Erosion Control Service of Forest Ecosystems: A Case Study from Northeastern Turkey

Can Vatandaşlar, Mehmet Yavuz and Michael Leuchner

Abstract Erosion is one of the most significant environmental problems in Turkey and many other regions of the world. Thus, appropriate erosion control services can help reduce soil loss and maintain ecosystem services (ES). Forests play a crucial role in this process as they are very useful in erosion control when properly managed. This chapter depicts a case of erosion control service in a forest ecosystem in northeastern Turkey by assessing statistical relationships of soil properties with forest inventory data through field observations, direct measurements and calculated data of growing stock, basal area, and soil erodibility (K-factor) from 108 forest plots. We found several significant correlations between those factors and in particular tree density, basal area, stand age, layered forest structure, stand height, undergrowth, and species composition along with some ecological parameters proofed to be useful indicators for a quick assessment of erosion control ES of forests. Erosion rates could be reduced by increasing the number of trees per unit area with smart forest management. It seems that optimum species composition can easily be achieved through the presence of the broadleaved trees ES indicator. Because mixed forests generally had lower silt content in their soil, they seem to be less prone to erosion processes. This case study helped to identify the site-specific key indicators for assessing erosion control ES as well as potential mitigation strategies for forest ecosystems in northeastern Turkey. It also showed that a single proxy indicator might not sufficiently represent such complex processes. Thus, the use of a bundle of indicators may result in more accurate estimates. For a more general assessment, sound ES indicators still need to be developed on regional or national level for decision-makers and practitioners to make wise decisions and proper land allocations.

C. Vatandaşlar (✉) · M. Yavuz
Department of Forest Engineering, Artvin Coruh University, 08100 Artvin, Turkey
e-mail: canvatandaslar@artvin.edu.tr

M. Yavuz
e-mail: myavuz@artvin.edu.tr

M. Leuchner
Department of Physical Geography and Climatology, RWTH Aachen University, 52056 Aachen, Germany
e-mail: leuchner@wzw.tum.de

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Introduction

Ecosystem services (ES) are briefly defined as "*contributions of ecosystem structure and function to human well-being*" (Burkhard et al. 2014, p. 5). These services can be divided into three main categories: (i) provisioning (forest products, fodder production, among others), (ii) cultural (e.g., recreational, hunting, bird watching, fishing as well as aesthetic value of fruit trees and shrubs), and (iii) regulating services (climate regulation, erosion control, etc.) (Burkhard and Maes 2017). Erosion occurs as a combined effect of such factors as (i) climate characteristics, (ii) soil type, (iii) topography (slope and slope length), (iv) vegetation cover, and (v) conservation measures (e.g., contour farming, terrace, etc.) (Ekinci 2005; GDF 2017). Since humans can easily modify the latter two, erosion studies generally focus on controlling these factors. Thus, both vegetation cover and its management play crucial roles in soil protection. Since forests are those ecosystems with the densest vegetation cover on Earth, they protect soils against erosion in the best possible way (FAO 1992).

The mountainous topography, climate characteristics, and soil structure of Turkey make its lands very susceptible to soil erosion by water. The mean elevation of Turkey is 1132 m a.s.l., reaching around four times the mean elevation of Europe (GDA 2007). When steep topography is coupled with an irregular rain pattern, various erosion types (i.e., gully, sheet) at different severities occur in approximately 80% of the country's area (Çepel 2007). Ultimately, between 168 million (CDE 2015; GDEA 2012) and 500 million tons (Çepel 2007; TEMA 2015) of productive topsoil are estimated to be lost every year as a result of various erosion processes. Therefore, soil erosion is still the most important environmental problem of Turkey (Kantarcı 1993; Çepel 2007; Günay 2008; Yavuz and Tufekcioglu 2019).

Apart from Turkey, soil erosion poses enormous environmental risks in many other countries, as well (CEC 2006; Braun et al. 2018). Consequently, 24 billion tons of productive soil in the world is washed away every year (IASS 2015). Soil transport of such an amount additionally causes sedimentation in freshwater springs and makes them unusable (Carpenter et al. 1998; Tüfekçioğlu et al. 2012; Tüfekçioğlu and Yavuz 2016). As a result of such hydrological processes, soil erosion influences a more significant number of population with impacts on the access to drinking and domestic water, a decrease in agricultural production, land degradation, floods, landslides, and desertification (Cerdan et al. 2010; Buttafuoco et al. 2012). Such problems currently adversely influence 1.2 billion people around the world and force approximately 135 million people to abandon their homelands (MEF 2006).

All these examples illustrate the vast importance of erosion control service of ecosystems. Thereby, it is vital to integrate erosion control service of forest ecosystems into management plans as active control over soil resources can be possible only through proper management practices in forested lands. To this end, erosion control ES first need to be quantified in a spatially explicit manner. In this way, forest planners can accurately determine the (i) forestlands that will be designated for soil protection, (ii) optimum species composition, (iii) silvicultural interventions required for the stands which will be managed for erosion control purposes, and (iv) proper harvest scheduling.

Erosion Control Service of Forests

Forest ecosystems provide benefits that can be related to the groups of provisioning, cultural, and regulating ES. Regulating services of forest include pollination, pest control, preserving soil fertility, flood control, global climate regulation, nutrient regulation, water regulation, air quality, noise remediation, and erosion control (Burkhard and Maes 2017). Amongst them, erosion control service is one of the most critical regulating ES, particularly in mountainous countries as they significantly suffer from soil erosion. Therefore, soil research as well as the combatting against erosion has been concentrated worldwide as forest vegetation has been understood to have an active role in soil protection since the twentieth century (FAO 1992). For Utah and Montana, Trimble and Mendel (1995) showed that a decrease of canopy cover to values below 1% increased erosion rates almost 200 times. More recently, Vatandaşlar and Yavuz (2017) stated that the soil protection performance of a fully covered Scots pine (*Pinus sylvestris*) forest was 70 times higher than that of sparsely vegetated and degraded woodland in the Tortum-North watershed, Turkey. They also reported that the amount of soil loss in forestlands was 32 times lower than that of agricultural land use at the same gradient in the same watershed. This protective effect of the forest cover against soil erosion can be outlined as follows: First, due to the canopy layer, forest ecosystems dissipate the energy of raindrops before it can reach the soil surface (Nanko et al. 2004, 2011). Second, they reduce the erosive effects of rainfall through interception (Levia et al. 2017). Third, forests enhance the infiltration capacity of the soil by improving soil structure with its roots (Morgan 2005). Lastly, they reduce soil moisture by transpiration (EPA 2013) (Fig. 1). Thanks to these features, forests are considered as the best ecosystem type on Earth in terms of erosion control ES (FAO 1992). Thus, accurate setting of forest structure (i.e., its composition and configuration) in forest management planning helps foresters to minimize erosion processes on forestlands.

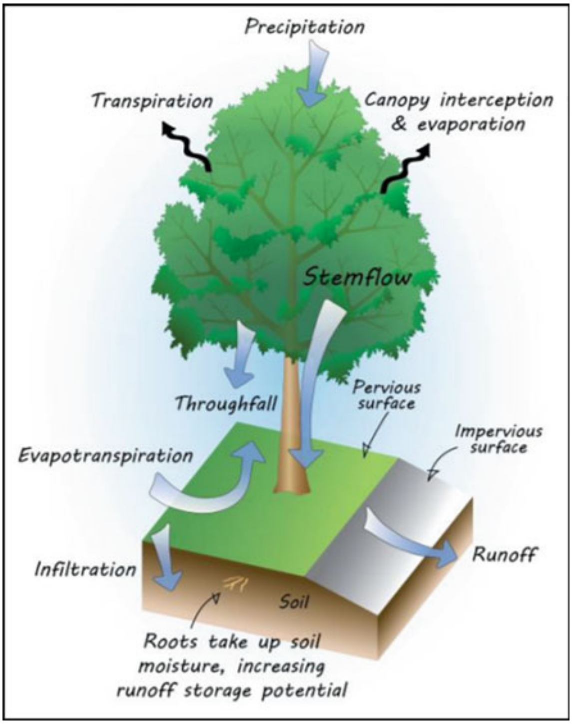

Fig. 1 Functioning of vegetation cover regarding erosion regulation (EPA 2013)

Spatial Quantification of Erosion Control Service

In contrast to provisioning and other regulating services of forest ecosystems, not many studies quantified erosion control ES in a spatially explicit manner. In the limited number of studies reviewed, biophysical quantification is generally made via three different techniques. These are (i) direct measurements (i.e., field experiments), (ii) indirect measurements (i.e., remote sensing or proxy indicators) and (iii) modeling (e.g., RUSLE) (Burkhard and Maes 2017). For all three techniques listed above, it is necessary to use existing ES indicators or to develop new ones. ES indicators are used to monitor the state and dynamics of ES supply, flow, and demand within a specific time interval (Vihervaara et al. 2017). In this context, a substantial indicator base has been developed worldwide in recent years to assess or measure ES.

The quantification of erosion control services was discussed by Guerra et al. (2014), who estimated the potential (without ES provisioning) and actual soil loss for South Portugal using RUSLE and calculated the ES provision capacity of the ecosystem by the difference of these two terms. At this point, land cover management (C) and conservation practices (P) factors played a key role. Then, they mapped the mitigation impact of this ES on soil erosion and provided suggestions like overgrazing being decreased for the risky areas. In another study, Pamukcu (2015) used various landscape metrics as well as Revised Universal Soil Loss Equation (RUSLE) and examined the relationship between these metrics and annual soil loss. A negative correlation was found between soil loss and percentage of landscape, largest patch index, and aggregation index especially in broadleaved forests ($r = -0.60$). Based on these relationships, the author concluded that an increase in aggregation in forestlands leads to a decrease in soil loss.

Researchers from many countries use different indicators in their ES quantification studies (Table 1). These may be primary indicators such as annual soil loss in unit area, or amount of erosion prevented as well as secondary indicators such as land cover, slope, or soil erodibility (Egoh et al. 2012). For instance, when specific forestlands are delineated primarily for erosion control service in Turkey's forest management maps at the planning stage, it is only taken into consideration that the slope rate in the area was over 60%. On the other hand, Koschke et al. (2012) used the run-off coefficient as an indicator in their extensive study in Eastern Germany. They scored the indicator values for each land use type according to expert opinions and assigned these values to related land use types in the map. As the examples demonstrate, there are many different indicators and threshold values in the literature for the same ES. Therefore, the indicators used in different countries are illustrated together in Table 1.

Table 1 Indicators used for assessing erosion control service (Yavuz and Vatandaslar 2017)

ES indicators	UK	EU	USA	CA	AU (VIC)	AU (NSW)	TR
Soil loss amount			✔			✔	
Soil type (texture)[a]	✔		✔	✔	✔	✔	
Soil stoniness					✔		
Soil color					✔		
Soil organic matter	✔			✔	✔		
Run-off coefficient					✔		
Rainfall amount						✔	
Elevation a.s.l.		✔					
Slope	✔	✔	✔	✔	✔		✔
Forest area[b]	✔	✔				✔	

[a]i.e., sandy loam, clay loam, silt, etc.
[b]The ratio of forest area which is managed for soil protection to the total forest area

Case Study from Turkey: Useful Indicators for Assessing Erosion Control Service of Veliköy's Forests

Study Area

Veliköy Forest Enterprise is the study area located in Artvin province, northeastern Turkey (Fig. 2). The elevation ranges between 630 m and 3150 m with an average elevation 1808 m. Its mountainous lands have a steep topography with an average slope of 35%. It has a semi-continental climate with 620 mm mean annual precipitation. The temperature ranges from –1.8 to 20.8 °C with an average 10.2 °C based on the Şavşat weather station at 1100 m altitude (TSMS 2018). It is located in the Caucasus Biodiversity Hotspot (CEPF 2003) and consists of highly diverse, uneven-aged mixed temperate forests. The area is dominated by conifers such as Caucasus fir (*Abies nordmanniana subsp. nordmanniana*), oriental spruce (*Picea orientalis*), and Scots pine (*Pinus sylvestris*). Deciduous tree species such as chestnut (*Castanea sativa*), beech (*Fagus orientalis*), birch (*Betula sp.*), hornbeam (*Carpinus orientalis*), poplar (*Populus sp.*), and oak (*Quercus petraea subsp. iberica*) also exist (Yavuz and Vatandaşlar 2018). Regarding soil type, moderately deep sandy loam soils are dominant in the study area (Duman 2017).

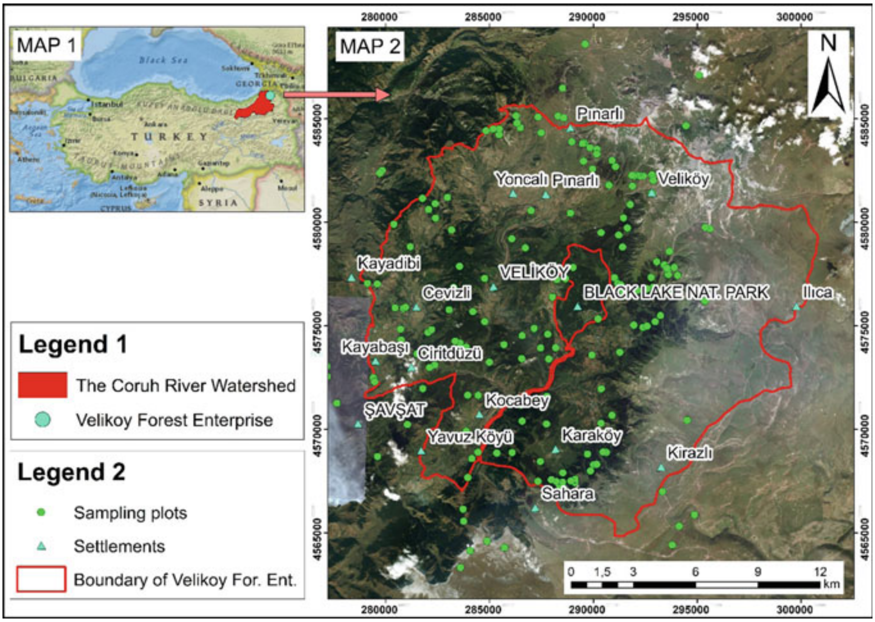

Fig. 2 Location of the study area and the sampling plots

Fieldwork and Methods

In the summer of 2018, 108 forested sampling plots were visited in the study area. A number of field observations and direct measurements were performed at two stages. The first step consisted of typical timber inventory for forest management planning purpose. Measured variables were tree height (m), diameter at breast height (cm), age (years), increment (mm/year^{-1}), canopy closure (%), and the number of dead trees. Moreover, species composition, stem quality, origin (high forest or coppice), and silvicultural interventions (if any) were also observed and noted into the inventory sheets. During the second stage, additional measurements and observations were performed on thickness of litter layer (cm), height (m) and closure of undergrowth vegetation (%), forest structure (even-aged or uneven-aged), regeneration status, number of snags, number of lying trees, number of tree layers, surface stoniness (%), surface roughness, soil color, soil moisture (i.e., very dry, dry, cool, moist, and wet), percent slope and slope length (m), and observed erosion type (i.e., rill, interrill, gully, mass movement). Furthermore, disturbed topsoil samples were collected at 0–15 cm depth in each plot for developing ES indicators. Collected samples were taken to the soil laboratory for mechanical and chemical analyses. Bouyoucos (1962)'s hydrometer method was used for the texture (sand, clay, silt content) analysis while the Walkley–Black wet oxidation method was applied for determining the organic matter content in soil based on Schumacher (2002).

Additional parameters such as growing stock (m^3/ha), basal area (m^2/ha) and K-factor (t ha h ha^{-1} MJ^{-1} mm^{-1}) were also calculated to be included as useful indicators. The K-factor was calculated according to the formulas in (1) and (2) (Torri et al. 1997, 2002). Each indicator was tested for normality through visual inspection of their frequency histograms, as well as the kurtosis and skewness values. After controlling whether they were normally distributed, we assessed the relationships among the indicators using Pearson's correlation analysis, independent samples t-test, and one-way ANOVA. Finally, a large geodatabase was set up in ArcGIS 10.3 for a full understanding of the spatial distribution.

$$K = 0.0293\left(0.65 - D_G + 0.24D_G^2\right)exp\left[-0.0021\left(\frac{OM}{f_{clay}}\right) - 0.00037\left(\frac{OM}{f_{clay}}\right)^2 - 4.02f_{clay} + 1.72f_{clay}^2\right] \quad (1)$$

$$D_G = \sum f_i \log_{10}(\sqrt{d_i d_{i-1}}) \quad (2)$$

where K is the soil erodibility (t ha h ha^{-1} MJ^{-1} mm^{-1}), D_G is the decimal logarithm of the geometric mean of particle size distribution, OM is the organic matter content in soil (%), f_{clay} is the clay content in soil (%), f_i is the mass fraction in the corresponding size class, d_i is the maximum diameter of the *i*th class (mm), and d_{i-1} is the minimum diameter of the *i*th class (mm).

Results

Statistically significant relationships were found between soil- and forest-related parameters. According to Pearson's correlation analysis, both K-factor and clay content in the soil correlated with tree density in forest stands. Other significant correlations can be seen in Table 2.

Aside from continuous data, there were statistically significant differences amongst soil- and forest-related categorical data. Independent samples t-test and ANOVA results showed that many soil properties differed depending on classified data such as aspect groups, the presence of broadleaved trees or dead trees in the stands (Table 3). We saw that if there were any broadleaved tree species in a coniferous forest, then the sand content in soil was significantly higher while the silt content was lower. Conversely, if there were conifers in a broadleaved-dominant forest stand, the clay content was very high. On the other hand, the presence of common rhododendron shrub (*Rhododendron ponticum*) in a stand, a common undergrowth species in the Eastern Black Sea's forests, generally came along with high K–factor values and low clay content. Moreover, litter layer thickness, soil stoniness, and surface roughness rates statistically differed based on aspect. Namely, stoniness and roughness were higher on the sunny slopes while litter thickness was thinner. Finally, we analyzed soil types for differences and observed that stand age, tree density, number of stumps on the forest floor and slope were significant factors affecting soil properties. Accordingly, tree density was low on loamy sand soils while the stand age was high. However, forest stands were very young on sandy clay loam and clay loam soil types. Clay loam soils, additionally, located on more flat sites in our study area. Regarding the number of stumps, they were highest on the loam soils and lowest on the loamy sand.

Table 2 Correlation analysis results of biophysical parameters

Soil-related data (continuous)	Forest-related data (continuous)	Significant level (two-tailed)	Pearson's r value
K-factor (t ha h ha MJ^{-1} mm^{-1}) (soil erodibility)	Tree density (no/ha^{-1})	<0.01	−0.35
	Mean stand height (m)	<0.01	0.34
	Ht. of undergrowth vegetation	<0.01	0.32
Clay content in soil (%)	Tree density (no/ha^{-1})	<0.01	0.38
	Stand age (years)	<0.05	−0.34
Silt content in soil (%)	Slope (%)	<0.01	−0.34
	Basal area (m^2/ha^{-1})	<0.05	0.30
Sand content in soil (%)	Tree density (no/ha^{-1})	<0.01	−0.34
	Stand age (years)	<0.05	0.31

Table 3 The results of independent samples t-tests and one-way ANOVA

Forest-related data (categorical)	Soil-related data (continuous)	Significant level (two-tailed)	Test (comparison of means)
Forest structure (single canopy vs. layered forest)	K-factor	<0.05	Independent samples t-test
Presence of broadleaved trees in a coniferous forest	Silt content in soil	<0.05	
	Sand content in soil	<0.05	
Presence of conifers in a broadleaved forest	Clay content in soil	<0.05	
Presence of standing dead trees	Silt content in soil	<0.05	
Presence of *Rhododendron ponticum*	K-factor	<0.01	
	Clay content in soil	<0.001	
Aspect groups (sunny vs. shadowed)	Stoniness in soil	<0.05	
	Surface roughness	<0.01	
	Litter layer thickness	<0.05	
Aspect subgroups (e.g., N, NE, E, S, …)	Top height of the stands	<0.05	One-way ANOVA
	Slope	<0.01	
Soil type (e.g., sandy loam, clay loam, silt, …)	Stand age	<0.05	
	Tree density	<0.05	
	Slope	<0.01	
	Number of stumps	<0.01	

Conclusion

It can be concluded that tree density, basal area, stand age, forest structure (i.e., single canopy vs. layered forest), stand height, undergrowth vegetation, and species composition along with some ecological parameters such as aspect groups could be utilized as useful indicators for a quick assessment of erosion control ES of the Veliköy Forest Enterprise. These indicators can help natural resource managers to take measures for appropriate land management. Accordingly, the eastern parts of the study area appear to be more vulnerable to erodibility mainly due to the lower organic matter content in soil. In contrast, the western parts provide higher capacities for erosion control ES as they have a dense and mixed forest cover.

Based on the inverse correlation between tree density and K-factor (soil erodibility), it can be said that erosion rates may be reduced by increasing the number of trees per unit area with smart forest management skills. Similarly, optimum species composition can easily be set through the presence of the broadleaved trees ES indicator. Because mixed forests generally had lower silt content in their soil they seem to be less prone to erosion processes. However, one should always bear in mind that these ES indicators are site-specific. Thus, they may not function in the same way across different regions.

Key Challenges and Smart Solutions

Many researchers from different countries suggest useful indicators for assessing erosion control performance of forest ecosystems (see section "Spatial Quantification of Erosion Control Service"). However, these are usually site-specific; thus, they may change from region to region. Therefore, one should always bear in mind that a robust indicator for a particular region may not represent the overall situation for the national level. That is why new and scientifically sound indicators should be developed primarily for unstudied erosion hotspots. On the other hand, most regulating services are related to ecological functions involving many processes. A single proxy indicator (e.g., land use or slope) may not sufficiently describe or represent such processes (Egoh et al. 2012). Thus, the use of a bundle of indicators (e.g., land use, canopy cover, and litter layer thickness) may result in more accurate estimates.

Another difficulty is related to the fieldworks. Due to historical anthropogenic pressure to nature, forestlands generally have shrunk to remote and mountainous areas across the world as well as the case study site in Turkey. Thus, fieldwork (forest inventory) is generally the most expensive, time-consuming, and labor-intensive stage of a forestry project. Indeed, it is very exhausting and sometimes impossible to reach all sample plots due to lack of road and trails. Moreover, dense understory vegetation makes walking difficult especially in moist forest sites. Aside from the access problem, measurement of some indicators requires expertise. Surface roughness, for example, may not be accurately measured by timber inventory teams. As such, they should be supported by soil and biodiversity experts on-the-ground. By doing so, assessment and mapping of all ecosystem services can be possible in a systematical manner. Therefore, timber inventory teams are periodically surveying all forested lands of the country while updating the management plans generally every ten years.

Conclusive Remarks

Various forestry regulations are made about soil erosion and erosion control service of forests in many countries. General awareness is formed in society. The role of Sustainable Forest Management and ES concepts in the formation of this awareness is undeniable worldwide. To date, we know well that different forest types and structures serve different soil protection performances. Our duty, as natural resource managers, is to model these services in a spatially explicit manner and integrate them into management plans with the help of numerous useful indicators developed for different regions as shown for the case study site from Turkey in the present chapter (see section "Case Study from Turkey: Useful Indicators for Assessing Erosion Control Service of Veliköy's Forests"). Thus, both decision-makers and practitioners will be able to make wiser management decisions and better priority settings than before. Ultimately, it is considered that the amount of billions of tons of soil loss worldwide will gradually be reduced.

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