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Ecology

POTENTIAL OF WATER PURIFICATION OF MACKA FOREST ECOSYSTEMS IN NORTHEASTERN TURKEY

L. ALTUN, U. KEZIK*, O. KARA, E. BABUR

Faculty of Forestry and Forest Engineering, Karadeniz Technical University, 61 000 Trabzon, Turkey
E-mail: *kezik@ktu.edu.tr*

Abstract. Forests are known to be critically important functions in terms of ecological, economical and social functions they serve. Forest ecosystems play a crucial role in the production of high quality and quantitiy water. Forests lands contain the necessary mechanisms to provide clean, healthy water, including the filtering effect provided by forests soils in watersheds. The objective of this study was to estimate the water filtration of forest soil in Macka Ormanustu Forest Research area, located in northeastern Turkey, which provides public drinking water supply to Trabzon province. For this purpose, the amount of filtered water which contributes to the stream flow per unit area was estimated by using water balance equation including annual precipitation, interception, surface runoff and the amount of water stored in the soil (AWHC). Soil properties such as soil depth, coarse fragment, texture, structure, pH, organic matter and avaliable water hoilding capacity (AWHC) were also determined in forest and open (grassland) area. Results from this study showed that filtered water was approximately 3751.2 $m^3\ ha^{-1}\ yr^{-1}$ in forest and 2986.1 $m^3\ ha^{-1}\ yr^{-1}$ in open area. Our results revealed that forests can reduce drinking water treatment costs by naturally filtering water through its porous soils.

Keywords: soil water, water production function, forest ecosystems, hydrological cycle.

AIMS AND BACKGROUND

Forest soils carry out essential ecosystem functions like carbon storage, nutrient uptake, water storage and filtration. In this study, we attempted to determine the ability of forest soil to filter water. This study was conducted in a small watershad area belong to Ormanustu Research Forest, located in Trabzon povinence, Turkey. The amount of filtered water was determined by using annual rainfall, interception, surface runoff and avaliable water holding capacity (Fig. 1).

Water in our ecosystems is absolutely critical. It plays a fundemental role in our healthy life, economy, agriculture, and environment. Human population growths dramatically affect water resource. Storing the water during rainy periods present on a regular and continuous manner for the benefit of life is paramount importance[1]. In this regard, forest ecosystems forming the most significant terrestrial biome play an important role in filtering water from the precipitation. It contributes to

* For correspondence.

produce high quality, regular and continuous feeding of ground water resources for public services[2–5].

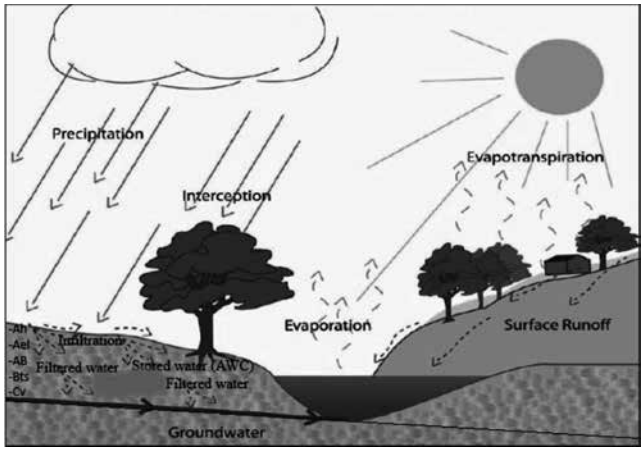


Fig. 1. Hydrological cycle in forest ecosystems[6]

Approximately 2/3 of the Earth is covered by water[7] and 97% of Earth water is contained within the oceans and seas as salt water, while remaning 3% is fresh water in lakes and frozen water in glaciers. Of that the 70% freshwater resources consist of glacier, the amount of liquid freshwater can be found underground and used for the continuation of terrestrial life, even less than 1% of the total water on earth[8].

Forests compose the world largest and most important terrestrial ecosystems[9] and represent a large part of the plant biomass[10]. Forest ecosystems, as a result of the interaction of biotic (living) and abiotic (nonliving) environment in a particular region and embodying many ecological relationships (Fig. 2), are unique systems[11]. A huge amount of organisms can be host in each gram forest soil[12,13].

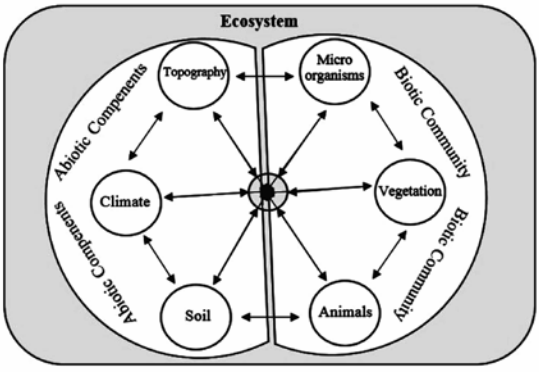


Fig. 2. Ecosystem compenents and their interrelations with each other

Forest ecosystems not only supply wooden raw material for the forest industry, but also regulate and affect the local and global climate conditions that contribute to the hydrological cycle, fresh air and water, regulating soil and water regime. They are known as an open system with ecologic, economic and social functions[2,14–16].

Soil systems in forest can perform usually several functions simultaneously[17,18]. Considering the hydrological aspect, when rainwater reaches the soil, rises to forefront of filtration function. This filtering function of the soil can be performed with its physical, chemical and bological properties (micropores, negative charges, decomposer organisms, etc.)[19].

The hydrological functions of forest ecosystem affect indirectly our urban ecosystem. The water, filtered to the forest soils after the rainfall, generates about two thirds of fresh and clean water in the United States. Forests also help to prevent waste that will be moved in many ways to the lakes, ground water and streams. Furthermore, trees and other plant roots system ensure to filter the water by tending of soil pore system in several layers before entering the groundwater. In this process, toxins, heavy metals and sediment are removed from water. Also leaves, plant waste such as branches and cones in the forest ground play an important role for water filtration. Through the process of denitrification, for example, bacteria in wet forest soils convert nitrates-a nutrient that can lead to harmful algal blooms if too much of it enters bodies of water-into nitrogen gas, releasing it into the air instead of into local streams[20–23]. Enzymatic activities in forest soils also are higher than in agricultural and cultivated lands[24].

Living filter systems as trees processing of wastewater have been identified as the best achievements in towns. The study states that in a city of 100 000 inhabitants, the daily amount of waste water is thought to be 4.5 million l. It has been demostrated that 552 ha forest area are necessary for filtering this waste water by living filter sistem[25].

EXPERIMENTAL

The study was conducted in a 645 ha (forest = 479 ha, open area = 166 ha) Ormanüstu research area located between Paparza and Camliduz streams in the Trabzon provinence in Northeast Black Sea Region of Turkey (40°47′00″–40°44′30″ N and 39°28′41′30″–39°30′00″ E) (Fig. 3). The mean elevation is 1860 m, slope – 32–70% with a west aspect. The region occupies a humid subtropical zone of oceanic climate. According to climatological data of the last 30 years, the area has mean annual temperature of 6.36°C and mean annual precipitation of 1042 mm, with about 424 mm of rainfall occuring in vegetation period between June and September. Major forest species are oriental beech (*Fagus orientalis*), oriental spruce (*Picea orientalis*) and Caucasian fir (*Abies nordmanniana subsp. nordmaniana*) and open area is grassland.

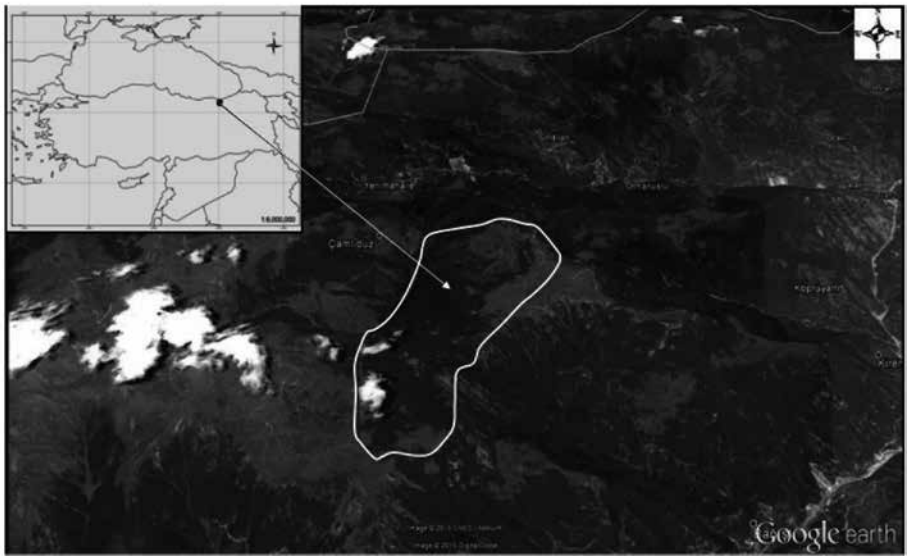


Fig. 3. Location of research area

Field working. Total 115 soil profiles, digged up to 120 cm depth, systematically distributed where on forest (82 profile) and open area (33 profile) were evaluated. Total 345 disturbed and undisturbed soil samples were taken based on soil layer (Ah, Ael, Bts and Cv horizons)[26].

Laboratory analysis. Some soil propeties such as soil texture[27], soil organic matter (walkley-black)[26,27], soil pH (H_2O) (Ref. 27), coarsa fragment (> 2 mm), fine fragment (< 2 mm), avaliable water holding capacity (AWHC) were determined.

The water holding capacity in soil is closely related to soil organic matter content, soil type, stone content and soil depth. Several formulas are used in estimating of soil water characteristics by using soil texture and organic matter[28]. In our study, we used soil texture, soil coarsa fragment (> 2 mm), soil depth and soil organic matter as soil properties in estimating AWHC per unit area for both forest and open area[29,30].

Hydrological calculations. Solum at the end of B horizon in a soil profil was used for determination of AWHC. During the calculations solum depth was taken as 100 cm because some soil depth is smaller or larger than 100 cm (AWHC values interpoleted to 100 cm).

In forest and grassland ecosystems, a certain portion of the total annual precipitation per unit area filtreted feeds to the stream flow and ground water and finally reaches the nearest reservoir. In these ecosystems, annual filtered water reaching the ground water was calculated using formula shown below.

Annual water filtration potential (*AWFP*). Numerous water balane equations developed for a watershed[31]. In our study, AWFP of soils in both forest and grassland (open area) ecosystems determined by using this equation $X = Y – (Z + T + Q)$, where X is the annual water filtration potantial (AWFP, mm); Y – the total annual rainfall (1042 mm m^{-2}); T – runoff (mixed forest: 18%, grassland: 36%) (Ref. 32); Z – annual interception ratio (mixed forest: 28% and grassland: 17%) (Ref. 32), and Q – available water holding capacity (AWHC) at 100 cm depth[33]. Water demands for evapotranspiration are met by the stored soil water[34]. Therefore, evapotranspiration parameter was not used in the water balance equation.

Statistical analysis. Soil properties according to the above formula of AWHC were analysed for comparison between forest and grasland area by One-way ANOVA at 95% confidence level. Statistical analyses were carried out using SPSS program version 15 and Microsoft Office.

RESULTS AND DISCUSSION

Forest and grassland soils in the study area are generally coarse-textured (sandy loam) and with slightly acidity reaction. One-way ANOVA demonstrated that forest soils contain significantly higher clay ratio, organic matter and AWHC than those in the open area soils (Table 1). Increased organic matter in the forests soils may be attributed to higher litter production compared to open area.

Table 1. Soil characteristics of the research area

Soil properties	Forest	Open area (grassland)
Sand (%)	69.33±10.85a*	67.88±6.49a
Silt (%)	10.21±5.68a	19.57±5.95b
Clay (%)	20.46±8.23a	12.55±4.54b
Coarsa fragment (> 2.0 mm, g l^{-1})	260.69±151.9a	241.82±134.50a
Fine fragment (< 2.0 mm, g l^{-1})	620.87±180.85a	753.11±161.97b
pH (H_2O)	5.76±0.35a	5.84±0.30a
Organic matter (%)	11.46±4.11a	10.13±2.84b
AWHC (at 100 cm depth m^{-3}) AWFP	3751.2±41.31a	2986.1±49.23b

*Different letters show significant differences at $p < 0.05$ level statistically. Values in rows represent the mean standard deviation.

To estimate the filtered water in research soil, the following general steps were carried out: firstly, available water holding capacity (AWHC) (kg m^{-3}) at 1 m soil depth was determined depending on some soil properties (Table 2); secondly, annual filtrated water of per unit area (ha^{-1}) was calculated by using water balance equation mentioned above. It includes canopy interception, evapotranspiration, runoff and soil water. Our estimates reveal that water filtration potential was higher in forest

area (3751.2 m^3) than those in open area (2986.1 m^3). Our results also show that amount of filtered water in the study area was higher than previous studies may be related to soil properties, climate and stand structure[35]. Similar studies show that water quality has been affected positively by the increasing of forest area in drinking water catchments. Increasing the forest area from 10 to 60%, the cost of physical and chemical treatment of drinking water may be reduced by two to third times (Ref. 21).

Table 2. Avaliable water holding capacity of research area (AWHC, kg m^{-3})

Land use	*N*	Minimum	Maximum	Mean	Std. deviation
Forest	82	46.05	316.80	188.50	41.31
Grassland (open area)	33	92.38	396.96	191.13	49.23

AWFP AWFP in forest area was significantly higher than in open area which might be related to increased organic matter of forest soil and decreased runoff coefficient. Forest litter that covering the soil surface protects the soil from sealing and crusting by raindrop impact, thereby enhancing rainwater infiltration and reducing runoff. In forest area, litter left on the soil surface leads to improved soil aggregation and porosity, and to an increase in the number of macropores, and thus to greater infiltration rates. Studies have shown that, moder humus types developed in coniferous forest, where high amount of rainfall (150 mm h^{-1}) easily percolates to soil[34].

The high content of organic matter in forest soil is another effective factor in the production of quality water. Forest ecosystems with root, shoot, litter and soil characteristics are affecting rainfall-runoff relationship in a positive direction. Therefore, it can be interpreted that forest ecosystems have the ability to filter, trap and recycle fertilisers, herbicides, urban waste and other forms of water pollution[36].

One of the most important environmental problems of our century is climate change and the other is water scarcity[37]. The structure and function of forest ecosystems affect these issues directly. Forest dominates hydrological cycles, soil development processes and the microclimate[38]. Forest ecosystems having ecological, economical and social functions together with vegetation and soils are unique systems[39]. These systems, on the one side, supply clean and qualified water to upstream reservior established for water demand of urban[40,41] and, on the other, serve as a filter in the city wastewater treatment[23,42]. These hydrological tasks are included in the ecological function of the forest ecosystems.

In this study, assuming that water treatment cost is about 2 Turkish Liras (₺) per m^{-3}, we calculated the annual treatment cost of water as approximately ₺ 7502 per 1 ha and ₺ 3 593 458 (7502 × 479) per the total forest area (479 ha). Our finding indicated that forests soils reduced drinking water treatment costs by naturally filtering in research area. This is consistent with previous studies showing that forest area may decrease to almost 50% water treatment cost of local governments[43].

CONCLUSIONS

Forests act as a natural water filter and storage system, keeping water clear, regulating streamflow, recharging groundwater supplies and reducing runoff. Our results show that the water purification benefits of forests are economically valuable in this ecosystem. Therefore, forest land managers consider the same ecosystem services just as important in rural areas in need of clean water.

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