدار به

ترتیب ۶ و ۶/۲ درصد برآورد شدند. تراکم درختان در توده ۱۸۸ درخت در هکتار با سطح مقطع ۵۱ مترمربع در هکتار، اندازه‌گیری شد. در طول دوره مطالعه، ۲۵ رخداد باران با مقدار تجمعی ۷۸۴/۸ میلیمتر ثبت گردید. تغییرات الگوهای مکانی تاج بارش در چهار کلاسه باران ۱۵>، ۳۰-۱۵، ۵۰-۳۰ و <۵۰ میلیمتر در طول دوره مطالعه مشاهده شد. مقدار تاج بارش و تغییرات مکانی تاج بارش (ضریب تغییرات تاج بارش ($CV_{TF}\%$))، با افزایش عمق باران و شدت بارندگی به ترتیب افزایش و کاهش معنی‌دار داشت ($P<۰/۰۱$). پژوهش حاضر نشان داد عمق باران و شدت بارندگی را می‌توان به عنوان مهمترین فاکتورهای اثرگذار بر مقدار، تغییرات مکانی و ثبات زمانی تاج بارش دانست. شناخت تغییرات مکانی و ثبات زمانی تاج بارش، به مدیران جنگل در اجرای عملیات پرورشی به منظور مدیریت بهینه توده‌های جنگلی یاری خواهد کرد تا درک بهتری از پراکنش مکانی تاج بارش رسیده به کف جنگل، از لحاظ دسترسی خاک جنگل به آب و مواد غذایی داشته باشند.

[DOR: 20.1001.1.16807073.2019.21.7.17.8]