Original Research

Effect of Heavy Rain Conditions on Throughfall in Evergreens and Conifers in Urban Settings

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Abstract

Recently, an increase in precipitation defined as extreme rains has been recorded in many parts of the world. These rains have become a risk factor because of their characteristic duration, intensity, and amount, and the increased hazard of runoff and flooding, especially in urban settings. This study investigated throughfall caused by heavy rains of long duration (>5 h) and in high amounts (>10 mm) under broad-leaved evergreen and coniferous species in urban settings. In the study, throughfall was determined for a total of eight samples, four individuals from two different broad-leaved evergreen tree species and four individuals from two different coniferous tree species. During the eight-month study period, 11 rain events distributed over 20 days were evaluated. Findings showed that 61.88% and 55.24% of the throughfall was measured under the broad-leaved evergreen and coniferous species, respectively. Heavy rains did not make a difference between the throughfall under the broad-leaved evergreen and coniferous species ($p>0.05$). Likewise, there was no difference in the throughfall in the broad-leaved evergreen and coniferous species after the increase in duration and amount of heavy rains ($p>0.05$).

Keywords: throughfall, broad-leaved evergreen, coniferous, heavy rainfall, urban setting

Introduction

Interception, as one of the important components of the hydrological cycle, can be briefly defined as the part of the rainfall falling to the ground that is retained by plants and then either evaporates back to the atmosphere or again falls from the leaves to beneath surface. In its simple form, interception can be determined through the difference between the net rainfall caused by the throughfall and the stemflow and the total rainfall in an open area [1-3]. The amount of rainfall lost through interception in different geographies and among different tree species varies between 9% and 60% of the total rainfall [4]. Many factors have an impact on throughfall and stemflow, and thus on interception [5]. It is possible to collect these factors under the main heading of tree qualities and climatic characteristics [6]. Among tree qualities that are effective on interception, leaf and canopy features generally affect the throughfall [7, 8], whereas trunk and branching features affect the stemflow [9, 10]. Many climatic characteristics affect throughfall, including the amount of precipitation [7, 11-13], duration [13-15], intensity [7, 12, 16, 17], frequency [16], and annual distribution [14]. In addition to the effect of the precipitation features, the leaf and canopy properties of the trees also have an effect

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[3,18]. Precipitation that occurs during the leafless period normally creates more throughfall, especially for deciduous broad-leaved species [4, 11, 19, 20]. In this form, the trees' lack of protection by the leaves or dense canopy as well as the amount and duration of precipitation at that time of the year, especially in temperate climate zones, are also effective. In the leafless autumn period and early spring, the number, duration, and amount of rain are all higher than in the summer period. The throughfall caused by these rains in broad-leaved evergreen and coniferous species is the determining factor in terms of interception [3]. Deciduous species usually produce higher throughfall.

When the entire year is considered, broad-leaved evergreen and coniferous species are known to generate less throughfall and more interception than broad-leaved species [5]. However, the behavior of broad-leaved evergreen and coniferous species in similar environmental and climatic conditions during heavy rains is only superficially known. More detailed information is needed about the similarities and differences between them in terms of interception and throughfall behaviors. Although the rate of interception among varieties of the same tree can be quite uneven [21], the interception rate can also be quite variable in trees with the same leaf area index [17]. In this respect, more details are needed regarding both the precipitation characteristics and the throughfall behavior of different tree morphologies during heavy rains. However, little information is available on the behavior of interception-throughfall relations during extreme rainfall and therefore, there is a need for many more studies on the subject [22].

Studies on hydrological cycle parameters such as interception, throughfall, and stemflow are generally carried out under forest or stand conditions [23]. However, it is known that forest or stand ecosystems differ from the urban environment [3]. On the other hand, throughfall, which is much more effective on surface runoff than stemflow, is also important in terms of risk management under urban conditions [24-26] and urban hydrology [27-30]. One of the points emphasized is that sudden and extreme rainfalls can create faster runoff in urban settings than in rural areas [29, 31]. This situation poses risks in terms of densely populated cities, and may result in greater property loss and infrastructure damage [32, 33]. At this stage, it is important for decision makers to consider a correct combination regarding plants/trees, soil, and water. However, decision makers lack sufficient information and data concerning the relationships between tree species, their capabilities, and their effects on runoff in cities [34-36]. This situation indicates that more studies are needed to examine the relationship of interception and throughfall with plant characteristics under urban conditions [37, 38]. However, in recent years, there has been an increase in studies elaborating on interception, throughfall, and stemflow, both in urban settings [28,

29, 39-42] as well as on the scale of individual trees [11, 24, 35, 42, 43].

Although many studies have been carried out on throughfall, there are still elements that need to be clarified. For example, Levia et al. [5] reported that the transition of throughfall from upper forest canopy to forest soil is not clearly understood, and that among the factors involved are the throughfall characteristics of deciduous (deciduous-evergreen) and coniferous species. Undoubtedly, many factors have an effect on throughfall, but it is generally accepted that the most important factor is the canopy structure and branch architecture [5]. In this respect, the effects of the canopy qualities of the broad-leaved evergreen and coniferous species are important in terms of throughfall.

This study aimed to contribute two important points about throughfall. The first was whether there is a difference in terms of throughfall characteristics between the broad-leaved evergreen and coniferous species that both retain leaves throughout the year, and the second was how heavy rains in high amounts and of long duration are effective on throughfall. To this purpose, the study investigated the throughfall characteristics of the broad-leaved evergreen species and coniferous species in an urban setting under heavy rain conditions. At the same time, the study evaluated the effects of increased amounts and duration of rainfall on the throughfall under the broad-leaved evergreen and coniferous species.

Material and Methods

Study Area

The study was carried out in Eregli, located in the north of Turkey on the Black Sea, 45 km away from the provincial capital city of Zonguldak. Eregli is a coastal city under the administration of Zonguldak province, with an average annual rainfall of 1163 mm and an average temperature of 13.7ºC [44]. December and November are the months having the highest rainfall, with an average of 150.6 and 142.4 mm, respectively, whereas May, with an average of 46.2 mm, is the month with the least rain [45].

The study was carried out within the boundaries of the Eregli Forest Management Directorate Campus, in a closed area isolated within the study environment. The study area, which contains many tree species, was chosen because it allowed the throughfall data to be controlled and the equipment and assemblies to be protected during the study (Fig. 1). In forests and stands it is very rare to find small areas that have trees of different species and arrangements where precipitation characteristics and topographic factors do not vary. By choosing such a campus area, variations in rainfall possibly caused by climate and topographic elements were minimal.

Fig. 1. Study area, aerial view of trees (O1-O4 evergreen, X1-X4 coniferous) and rain gauge (R) located in an open area.

Determination of Rainfall and Throughfall

A rain gauge (Wilh. Lambrecht KG Göttingen, Germany) installed in an opening in the study area was used to determine the total rainfall (Fig. 1). The rainfall on the open area was determined by the rain gauge, whose water collection area was established by proportioning the area in square meters. It was duly installed in an area where there were no trees surrounding (Fig. 2a). The study covered the period from the beginning of November 2018 to the end

of June 2019. The amount and duration of each rain event occurring during this period was determined and recorded. As the study aimed to reveal the effect of heavy rains, rains with a quantity of <10 mm were not taken into consideration. A 4-h period without precipitation between two rains, and rains with no rainfall of at least 4 h between them were considered to be the same rain event [16, 24].

In the study area, a total of eight trees were selected: four of the broad-leaved evergreen species and four of the coniferous species, all being suitable
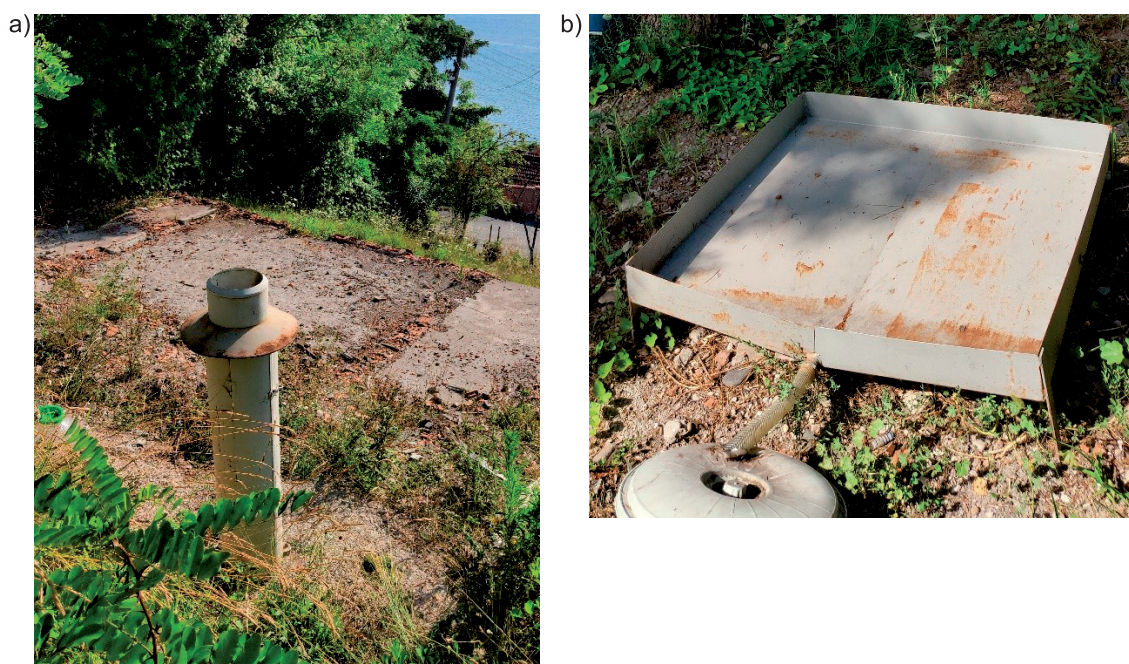

Fig. 2. a) Rain gauge installed in the study area; b) assemblies used to determine the throughfall.

Table 1. Some information about evergreen and coniferous trees.

Common name	Botanical name	Leaf type	Altitude (m)	TH (m)	DBH (cm)	PCA (m²)	LAI
Laurel	*Laurus nobilis* L.	E	17	6	27	23.76	3.07
Laurel	*Laurus nobilis* L.	E	19	7	32	26.88	1.92
Holm oak	*Quercus ilex* L.	E	19	8	30	36.58	1.77
Holm oak	*Quercus ilex* L.	E	18	10	46	67.93	2.02
Lebanon cedar	*Cedrus libani* A. Rich	C	27	16	42	35.78	1.29
Lebanon cedar	*Cedrus libani* A. Rich	C	19	12	30	35.25	2.09
Black pine	*Pinus nigra* Arnold.	C	22	14	42	36.05	1.57
Black pine	*Pinus nigra* Arnold.	C	21	15	50	50.90	2.03

TH: Tree height, DBH: Diameter at breast height, PCA: Projected canopy area, LAI: Leaf area index, E: Evergreen, C: Coniferous

for the purpose and not posing measurement problems (Fig. 1). The throughfall was determined using the assemblies installed under these trees (Fig. 2b). The metal assemblies used in determining throughfall were designed as square-shaped and 1×1 m in size. On all four corners there were 30-cm tall metal feet fixed to the ground. The sides were 15-cm high in order to prevent drops splashing in from the outside and to stop drops falling from the tree from splashing out. To ensure fluidity, these throughfall holding devices were positioned on the ground at an angle of 2%. There was an outlet channel in the center of the front part of the assemblies and from this point the rainwater throughfall was transferred to 50-liter collection tanks via a drainpipe. These tanks were covered with a lid and were not affected by any raindrops splashing from the tops or sides. The idea of using a larger surface area to catch throughfall was effective in choosing this type of collection device for the study instead of the standard rain gauges for determining the throughfall. Since the area of the collection devices was 1 m², the accumulated throughfall was directly evaluated in the form of rainfall (mm) per unit area (square meter). For

this reason, no multiplication or correction coefficient was applied to the amount of throughfall determined over the setup.

Characteristics of Tree Species

For the purpose of the study, the throughfall was determined for a total of eight trees, four each of the broad-leaved evergreen and coniferous species. Two of the broad-leaved evergreen trees (O1-O2) selected were laurel (*Laurus nobilis* L.) and the other two (O3-O4) were holm oak (*Quercus ilex* L.). Two of the coniferous species (X1-X4) selected were cedar (*Cedrus libani* A. Rich) and the other two (X2-X3) were black pine (*Pinus nigra* Arnold.) (Fig. 1). Information on some characteristics of the selected broad-leaved evergreen and coniferous species is given in Table 1.

Statistical Analysis

Any differences in throughfall between the broad-leaved evergreen and coniferous species were
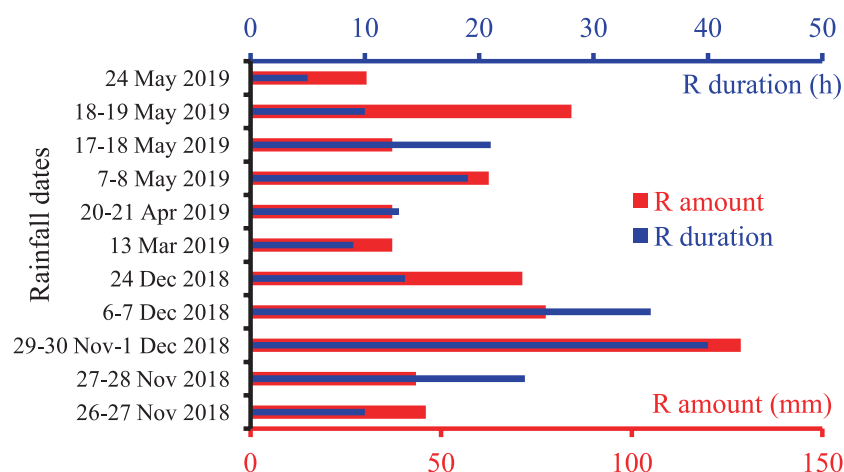

Fig. 3. Rainfall dates, amounts, and durations.

Table 2. Throughfall amounts, averages, and ratios to total precipitation in evergreen and coniferous species.

Leaf Type	Total TF Amount (mm)	Average (mm)	Rainfall / TF Rate (%)
E	405.59	36.87±26.36 a*	61.88
C	362.06	32.91±26.29 a*	55.24

TF: Throughfall E: Broad-leaved evergreen, C: Coniferous; * $p>0.05$ (same letters in the columns indicate values are not significantly different)

determined by the t-test. Possible throughfall differences between broad-leaved evergreen and coniferous species depending on rain amount and duration were also determined by the t-test.

Results and Discussion

Rain Characteristics

During the study, a total of 11 throughfall-generating rain events with an amount >10 mm were evaluated. A total of 655.46 mm of rain fell during these rain events, which were spread over 20 days. The lowest amount of rain was 30.47 mm on 24 May 2019 and the highest amount was 128.61 mm with three days of rain on 29-30 November and 1 December 2018. The total duration of the rain was 199.5 h, and the average duration of the 11 rain events was 18.14 h. The rain events with the shortest and the longest duration were also the rains having the lowest and the highest amounts. They lasted 5 and 40 h, respectively. Details regarding the dates, amounts, and durations of the rain events are shown in Fig. 3.

Throughfall

In two of the 11 rainfall events (27-28 Nov 2018, 24 Dec 2018), the coniferous species produced higher throughfall, whereas in nine, the broad-leaved evergreen species generated higher throughfall.

After heavy rains, the total throughfall amount, average value and the ratio of throughfall to total precipitation were, respectively, 405.59 mm, 36.87 mm, and 61.88% for the broad-leaved evergreen species, and 362.06 mm, 32.91 mm, and 55.24% for the coniferous species. The results of the t-test revealed that no difference was found between the broad-leaved evergreen and coniferous species in terms of throughfall (Table 2).

According to the average throughfall results at the species level for the broad-leaved evergreen and coniferous leaves, the highest amount was 423.25 mm (64.57%) for the oak, followed by the laurel with 387.93 mm (59.18%). The throughfall amounts of the coniferous species placed after the broad-leaved evergreen species in the ranking, with 384.73 mm (58.70%) and 339.40 mm (51.78%) in the pine and cedar, respectively (Fig. 4). For a total of 11 rainfall events, the oak and laurel produced the highest throughfall four times, whereas the pine produced the highest throughfall twice and the cedar once. In the rain events, the cedar produced the lowest amount of throughfall five times, whereas pine and laurel produced the lowest amount of throughfall three times. The oak did not produce the lowest amount of throughfall in any of the 11 rainfall events.

Conditions affecting throughfall from individual trees in settlements and cities vary, with conditions affecting throughfall in urban forests varying more. Certainly, there are different conditions for natural forests and stands. As a matter of fact, Inkilainen et al. [46] stated that throughfall varied a lot in urban settings and moreover, there was a difference among seasons in terms of throughfall. In this study, the throughfall was 61.88% in the broad-leaved evergreen species and 55.24% in the coniferous species (Table 2). When studies carried out in urban conditions were evaluated, variations were seen in terms of results. However, it is possible to state that coniferous species produced
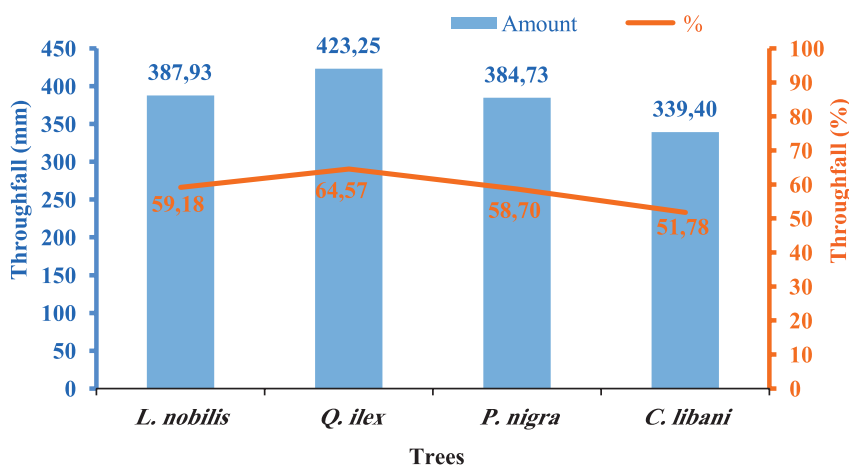

Fig. 4. Throughfall amount and percentage rates in evergreen and coniferous species.

Table 3. Mean throughfall from evergreen and coniferous species of gross rainfall for different rainfall characteristics.

Throughfall (mm)	Rainfall characteristics			
	Amount (mm)		Duration (h)	
	10-50	>50	<15	>15
	n = 24	n = 20	n = 24	n = 20
E	20.98±5.27 a	54.59±28.18 a	28.90±17.48 a	46.82±30.58 a
C	16.74±9.92 a	53.46±27.58 a	26.63±19.40 a	38.38±33.32 a

E: broad-leaved evergreen, C: coniferous; ± figures are mean standard deviation (same letters indicate no statistical difference between columns)

lower amounts of throughfall than broad-leaved evergreen species. Asadian and Weiler [43] reported 46.2% throughfall under western red cedar and 50.1% under Douglas fir in an urban environment. In recent studies it was stated that 53% [47] and 33.7-54.6% [48] throughfall occurs under pine and cypress trees, respectively. On the other hand, in other studies, the broad-leaved evergreen species were found to produce throughfall of around 57% [41], cork oak to generate 58% [16], and lemon to produce 71% [34].

When the throughfall formed under broad-leaved evergreen and coniferous species in forests or stands are compared, results stand out as similar to the situation in urban settings. In general, the rate occurring under broad-leaved evergreen species was higher than that of coniferous species. The throughfall was determined as 56.6% under the broad-leaved evergreen species of holm oak [49], 61.2% under maquis (sclerophyllous species) [50], and 82% under a broad-leaved evergreen species-dominated stand in northern Thailand [51]. Su et al. [52] reported an average of 84.8% throughfall under broad-leaved evergreen and mixed-deciduous stands in China, whereas Oyarzun et al. [53] stated that the throughfall value under broad-leaved evergreen stands varied between 64% and 87%. On the other hand, throughfall for coniferous species was reported as 55% under ashe juniper [54], and 59.4% under mixed spruce-fir-pine stands [55].

When a general evaluation was made, the coniferous species were found to generate less throughfall than the broad-leaved evergreen species, in both urban and forest-stand settings. This study produced a similar result in terms of throughfall amount. The coniferous pine and cedar trees produced less throughfall than the broad-leaved evergreen laurel and holm oak (Fig. 4). However, prior to the study, it was predicted that heavy rains would generate a higher rate of throughfall in both the broad-leaved evergreen and the coniferous species.It seems that this prediction did not come true. Compared to forests or stands, in urban settings, the fact that the trees are much more in the open may have increased the evaporation efficiency and interception. Intense heat-reflecting materials such as concrete, asphalt, and roofing that are pervasive in the urban environment may have had an effect on increasing interception.

Relation of Throughfall with Rain Amount and Duration

The amount and duration of the rains were divided into two groups and their relationships with throughfall in the broad-leaved evergreen and coniferous species were determined. Accordingly, six rain events with a quantity of <50 mm and five rain events with a quantity of >50 mm were evaluated as different groups. The average value of <50 mm rains was 38.56 mm, whereas the average value of >50 mm rains was 84.81 mm. Six rain events with a duration of <15 h and five rain events with a duration of >15 h were evaluated as different groups. The average of the <15 h rainfalls was 10.08 h and the average of the >15 h rainfalls was 27.80 h. According to the amount and duration grouping, the coniferous species generated lower throughfall than the broad-leaved evergreen species. However, the difference between throughfall under the coniferous species and throughfall under the broad-leaved evergreen species was not statistically significant (Table 3).

Many studies have shown that there is a relationship between the increase in the amount of rain and the amount of throughfall [3, 12, 15, 56, 57]. Increased rain saturates the canopy water storage capacity, causing an increase in throughfall [58]. However, the main issue that this study sought to emphasize was whether a significant difference could be found in the amount of throughfall formed under broad-leaved evergreen and coniferous trees during conditions of heavy rain. The results demonstrated that this difference did not exist. Increasing duration and amounts of rainfall did not reveal a significant difference in throughfall between the broad-leaved evergreen and coniferous trees (Table 3). The fact that precipitation only in the form of rain was evaluated in this study may have been a factor in such a finding because snowfall was retained more in the above-ground parts of the coniferous species, creating a higher interception rate, which means a lower throughfall rate.

There have been not many studies that directly demonstrate the effect of rainfall amount and duration on throughfall under broad-leaved evergreen and coniferous species in urban settings in a comparative manner. This study was carried out in a campus area

and measurements were made under broad-leaved evergreen and coniferous trees situated only meters apart from one another. Therefore, it was predicted that climate and topography factors would have little opportunity to play a differentiating role on throughfall. The results can be evaluated as the reflection of the dynamics of the broad-leaved evergreen and coniferous species in terms of throughfall. Similar studies expanded by selecting a greater variety of broad-leaved evergreen and coniferous species would enable a more comprehensive assessment to be carried out on the subject.

Conclusion

In urban settings, rainfall in high amounts and of long duration has a greater effect on the formation of flooding and runoff. Throughfall is an important component of urban hydrology as a parameter that is effective on flood and runoff formation. This study compared the roles played by the amount and duration of rains in throughfall formation under broad-leaved evergreen and coniferous tree species in an urban environment. In the study, the throughfall rate from heavy rain was lower than predicted for both broad-leaved evergreen and coniferous species. The expected prediction of higher throughfall for both groups with the greater amount and duration of rainfall was not realized. On the contrary, with the increase in rainfall amount and duration, no difference was observed between the broad-leaved evergreen and coniferous species in terms of throughfall. Under conditions of heavy rain, the broad-leaved evergreen and coniferous trees exhibited similar throughfall behavior.

Acknowledgments

Conflict of Interest

The authors declare no conflict of interest.

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