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Optimum density and space structure of Kyrgyzstan`s juniper stands for identifying water protective properties

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Abstract. Central Asia, including Kyrgyzstan, is a disaster-prone region, suffering from snow avalanches, landslides and flooding. Within Tien-Shan, a mountainous region in southern Kyrgyzstan, there has been an increasing number of natural hazards in recent years. One of the possible causes of this increase is deterioration of juniper forests in the region. Juniper has a large economic and ecological importance for Kyrgyzstan. However, conditions have worsened for these forests. Since 1980 approximately 20% of juniper forests have been lost due to intensive deforestation, forest fires and excessive cattle grazing. Climate change may also affect juniper trees and soil properties. The aim of this study is to investigate the impact of juniper forest on local hydrology and to characterize its water protective properties.

Key words: deforestation, forest density, forest management, juniper, water protection

Introduction

This article presents research results concerning the relationship between the density and spatial structure of juniper stands and their water protective properties for the northern slopes of the Turkestan-Alai mountain chain.

There are two exact antipodes of opinion about the impact of forest on precipitation enhancement. The first states that forest, including montane forest, enhances precipitation from 1 - 3 to 15 - 20% in summer and up to 70 - 80% in winter. Examination of precipitation measuring accuracy reveals a systematic measuring error from 3 - 12% for liquid precipitation to 16 - 70% for solid precipitation. According to the second opinion, roughness in montane forest is 10 - 20 times as much as that in treeless areas. This intensifies turbulent interactions and restrains airflows which leads to extra precipitation and entrapment of horizontal precipitation, particularly in the context of high humidity (Rakhmanov 1962, Toktoraliev *et al.* 2009). Precipitation transfer in juniper stands (precipitation interception by juniper crowns, snow cover distribution and snow melting regime) is an issue of much interest (Bikirov and Koshumbaev 2002, Gan and Chub 1978, Gan 1982, Djanaeeva 1965, Molchanov 1960).

Forests have an important impact on snow accumulation, snow storage distribution and snow melting regime. Research on these topics has usually referred to plains. Similar investigations relating to mountain territories, particularly to juniper biogeocenoses of Kyrgyzstan, have so far been lacking (Bochkov 1954).

In mountains it is practically impossible to compare snow storage in the field and forest. Therefore, it is important to compare snow storage under shelterwood and in the nearest glade area; and for total woodland to be calculated based on the values of these indicators with due consideration of their proportionate areas (Botman 1975; Kosmynin 1985).

A peculiarity is the small number of precipitation events in the first half of the winter period. The basic mass of snow accumulates in February–March and snow storage grows to a maximum level; the density of snow cover is therefore not high. These conditions have a specific impact on the snow-melting regime of juniper stands. Snowmelt intensity is lower in forest than in glade and open areas; however, snow-melting finishes earlier here due to less snow storage (Kosmynin 1988, Kosmynin and Klavdienko 1976, Kitredj 1961).

Thus, the protective properties of juniper stands are prolongation of the snow-melting period, reduction of the intensity of water yield from snow and the impediment of snowmelt runoff. Juniper forests grow on steep mountainous slopes and in upstream areas where groundwater recharge occurs, they prevent soil erosion by water and wind, formation of mudflows, soil flows, mountain creep, impede rapid snow-melting, destructive floods and secure groundwater runoff (Musuraliev 1988, 2001; Mukhamedshin 1967). Moreover, forest entraps atmospheric precipitation. Relatively little research has been done on the distribution and interception of precipitation in mountain forests
of Kyrgyzstan compared to the plains. The amount of precipitation interception is highly variable during the vegetation period since the depth of precipitation is extremely irregular during the year.

Water resources of southern Kyrgyzstan sustain a cross-border water supply as they support the requirements for water throughout the Fergana Valley (Fig. 1, 2). Water supply plays an important role in maintaining environmental stability in many densely populated areas. However, river discharge is subject to the impact of climatic and anthropogenic changes, which leads to increasing drought and problems to secure the drinking water supply. It also has an impact on irrigation issues and the environmental state of water ecosystems (Kitredj 1961, Toktoraliev *et al.* 2009).

An important challenge of global climate change is the assessment of "forest-water" interaction systems; therefore detailed investigation of the "forest-water" system is an important issue of this research work (Fig. 3, 4).

One of the problems within the "forest-water" system is connected with the threat of a possible reduction of potential snow storage in mountainous areas, which is expected to occur under global warming. The consequence will be a changed hydraulic regime of snowmelt and runoff.

Mountainous areas have different climates compared to plains due to their high variability caused by the diversity of the landscape. They are characterised by higher altitude, lower water and soil temperature and an increasing number of precipitation events up to a certain level, while the vegetation period is shorter (Koval 1975). The main climatic peculiarity in the juniper forest belt is drought in the second half of the vegetation period. The average annual air temperature is 4.30˚ C and annual amplitude is 20˚ C. The summer is comparatively cool, June being the warmest month with an average temperature of 14.9˚ C and a maximum temperature of 29.2˚ C. The coldest month is January with an average of -5.1˚ C and an absolute

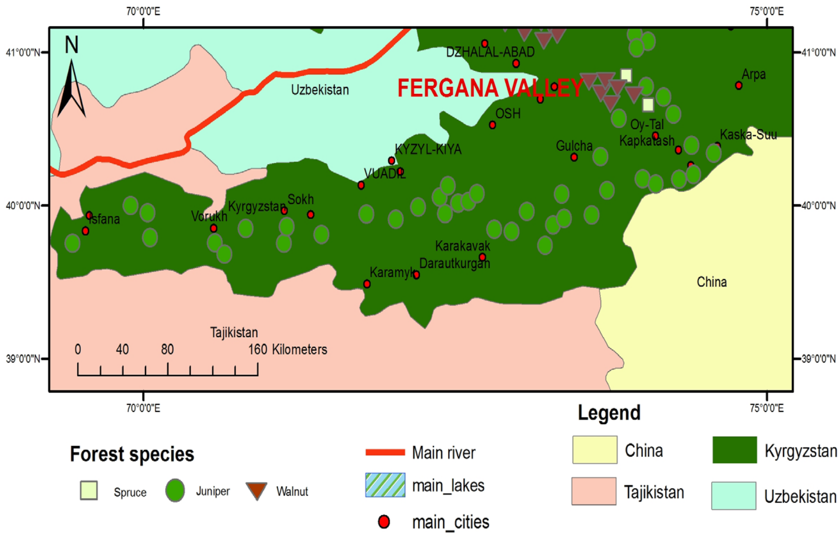

Fig. 1. Fergana Valley

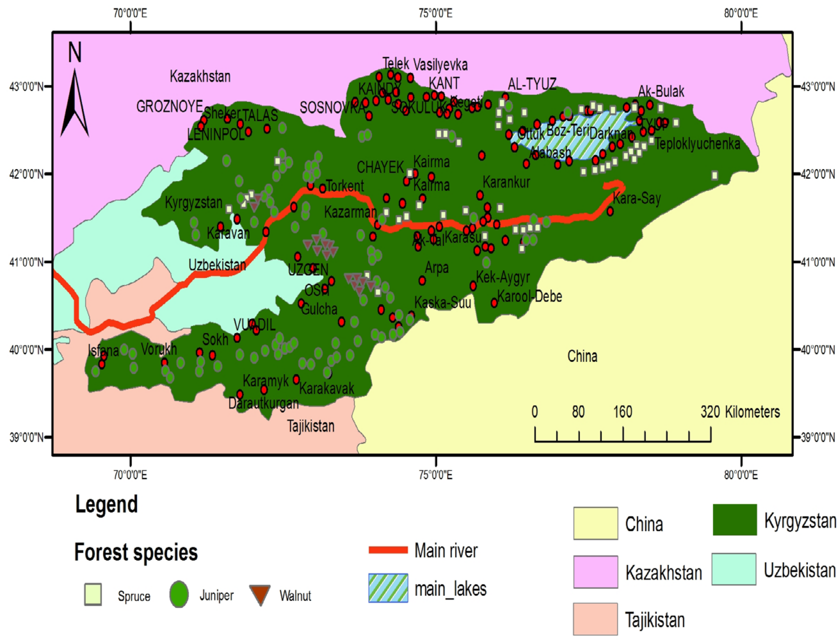

Fig. 2. Cross-border water supply

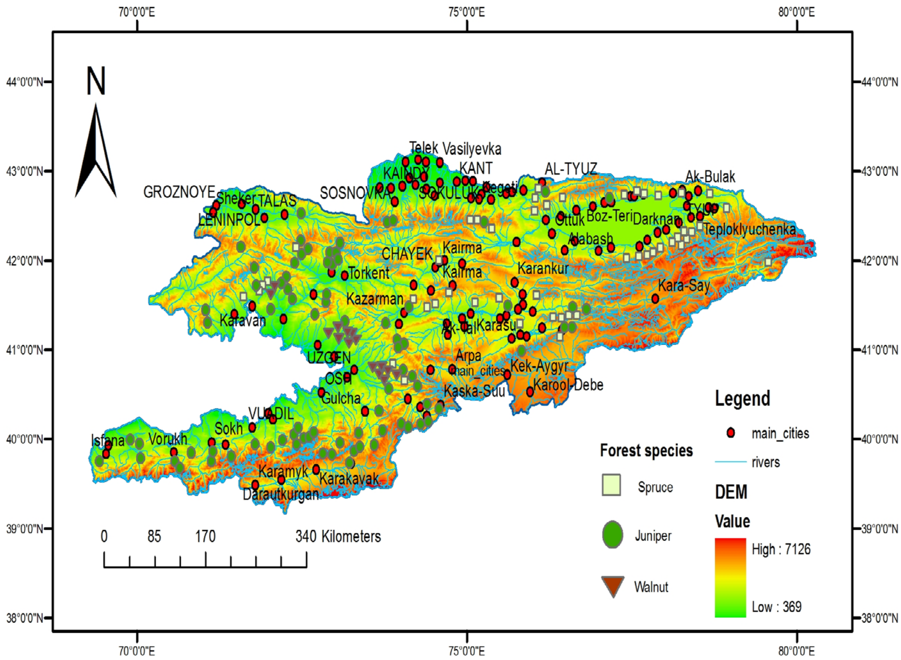

Fig. 3. Overview of occurrence of juniper and walnut forest ecosystems in Kyrgyzstan

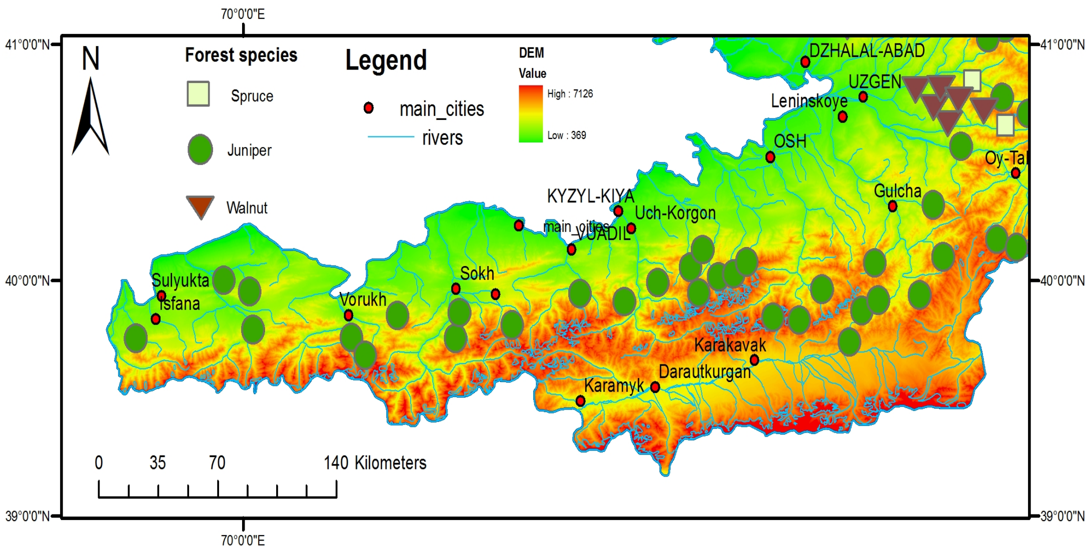

Fig. 4. Juniper distribution in southern Kyrgyzstan (Osh and Batken oblasts)

minimum of -22° C. The duration of the frostless season is on average 180 days, from April to September. Positive average daily temperatures are common from mid-April to mid-October, but cold spells occur frequently in late spring and early autumn.

The soil moisture regime is completely dependent on the intensity of precipitation distribution during the year. The average annual precipitation is 615mm, with 47% of the total annual being observed in spring and the first half of summer. The second half of the vegetation period, August–September, has the least precipitation. Precipitation increases after September. Winter precipitation is 26% of the annual total, with snow cover lasting from November to April and reaching 35cm, rarely up to 70cm.

All rivers originating from the mountains flow into the valley part of the Nookat region and belong to the Syr-Darya river basin. In early spring some of them have manifold flow of temporary streams. These rivers are mainly glacier- and snow-fed with a water regime that is typical for mountainous regions. The annual discharge regime is divided into two distinct periods: spring–summer (floods and autumn–winter (low discharge). The start of the flood season changes from year to year depending on the weather conditions. Floods on the rivers of the Turkestan-Alai mountain chain start on average in early April and end in the second half of August.

Maximum runoff is usually observed in June. Increased runoff during the flood season depends on the dryness of the year, on average ranging from 40 to 70 sm. Minimum runoff is observed in the pre-flood period.

Material and Methods

On the basis of research on the hydrological role of juniper trees, the water balance method was used which provides broad opportunities to identify interaction of moisture exchange in the forest formation. This method of investigation in montane forests was used in order to identify the protection characteristics of juniper forests and to estimate their level of influence on hydrological-physical properties of soil (Kosmynin 1976,1985,1988).

Data collection was facilitated by cartographic material. *Landsat imagery* demonstrates the state of tree, shrub and grassland vegetation, soil and other conditions (Fig. 5, 6). This allowed the use of a differentiated approach for assessing natural resources and planning of actions in the investigated zone.

Studying the hydraulic peculiarities in the "forest-water" system requires modern research methods. Formation of snow cover, interception and distribution of solid precipitation and the snow-melting regime were defined on the basis of snow survey methods with the use of a snow sampler and a snow stake once a month from the first permanent snow cover (October), with more frequent sampling (every 3 - 5 days) during the snow-melting period. Interception of liquid precipitation by the crown layer of junipers and shrubs was measured by use of precipitation gauges.

Results and Discussion

The water-protective and water-regulating role of juniper stands is the conservation of soil moisture on mountain slopes. By preventing formation of overland runoff and its transfer into deeper soil layers, they contribute to moisture accumulation

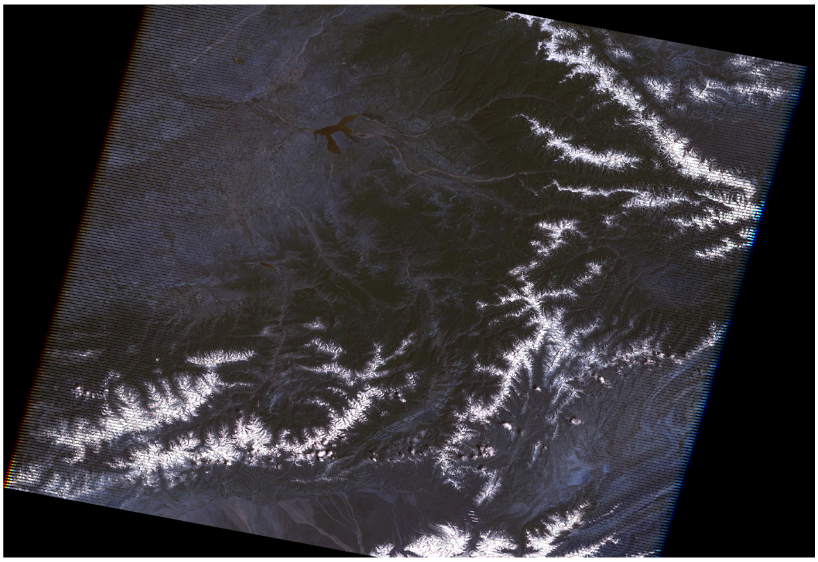

Fig. 5. Landsat image of southern Kyrgyzstan Kara-Darya basin

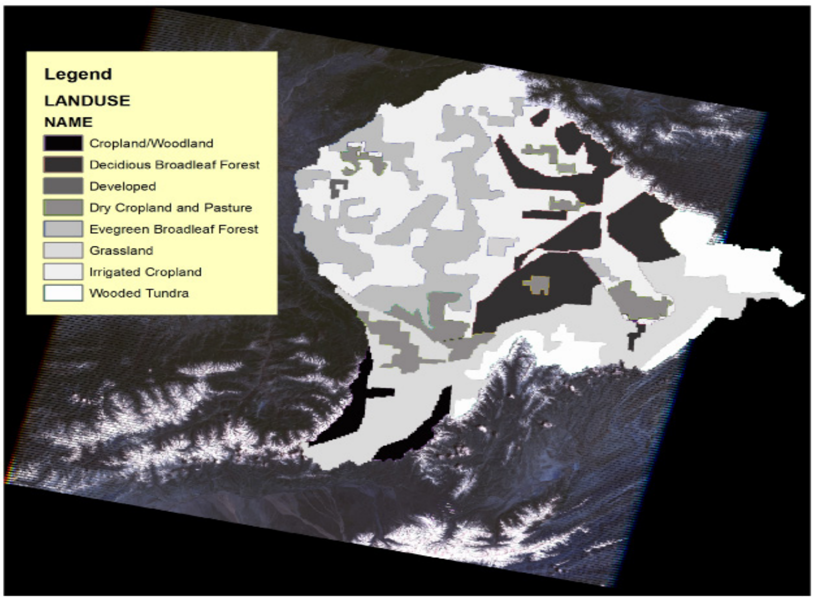

Fig. 6. Landuse of southern Kyrgyzstan Kara-Darya basin

in the soil and its use during the dry part of the vegetation period.

Additionally, the slope-protective role of juniper stands is significant; it depends on the water and physical characteristics of the soil not only in high-density stands but even in open forests. Juniper forests have the strongest impact through mineralization of forest floor outputs and removal to lower areas by fertilizing soil with soil nutrients element and improving soil structure.

Soil types in the main areas of juniper stands, which are more concentrated in middle-mountain and high-mountain sub-belts, are distinguished by higher infiltration capacities compared to treeless areas, which influences the snow-melting regime of juniper stands. The duration of the snow-melting period depends on the weather conditions and varies from 0.5 to 1.5 months. The snow-melting period in juniper stands is prolonged by up to 20 days compared to treeless slopes.

The maximum rate of water loss from snow is balanced, which prevents the formation of snowmelt surface flow. There is no wind-driven snow re-sedimentation in the juniper forest belt, even in open forests, which contributes to bedding snow cover and prevents descent of snow slips. This phenomenon is practically not observed where canopy density is 0.3 - 0.4. Hence, juniper stands also reduce the likelihood of avalanche occurrence. These observations demonstrate the high adaptability of juniper to arid conditions and the significant positive impact of juniper stands on hydraulic regime.

Conclusions

Forests play a key role in water resources production. Trees are water consumers but they also protect soils and hence increase water productivity. Our findings show that the slope-protective role of juniper stands to a considerable extent depends on the water and physical characteristics of the soil both in close and open forests. Juniper forests have the strongest impact through mineralization of forest floor outputs and removal to lower areas by fertilizing soil with soil nutrient elements and improving soil structure.

Research results confirmed that soil in the main areas of juniper stands is distinguished by higher infiltration rates compared to treeless areas. Juniper stands have a significant influence on the snow-melting regime. Experiments proved that wind-driven snow re-sedimentation is not observed in the juniper forest belt and in open forests. This contributes to proportional snow cover and prevents avalanches. This phenomenon is practically not observed when canopy density is 0.3 - 0.4.

Research has shown that the juniper stands of Kyrgyzstan carry out all environment-protective and water-protective functions. We therefore conclude that juniper forests adapt to different natural conditions and have a positive impact on the hydraulic regime of mountain ecosystems.

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