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ANALYSIS OF INFILTRATION RATES OF SOILS ON THE INNER SLOPES OF THE LAKE SFÂNTA ANA CRATER

Péter SZMOLKA[1*] & Norbert FRANK[2]

[1]*Tg. Secuiesc Private Forest Management Office, str. Ady Endre nr. 13A, Tg. Secuiesc, Romania. Szmolka.Peter@phd.uni-sopron.hu; *corresponding author: Szmolka.Peter@phd.uni-sopron.hu*

[2]*University of Sopron, Faculty of Forestry, Institute of Silviculture and Forest Preservation, H-9400 Sopron Bajcsy-Zsilinszky u 4, Hungary. Frank.Norbert@uni-sopron.hu;*

Abstract: The present study consists of the comparative analysis of infiltration rates of soils under different land-cover conditions (dirt trails, grass plots and different types of forest stands) on the inner slopes of the Sfânta Ana crater, the catchment area of Lake Sfânta Ana in Romania. According to historical data, the depth and the surface of Lake Sfânta Ana have been undergoing significant changes during the last century, it lost in depth and the surface area shrunk approximatively 1,5 hectares. The losses are considered to be the consequences of the sedimentation as a result of the inflow processes from the catchment area, reduction of water level and eutrophication. The assessment and comparative analysis of steady infiltration rates of soils under different land-use categories in the catchment area were carried out to identify the possible sources of generation of surface flows responsible for sediment transport towards the lake using In Situ determinations with Double Ring Infiltrometers (DRI). Statistically significant differences were found between samples collected from grass plots, forests and the dirt trails, and within different forest stand structures. Results show that dirt trails and grass plots can be held responsible for the generation of surface flows. The main cause of low infiltration rates is soil compaction. Different forest stands are characterized by steady infiltration rates with high values and therefore provide effective protection. High forest coverage must be maintained in the crater, the problem of soil compaction on grass plots and dirt trails must be addressed.

Keywords: infiltration rate, soil compaction, double ring infiltrometer, surface flow, Sfânta Ana, Ciomatu

1. INTRODUCTION

Lake Sfânta Ana is one of the most popular tourist destinations in Romania. The lake, that took being in the Sfânta Ana crater of the Ciomatu volcano, is a Nature Conservation Site of National Interest and it is part of the Nature 2000 network (ROSCI0248 Tinovul Mohoș - Lacul Sf. Ana). During the last decades changes in perimeter, depth and water quality were documented, all these parameters of the lake have been decreasing. Conservation of Lake Sfânta Ana is only possible by maintaining morphometry parameters and improving the degraded quality of the lake's water. Studying the phenomena that can have an impact on the feeding components of the water budget is of great actuality, determination of the causes and mechanisms of processes that lead to the reduction of water level and deterioration of quality is of major importance. Identifying the sources of surface inflows with high sediment load during heavy rain events is perhaps of greater importance, but mapping the effectiveness of water intake for the various land-cover conditions contributes to the understanding of the soil protection value of these land use categories in the catchment area of Lake Sfânta Ana.

The geological and geomorphological properties of the lake catchment area the result of volcanic activity and the area is characterized by a particular evolution of the hydrologic, pedologic processes, topo-climate and vegetation. The anthropogenic impact is also notable, the lake is a popular tourist destination. Although bathing is forbidden, and waste collection is well managed, treading on the grass-plots of the lake-shore and the tourist trails can influence the hydrologic properties of these land-use categories. The future of Lake Sfânta Ana is closely related to the development of the catchment area.

The aim of the analysis is to identify conditions or local soil properties that favorize the occurrence of surface flows and the land-use categories that ensure a higher infiltration rate of water in soil, thus reduce the frequency and intensity of the unwanted processes. The effectiveness of protection against soil erosion due to significant differences in infiltration rates under the main stand conditions identified (beech stands, spruce plantations, small regeneration plots, where the mature beech were harvested) is also evaluated.

2. STUDY SITE AND RELATED LITERATURE

Geographically the research area is defined as the inner slopes of the Sfânta Ana crater found in the Ciomatu volcanic cone (Fig. 1). The Ciomatu mountain is situated in the Southeastern part of the Harghita Mountains, constituent of the Calimani-Gurghiu-Harghita volcanic chain, located in the Eastern Carpathians (Geografia Romaniei, 1987). The Ciomatu volcano is built up mainly by potassic dacites with pyroclastic deposits. The Mohoș and Sfânta Ana craters are the result of explosive volcanic eruptions. The latest eruption of the Sfânta Ana crater, is estimated to have taken place 29.500 BP (Harangi et al., 2010).

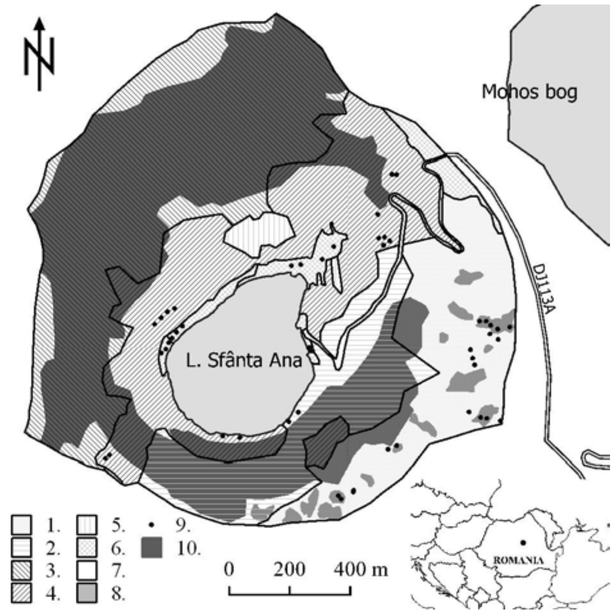

Figure 1. Map of Lake Sfânta Ana (Legend: 1. old even aged European beech stands; 2. uneven-aged European beech – Norway spruce – Silver fir; 3. middle-aged mixed stands; 4. middle-aged Norway Spruce; 5. young mixed stands; 6. grass plots; 7. paved roads; 8. small regeneration plots in European beech stands; 9. sampling sites; 10. areas with slopes exceeding 20º).

Lake Sfânta Ana is located 950 m. asl.

The study area is situated in the temperate continental climate, it is part of the topo climatic complex of the Eastern Carpathians.

The area is characterized by cold and wet winters, with a mean temperature of the coldest month below -4°C, and the mean temperature of the warmest month above 14°C. The annual mean temperature is around 5°C, the total annual precipitation is around 800 mm, the wettest period of the year is May - July, with less precipitation during the winter (Atlasul climatologic al R.S.R, 1966).

The main soil type in the study area is Andosol according to the Romanian Soil Taxonomy System 2012 (SRTS 2012), corresponding to Andosol according to the WRB 2014 system, with the profile horizons Au-AC-C (Au – A umbric humus accumulation horizon at 0-20 cm, AC – transition horizon between 20 and 30 cm, C – base material). The Au and A/C horizons show a sandy to sandy-loam texture, with humus content around 5%, pH 4.1, colors 10YR 2/1 in the Au horizon, 10YR 3/4 in the A/C and gravel content exceeds 10%.

The Sfânta Ana Crater has a total area of 202,5 ha, of which Lake Sfânta Ana occupies 9,3% with an area of 18.9 ha. The catchment area (183.6 ha) of Lake Sfânta Ana consists of the inner slopes of the crater), with an average slope of 20° (97.4 ha below 20° and 86.2 ha steeper than 20°), characterized by a variety of land-use categories. A great part of the catchment area is covered by forests (95.9%) and grass-plots (3%), the remaining area consists of dirt-roads, trails (0.3%) and the asphalt highway descending from the crater rim to the lakeshore (0.8%). Forests consist of old even-aged European beech (*Fagus sylvatica*) stands (32.1 ha of which 3.9 ha on slopes exceeding 20°), uneven-aged European beech – Norway spruce (*Picea abies*) – Silver fir (*Abies alba*) stands (25.3 ha of which 15.8 ha on slopes exceeding 20°), middle-aged Norway spruce (45.6 ha of which 10.4 ha on slopes exceeding 20°) and young to middle-aged mixed beech – spruce stands (73 ha of which 56.1 ha on slopes exceeding 20°) with participation of birch (*Betula pendula*), aspen (*Populus tremula*) and Goat willow (*Salix caprea)* in variable proportions. The young and middle-aged coniferous stands are of artificial provenience (plantations). The main natural forest ecosystem is *European beech with Oxalis-Dentaria-Asperula* flora according to the Romanian Forest Ecosystem Types Classification, 91V0 Dacian beech forests (*Symphyto-Fagion*) according to the Natura 2000 classification.

The maximum depth of the Lake Sfânta Ana was 8.3 meter at the end of the first decade of the 20th century, documented by Gelei (1909), who built the first depth-map of the lake. Jánosi did bathymetric measurements in 1971, his bathymetric map was published by Pál (2000). Pándi (2008) describes a 10% reduction in perimeter and a 4% reduction in the diameter of the lake, compared to the 1909 situation. Mihály, using the same measurement method as Gelei, measured less than 7.2 meters in 2018. By using an echo-sound method a maximum depth of 4.85 m was also recorded in 2001 by Pál. In spite of measuring depth from the actual water level, without having a common altitudinal reference point, and applying different methods, at least a one-meter decrease of lake depth can be concluded. The decrease in maximum water depth is considered to be a consequence of the decreasing water level and the fill-up processes (Mihály, 2018).

The major sources of water for the lake are considered to be precipitation and surface inflow during heavy rains or melting of snow. Subsurface inflow is not documented at the present time, although the possibility of this water source cannot be ruled out. The lake does not have permanent surface inflow sources. A water-budget equation for Lake Sfânta Ana was constructed by Gâştescu & Driga (1983), where changes in storage were described as a result of surface-inflow and precipitation equaled by subsurface outflow and evaporation.

Sedimentation rates in Lake Sfânta Ana were determined by Begy et al., (2011), results showed a mean linear sedimentation rate of 2.4 ± 0.4 cm/year. Their findings show that the process of eutrophication will probably transform the lake into a peat bog in approximately 300 years.

The environmental changes and water depth fluctuations of Lake Sfânta Ana during the Holocene were mapped by Magyari et al., (2009).

Water quality parameters have been declining in the past decade. Due to the growth of algae (a-chlorophyll content), the trophic state of the lake was not oligotrophic, but eutrophic, while, according to the OECD (Organisation for Economic Co-operation and Development) classification system, based on phosphorous content and water transparency (Secchi depth), the lake is mesotrophic (Máthé et al., 2018).

As the lake's bathymetric and water quality parameters are not independent of the processes taking place on the inner slope of the Sfânta Ana crater, studying water related processes, especially infiltration and its relations with land use and landcover type is of great actuality.

Relations between landcover and soil infiltration have been studied worldwide. Impact on important pedo-hydrological parameters were detected in the case of forest stands by changing species composition and stand structure during a forest transformation practice by Bens et al., (2007), showing different levels of hydraulic conductivity for different stands. The changes are attributed to soil development due to changes in microclimate, the quantitative and qualitative changes of plant litter, factors that induce soil development. Changes were detected in humus forms and the thickness of humous topsoil.

Changes of soil properties influencing infiltration rates occurred in the case of soils where forests were cleared for agricultural use and then abandoned, in comparison to the forested sites in the Canary Islands. Neris et al., (2012) showed that the decline of the aggregation percentage and structural stability led to substantially lower soil infiltration rates. Păltineanu et al., (2020) studied the steady state effluent rate in different types of soils, pointing out that movement of water and nutrients in the soil also depend on the physical properties of the subsoil and geological deposits towards the groundwater.

Chen et al., (2014) found that appropriate silvicultural interventions significantly increased soil infiltration rate and water storage capacity can be regulated by adjusting stand density in forest management.

3. METHODS

3.1. Plot setting

Sampling was carried out on slopes not steeper than 20° in three different land use categories: forests, grass-plots and dirt trails. Systematic, spatially even distribution of sampling points throughout the crater was not possible due to the limited accessibility with the equipment necessary to carry out the measurements.

In the case of forests three subcategories were differentiated: European beech stands, Norway spruce stands and small regeneration plots in beech stands. Stand biometric parameters (species, breast height diameters, tree heights, stem density/ha) were determined by forest inventories in sample plots for the stands studied.

The European beech forests studied are 130 years old even aged pure beech (*Fagus sylvatica*) stands, with mean surface area of G=43 m^2/ha, having mean breast height diameters of the surface area around 38 cm with corresponding heights of 32 m, canopy closure 80-100%, stand volumes around 730 m^3/ha and a mean stand density index of 0.96. These European beech stands are generally situated in the relative yield class II., according to the Romanian yield tables by relative yield classes as published by Giurgiu & Drăghiciu (2004), and are considered to be of medium productivity (current annual yield 8,6 m^3ha^{-1}). Beech stands are of natural regeneration provenience, but the even aged structure in the studied stands reflect the fact that silvicultural interventions were applied during the past century in these forests. Herbaceous flora consists of *Cardamine glanduligera*, *Pulmonaria rubra*, *Asperula odorata, Symphytum cordatum, Paris quadrifolia,* *Glechoma hederacea, Euphorbia amygdaloides, Cardamine bulbifera, Lamium galeobdolon, Oxalis acetosella, Myosotis sylvatica, Mercurialis perennis, Geranium robertianum.*

The Norway spruce (*Picea abies*) stands are 60-70 years old even aged pure stands, with mean surface area of G=58 m^2/ha, having arithmetic mean breast height diameters of the surface area around 30 cm with corresponding heights of 28 m, canopy closure 90-100%, stand volumes around 760 m^3/ha and a mean stand density index of 1.02. These Northern spruce stands are highly productive, situated in the relative yield class II., according to the Romanian yield tables by relative yield classes. Northern spruce stands are mostly of artificial regeneration provenience, consisting of even aged plantations, generally with high productivity (current annual yield 14.9 m^3ha^{-1}). The main herbaceous plant species are *Oxalis acetosella*, *Pulmonaria rubra, Luzula luzuloides, Vaccinium myrtillus, Geranium robertianum, Symphytum cordatum, Asperula odorata, Cardamine bulbifera, Stellaria nemorum*.

The small regeneration plots in beech stands, resulted from patch cuts executed in the year 2017 aiming to enhance natural regeneration of beech stands, are situated in the beech forests described above. They can be described as patches of diameters of 1 to 3 tree heights (30-80 meters). As mature stand was cut in these areas, the plots can be characterized by the presence of European beech seedlings of 0.5-2.5 m height with varying density covering at least 60-70% of the cut area. Species like European red raspberry (*Rubus idaeus*), blackberry (*Rubus hirtus*), stinging nettle (*Urtica dioica*) cover the unregenerated areas of the patches.

The lake shore is covered by herbaceous vegetation in some places, mainly in the eastern and northern parts of the shore. The main grass species in these degraded grass plots are *Festuca rubra, Poa pratensis, Poa annua*, *Dactylis glomerata*, etc. These areas are exposed to human activity by treading, although of smaller intensities than in the case of dirt trails. Soil is covered by herbaceous species in a continuous layer.

Intensive treading caused by tourism led to the development of dirt trails from the crater rim to the lake shore and a dirt road is running around the lake. These paths are characterized by the lack of vegetation cover, the uncovered soil surface is compacted by the constant flow of tourists. On trails developed on the steeper parts of the slope upper horizons of soil are eroded, in other parts soil is heavily compacted and tree roots are exposed, forming a barrier against further erosion. Traces of small surface flows can be detected, especially after heavy rains, leaves and spruce needles are displaced and aggregations of these plant parts are formed behind barriers (ex. roots exposed, with a perpendicular layout in relation to the direction of the slope). On the plain surface of the lake shore, in lower parts, surface is covered by mud formed from organic topsoil and the constant disaggregation of litter (mainly beech leaves and spruce needles) as a result of mechanical erosion caused by treading, mixed with mineral soil particles. Water is ponding in these areas during heavy rains.

3.2. Determination of soil infiltration rate

Water from the surface of the soil enters the soil during infiltration process and the amount of infiltration is the quantity of water entering below the surface of the soil. The measurement unit of infiltration rate is mmh^{-1}, representing the amount of infiltrated water for a period of time. The changes in time of the intensity of infiltration are expressed by the infiltration curve. The permeability of soils is determined by the amount of micro- and macropores and their distribution by size (Gombos, 2011). After a while the infiltration amount tends to become stable for a unit of time. This is called the steady infiltration rate. Different infiltration equations have been developed to model the infiltration process. If rainfall intensity exceeds the infiltration rate of the soils, water will accumulate on the soil surface and surface runoff will begin, causing transportation of organic matter and sediments resulted from erosion processes.

Double cutting-ring infiltrometers with float-valve control were used to determine steady infiltration rates, applying the constant head method. The advantage of double ring infiltrometers versus the single ring infiltrometers is the separation of the vertical component of the infiltration process, infiltration towards lateral directions is compensated by the infiltration of water from within the inner and outer cylinders. The internal diameter of the inner ring used was 220 mm, the diameter of the exterior ring was 380 mm. The height of the cylinders used was 400 mm. The infiltrometer rings were inserted into the soil vertically in a concentric way, at the depth of 150 mm. Insertion in the soil was done by hammering, with minimal disturbance of the soil and the litter horizon both inside the inner ring and the outer ring. In case of insertion on slopes (never exceeding 20°, where proper vertical insertion of the infiltrometer rings becomes difficult, with the risk of compromising the results), the 15 cm depth was achieved on the lower side of the inner ring. A nylon cloth was placed on the soil surface in the inner ring and between the inner and outer rings of the infiltrometer. A thin layer of fine sand was placed on the nylon cloth to reduce the effects of preferential flow through macropores as described by Zhang et al., (2017). A constant head of water of approximately 25 mm (measured in the geometric center of the inner ring) was maintained through the measurement process in the inner ring, and an equal level was ensured between the inner and outer rings using float-valves both in the inner ring and the inter rings area. Water was supplied from separate water tanks for the inner ring and the area between the inner and outer rings. Readings were taken for the inner ring through a calibrated sight-tube mounted on the side of the supply tanks. Measurements lasted until a constant infiltration rate was achieved, generally not more than 180 minutes. Infiltration rates (mm/h) were determined from water column drop (mm) readings in the sight-tube with observation of reading time (hours, minutes and seconds). As a significant amount of water was needed to execute measurements, the plots were chosen in areas where water could be brought to the site through garden hoses from water tanks mounted on a terrain vehicle. Thus, the distance of plots from vehicle-accessible trails could not exceed 100 meters, over this distance, sampling became overwhelmingly laborious. Sampling in forests was carried out by centering the infiltrometer positions at an approximately equal distance from the adjacent trees. In the case of dirt trails samples were taken from the areas where topsoil was present (horizontal areas or shallow slopes).

3.3. Soil bulk density, gravel and organic carbon content measurements

Soil bulk density was assessed at each infiltration sampling site as described by Dincă et al., (2012.), cylindric soil cores were extracted from the topsoil, using steel cylinders that were hammered in the soil from the surface in vertical direction (Samples were extracted near the soil infiltration samples, as soil surface was disturbed in the area of the infiltration measurement at extraction of the infiltrometer). The cores had a constant volume of 250 cm^3 (length 10.5 cm, diameter 5.5 cm). Samples were dried at 105°C, gravel was extracted using a 2 mm sieve. Dry mass, gravel (skeleton) mass and volume, soil texture, bulk density, skeleton volumetric ratio were determined. Soil organic carbon content was measured using the potassium dichromate method (Jakab S, Krézsek J, 2008).

3.4. Determination of soil compaction

A soil penetrometer (Wile Soil Compaction Tester) was used to determine soil compaction at each sampling site, to determine the compaction of the first 15 cm of the topsoil. The maximum read value was registered for each determination, three measurements were averaged on each site to express compaction (kg/cm^2). All sites were measured on the same late spring day, after a rainy period followed by two days without precipitations. At each infiltration sampling site three compaction measurements were taken, around the soil core extraction positions and an average value was calculated.

3.5 Statistical analysis

Observations were carried out in the three main forest cover categories (beech and spruce stands, small regeneration plots in beech stands) and the two other land use categories (grass plots and dirt trails). Steady infil

ng. Normality assumption was verified by Shapiro-Wilk test. One way ANOVA was used to evaluate differences of means between the three main forest cover categories. Equality tration rates were determined. A number of 10 observations were carried out in each category, except spruce stands where 11 determinations were conducted, due to miscounting the total amount of samples. All samples were kept though, to avoid manipulation of the results. Data analysis was carried out using Statistica 13.5.0.17 software. Effects of two different factors were analyzed:

a. The effect of forest cover category (beech stands, spruce stands and small regeneration plots in beech stands) was expressed in relation with soil infiltration rate in the case of forests.

b. The effect of land use category (forests, grass-plots, dirt trails) on soil infiltration rate was studied.

A significance level of α=0.05 was used for testiof variances for the forest cover categories was verified using Levene's test. Tukey Unequal N HSD post hoc test was applied to evaluate the differences between the groups.

The effect of land-use category (forest stands, grass-plots and dirt trails) was assessed using Kruskal-Wallis ANOVA as normality condition was not met in the case of the dirt trails category.

Following the analysis of the effects shown above, correlation analyses were carried out seeking for explanation to the variability observed against the soil properties analyzed (bulk density, skeleton volumetric content, soil organic carbon content and soil compaction).

The differences in soil compaction, by land-use category (forest stands, grass-plots and dirt trails) were verified using Kruskal-Wallis ANOVA as the assumption of homogeneity of variances was not met.

4. RESULTS AND DISCUSSION

Measured steady state infiltration rates (Table 1 and Table 2) were very high (>145 mm/h) in all samples in the case of Norway spruce and European beech stands, very high in case of the small regeneration plots in beech stands having one sample in the very low (1.1-5.0 mm/h) infiltration rate category. Grass plots were characterized by infiltration rates ranging from low (5.1-30 mm/h) to very high infiltration rate categories. The lowest infiltration rates were determined in the case of dirt trails having values generally in the very low or medium (30.1-70 mm/h) with only one sample in the high (70.1-145 mm/h) infiltration rate range according to the classification given by Târziu (1997).

Table 1. Values of determined steady state infiltration rates (mm/h) in Lake Sfânta Ana's crater.

Norway spruce	European beech	Small regeneration plots in European beech stands	Grass plots	Dirt trails
756	259	5	42	117
659	635	302	21	41
890	525	210	304	28
573	884	360	325	3
1115	570	581	82	2
1232	944	155	286	2
229	634	229	164	3
249	460	720	323	80
897	627	426	24	23
559	666	564	148	12
847				

Table 2. Steady state infiltration rates (mm/h) descriptive statistics of the different forest cover and land use categories.

Category	Mean	Min.	Max.	St. Dev.
Norway spruce stands	727.8182	229	1232	317.6985
European beech stands	620.4000	259	944	195.7045
Small regeneration plots in European beech stands	355.2000	5	720	219.9135
Grass plots	171.9000	21	325	127.7910
Dirt trails	31.1000	2	117	38.8457

As seen in figure 2, stable infiltration rates (SIR) decrease from 1200 mm/h in forested sites through grass plots to near 0 mm/h values in the case of dirt trails.

A statistically significant difference was found between groups determined by one-way ANOVA ($F(2,28) = 5.950$, $p = 0.007$) as shown in Table 3.

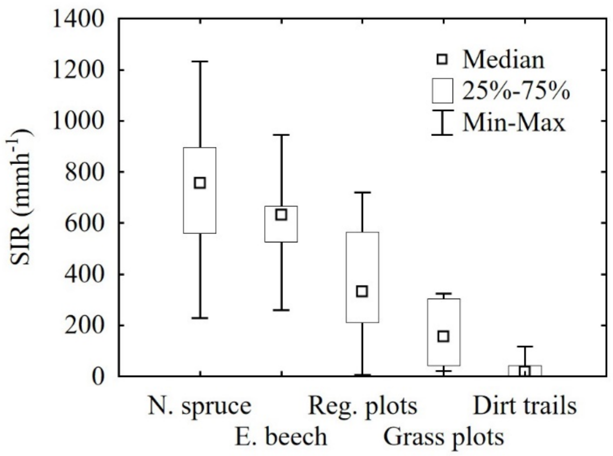

Figure 2. Effect of forest cover and land uses on steady state infiltration rate (SIR) in the inner slope of Lake Sfânta Ana

Tukey Unequal N HSD test (Table 4) shows a statistically significant difference between Norway spruce stands and small regeneration plots in European beech stands.

Table 4. Tukey Unequal N HSD results for the forest cover categories (1. Norway spruce; 2. European beech; 3. Small regeneration plots in European beech stands; fields marked with * represent statistically significant differences at α=0.05)

Groups	1.	2.	3.
1.		0.613823	0.007384*
2.	0.613823		0.065840
3.	0.007384*	0.065840	

Statistically significant differences were found among land use categories, determined by Kruskal-Wallis ANOVA ($H(2,N = 51) = 28.97883$, $p < 0.0001$) as shown in Table 5. The results of land use category effect on stable infiltration rates provide further evidence of the efficiency of forests in maintaining the high hydraulic conductivity of soil in contrast to other land uses, by significantly higher infiltration rates than in the case of both grass plots and dirt trails.

Analyzing the effect of the forest cover category, measurement results show that the highest steady state infiltration rates occur under Norway spruce and European beech stands with canopy closures over 80%. As all samples taken in these stands showed a steady. infiltration rate above 200 mm/h, generation of surface inflows towards Lake Sfânta Ana are of a very low

Table 3. One-way analysis of variance table for stable infiltration rates. Different forest cover categories show a statistically significant difference (α=0.05).

Effect	SS	DF	MS	F	p	Partial η^2	Non-centrality	Observed power (α=0.05)
Between categories	760491	2	380246	5.9504	0.007022	0.298258	11.9007	0.841082
Within categories	1789284	28	63903					

Table 5. Differences in steady infiltration rates among the land use categories. Computed *p*-values of the Kruskal-Wallis test. (1. Forests; 2. Grass plots; 3. Dirt trails; fields marked with * represent statistically significant differences at α=0.05)

Land use category	1. R: 34.581	2. R: 18.100	3. R: 7.300
1.		0.006903*	0.000001*
2.	0.006903*		0.312824
3.	0.000001*	0.312824	

probability. Taking into account the crown retention of precipitation in these forest stands, occurrence of surface flows in these land-cover conditions are extremely rare. Surface flows in these forest stands can occur in the case of rain and/or snow-melting events on water-saturated frozen topsoil, a condition that would dramatically reduce infiltration. There is no statistically significant difference between steady infiltration rates of Norway spruce and European beech stands in the studied area.

In the case of small regeneration plots in beech stands a mean steady state infiltration rate exceeding 350 mm/h is also a favorable condition. Triggering of surface flow events would not be of a high incidence, although it could occur in less severe conditions than under the forest stand types described before, based on the existence of a measurement showing a stable state infiltration rate of only 5mm/h. Reduction of steady state infiltration rates in small regeneration plots in beech stands is a phenomenon that should be further investigated and understood. The changes cannot be explained by soil disturbance during harvesting, places showing visible marks of soil disturbance were avoided during sampling. Microclimatic and vegetation condition changes lead to changes in soil properties compared to the stand-conditions preceding harvesting, resulting in lower infiltration rates. Changes induced by local conditions led to significant differences in comparison with other vegetation cover, namely Norway spruce stands growing on the same forest site conditions, as shown in Table 4. On comparing steady infiltration rates against the land use categories, the results show significant differences between forest-stands and grass-plots or dirt trails.

Grass plots of the lake shore have less favorable steady state infiltration rates. The steady state infiltration rate is significantly lower than in the case of the forests (Table 5). Although the mean value of the samples is situated in the high infiltration rate category, values determined in case of some samples indicate that surface flows can occur during high intensity precipitations in some places on the grass plots. Although slopes of these plots are not steeper than 10° and the length of the steepest slope is less than 50 meters in most places, with a maximum of 160 meters, there are substantial amounts of small organic and mineral residues (plant pieces and soil particles, other residues of anthropogenic origin) that can be washed in the lake due to the crumbling effect of treading by tourists.

Dirt trails are intensively treading by tourists, and thus topsoil porosity is heavily affected. The results of the measurements show unfavorable steady state infiltration values in most of the samples. Surface ponding and surface flows occur in some areas of the dirt trails with every major precipitation event. Lack of significant statistical difference between grass plots and dirt trails is probably rather due to the unfavorable condition of the grass plots, being areas that are also affected by high tourist-traffic, with all the negative effects of treading to soil properties. Based on the measurement results, an important role can be attributed to the trails descending on the eastern slope from the tourist reception area located on the crater rim. Although a paved road exists, many visitors would choose to approach the lake-shore on the shortest route, via these trails. These trails continue to feed Lake Sfânta Ana with sediment-rich surface flows during heavy precipitation events (Fig. 3).

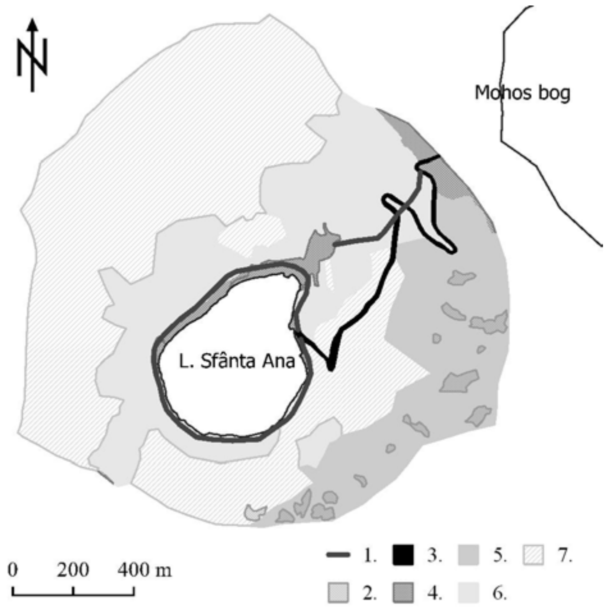

Figure 3. Mean infiltration rates in different land use categories at the Lake Sfânta Ana (1. dirt trails -31,1 mm/h; 2. small regeneration plots in European Beech stands – 355.2 mm/h; 3. asphalted road – 0 mm/h; 4. grass plots – 171.9 mm/h; 5. European beech stands; 6. Norway spruce stands – 727.8 mm/h; 7. Other forested plots not studied, with slopes generally over 20º).

To explain the significantly different steady infiltration rate values under different forest cover and land use categories, correlations were studied to some properties of the topsoil.

As soil samples contained a high (>80%) content of sand, and there were no differences between the forest types and land use categories $r(49)$=-0.0379, p=0.792, the ratio of loam and silk was not further determined, as no significant differences could be expected. Infiltration and soil organic carbon content were found to be weakly negatively correlated, $r(49)$ = -0.0599, p = 0.676. A low degree of negative correlation was found between infiltration and soil bulk density, $r(49)$= -0,1701, p = 0,233. Infiltration and soil skeleton volumetric ratio (%) were found to be moderately negatively correlated, $r(49)$ = -0.4214, p = 0.002. A strong negative correlation was found between infiltration and soil compaction, $r(49)$ = -0.6184, p < 0.001.

Variations in soil organic carbon content and bulk density do not explain the differences found in steady infiltration rates of soils. Although a moderate negative correlation was found between steady infiltration rates and soil skeleton volumetric ratio, establishing it as a cause of lower infiltration rates is questionable. It is more probable that selective erosion of soil particles by surface water runoff due to soil compaction could have caused the increased gravel ratios in soils in the case of grass plots and dirt trails (Table 6).

Table 6. Descriptive statistics of studied soil parameters under different forest cover and land use categories (1. Norway spruce, 2. European beech, 3. Small regeneration plots in European beech stands, 4. Grass plots, 5. Dirt trails).

Property	Forest cover and land use categories	Mean	Min.	Max.	St. Dev.
Soil organic carbon (%)	1.	5.1982	0.30	10.57	3.6430
	2.	2.1380	0.36	3.76	1.2289
	3.	1.3750	0.09	2.67	1.1368
	4.	5.1370	0.09	16.37	4.5465
	5.	3.4940	0.15	9.99	3.5862
Soil bulk density (g/cm3)	1.	0.4591	0.23	0.72	0.1852
	2.	0.6720	0.43	0.81	0.1259
	3.	0.7380	0.57	0.84	0.0978
	4.	0.6410	0.33	1.25	0.2981
	5.	0.6740	0.32	0.98	0.2509
Compaction (kg/cm2)	1.	4.3636	3.00	9.00	1.7477
	2.	8.0000	4.00	14.00	3.0551
	3.	8.3000	4.00	14.00	3.0930
	4.	16.1000	5.00	23.00	4.9542
	5.	18.3000	8.00	28.00	7.3189
Skeleton volumetric ratio (%)	1.	6.3636	0.40	13.20	3.3963
	2.	9.2800	7.20	11.20	1.4336
	3.	10.9600	7.20	16.00	2.7208
	4.	13.9600	1.60	32.80	9.1125
	5.	17.6000	5.20	36.80	9.2799
Texture (sand %)	1.	91.8746	83.53	97.14	3.6365
	2.	95.6340	93.90	96.66	0.8595
	3.	94.0540	85.87	98.22	3.5171
	4.	95.4330	91.34	97.35	1.7758
	5.	91.0860	81.37	96.62	5.0278

Compaction of soil can be established as the main factor explaining differences in infiltration rates (Fig. 4). Kruskal-Wallis test shows significant differences in compaction of soil in forests and other (grass plot and dirt trail) land use categories (Table 7). There is no statistically significant difference in soil compaction of grass plots and dirt trails. Forest cover types (Northern spruce, European beech and small regeneration plots in European beech) do not show statistically significant differences in soil compaction.

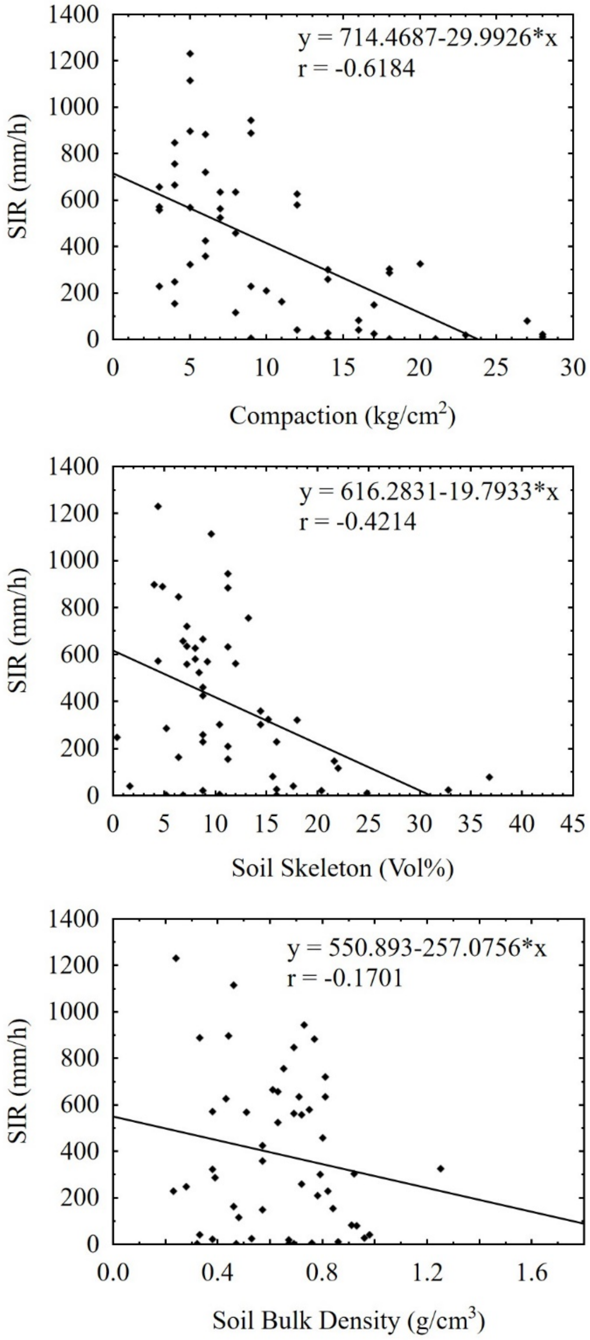

Figure 4. Correlation degrees between soil compaction, soil bulk density, soil skeleton volumetric ratio and soil steady infiltration rate.

Table 7. Differences in soil compaction between the land use categories. Computed *p*-values of the Kruskal-Wallis test. (1. Forests; 2. Grass plots; 3. Dirt trails; fields marked with * represent statistically significant differences at α=0.05)

Land use category	1. R: 34.581	2. R: 18.100	3. R: 7.300
1.		0.000249*	0.000064*
2.	0.000249*		1.000000
3.	0.000064*	1.000000	

5. CONCLUSIONS

Norway spruce, European beech stands, and even small regeneration plots in beech stands can be characterized by high steady infiltration rates, these plots prove to be efficient against the formation of surface flows, having a great protective value in the conservation of Lake Sfânta Ana against silt deposition and enrichment in nutrients. Although, measurements were carried out on slopes not steeper than 20° due to technical considerations, the results show that compaction of soil is the main factor influencing infiltration rates, and as no significant differences were detected between the analyzed forest cover types, it is highly probable that infiltration values in slopes exceeding 20° do not differ significantly from values measured on slopes not exceeding 20°. However, more research with adequate equipment would be needed to verify these areas. In the case of grass plots and dirt trails, these are found on slopes not exceeding 20°. Mean value of steady infiltration rates measured in the case of grass plots are less than half of the mean found in case of the forest land use category. Steady infiltration rates of the dirt trails are generally very low, about one tenth or less of the values measured under forest stands, in some areas even tending towards 0.

Differences observed between the values obtained for the different land use categories, explain clearly the phenomena observed during heavy precipitation events. Ponding of water and generation of surface flows on the dirt trails is possible due to the low infiltration rates of this land use category. Grass plots provide a better protection. However, surface flows can still occur during high intensity precipitation events. The results show no statistically significant differences between Norway spruce and European beech stands with high canopy closure. Small regeneration plots have somewhat smaller steady infiltration rates, but still high enough to ensure an effective protection. Small gaps created in the forest stands, resulting from natural causes or forest management practices, will not compromise the protective role of this land use category. In the case of grass plots and dirt trails treading due to tourist traffic led to the compaction of the topsoil, and reduction of pore volume.

Based on the results, it is obvious, that the sediments washed into Lake Sfânta Ana originate mainly from dirt trails, and to some degree from the grass plots surrounding the lake. The quantity of sediments deposited in the lake originating from surface flows from under different forest stands with undisturbed soil is negligeable. Organic sediments of forest origin (leaves, branches, etc.) are transported into the lake mainly after falling on the dirt trails/ grass plots, are carried by wind or fall directly into the water from the vegetation of the lakeshore. The protection role attributed to the treaded grass plots, as an actor in effectively filtering sediments from surface flows should be reconsidered in the case of Lake Sfânta Ana's shore. Due to the low steady infiltration rates this role is considerably weakened.

Forest vegetation, by maintaining high infiltration rates of soils, delivers a powerful protection against erosion processes. These rates can contribute to the rapid infiltration of water in deeper horizons, beyond the root zone of the forest vegetation, contributing this way to subsurface flow process, and the water budget of the lake. The magnitude of this contribution is not known in case of the study site. More research is needed to identify the stand structures which prove to be the most efficient from the point of view of contribution to the water budget.

Maintaining the actual high forest cover degree in the inner crater of Lake Sfânta Ana is recommended for the protection of the lake. Forest management practices should aim to create forest stands with high stability against damaging abiotic and biotic factors. Even conventional silvicultural operations, if correctly applied, would ensure the conservation of the soil infiltration capacity. The application of techniques involving small regeneration plots (with diameter below 1-2 tree heights) with long natural regeneration periods would not compromise the infiltration rate of soils. Obviously, clear-cuts affecting bigger areas could expose the soils with light, sand or sandy-loam texture to erosion. Smaller size plots resulting from windthrow or windsnap are not a cause of concern for the soil infiltration capacity and soil erosion.

From the perspective of conservation, it is obvious that the problem of dirt trails and intensively treaded grass plots has to be addressed. Solutions must be found to reduce the effects of treading by channeling tourist flow to paved trails with water-flow management solutions, and reducing the anthropic pressure on the grass plots and trails developed.

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