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Characteristics of water-heat fluxes in typical forests and grasslands on the northern slopes of the Qilian Mountains and their influencing factors

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Abstract: *Quantitative assessment of water-heat exchanges between forests and grasslands and the atmosphere in the Qilian Mountains contributes to a deeper understanding of the water cycle and energy balance processes in vegetated ecosystems. In this study, half-hourly and daily water heat flux data of forests and grasslands on the northern slopes of the Qilian Mountains in 2023 were obtained based on eddy covariance techniques, and the daily and seasonal characteristics of latent heat flux (LE), sensible heat fluxe (H), and Bowen ratio (β) of forests and grasslands were compared and analyzed, Structural equation modeling (SEM) and Pearson correlation analysis (Pearson) were used to explore the effects of eight environmental factors, namely, net radiation (Rn), air temperature (Ta), wind speed (u), rainfall (P), saturated vapor pressure difference (VPD), relative humidity (RH), soil temperature (Ts), and volumetric soil water content (VWC), on the water-heat flux. The results of the study showed that (1) the daily changes of LE and H in forest and grassland showed a single-peak pattern, with the daily mean value of LE in forest higher than that in grassland, and the daily mean value of H in grassland higher than that in forest; (2) The seasonal changes of forest and grassland LE are single-peaked, the seasonal changes of H are bimodal, and the seasonal changes of β are U-shaped; the monthly mean value of forest LE is higher than that of grassland, the monthly mean values of grassland H and β are higher than that of forest, and the value of β is greater than 1 in summer, and the value of β is less than 1 in the rest of the seasons, and summer Heat exchange between the earth and air was dominated by latent heat form, and the rest of the season was dominated by sensible heat form; (3) Eight environmental factors were correlated with forest and grassland LE, H, and β in the growing season, and P and SWC were not correlated with forest and grassland LE, H, and β in the non-growing season, and the degree of correlation was stronger in the growing season than in the non-growing season, and the degree of correlation in the grassland was stronger than in the forest. Throughout the year, LE, H, and β are mainly affected by the direct positive influence of Rn, u, and VPD, and the direct negative influence of RH, in addition, Rn indirectly affects LE, H, and β by affecting u, VPD, and RH, and VPD indirectly affects LE, H, and β by affecting RH and u. The results of this study can provide a theoretical basis for the management and effective utilization of forest and grassland water resources on the northern slopes of the Qilian Mountains.*

Keywords: *latent heat flux; sensible heat flux; eddy covariance; environmental factors; north slope of Qilian Mountains*

1. Introduction

There is a continuous circulation of material and energy flow between the surface and the atmosphere [1-3], in which the water-heat flux is a core parameter characterizing the geo-air energy balance, describing the dynamic processes of water vapor and energy between the near-surface atmosphere and the subsurface [4-5]. Water-heat flux include mainly latent heat fluxes, sensible heat fluxes [6], Latent heat flux refers to the energy exchanged between the atmosphere and the subsurface by the phase change of substances, such as the energy absorbed or released by the transpiration of vegetation and the evaporation process of the soil; sensible heat flux refers to the direct transport of energy through the temperature gradient without phase change of substances between the atmosphere and the subsurface [7]. Bowen ratio can reflect the characteristics of surface heat exchange, which affects the energy exchange between the surface and the atmosphere [8], and the magnitude of its value directly reflects the proportion of surface energy distribution between sensible and latent heat. Water-heat flux are affected by a complex of environmental factors such as climate, soil, etc., with net radiation, saturated water vapor pressure

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difference and air temperature being the main environmental factors affecting Water-heat flux [9-10].

Surface flux observation methods include the eddy covariance method, aerodynamic method, Bovinby energy balance method, and large aperture scintillometer method [11-13], among which the eddy covariance method, which is a method based on the principle of micrometeorology and used to measure the energy and mass exchanges between vegetation canopies and the atmosphere [14], which is widely used to determine the characteristics of the changes in the heat fluxes of surface water in agricultural fields, forests, and meadows, as well as their responses to the environmental factors, through the establishment of flux observatory sites in different subsurface for long-term flux observations [15]. Overseas scholars have conducted numerous studies on water heat exchange, and Ando et al. found in the urban built-up area of Sakai City, Osaka Prefecture, Japan, that both sensible heat flux and latent heat flux dominated in summer on the daily scale, with anthropogenic water vapor emissions likely to be responsible for the high latent heat flux in summer [16]; Fischer et al. found that latent heat fluxes decreased and sensible heat fluxes increased after experiencing burning and drought conditions in the southern Great Plains of the United States [17]. At the same time, China has also carried out a large number of studies on water-heat fluxes, including forests, the cold-temperature coniferous forests in the Qilian Mountains [18], deciduous broad-leaved forests in the Songshan Mountains of Beijing [19], larch in the Daxing'anling Mountains [20], mixed mixed coniferous and broad-leaved forests in the Jinyun Mountains of Chongqing [21-22], and tropical monsoon rainforests in Xishuangbanna [23], and other studies have been carried out; In terms of grasslands, desert grasslands [24-26]and steppe meadows [27]in Inner Mongolia and alpine grasslands [28] on the Plateau have been studied.

Qilian Mountains is an important ecological security function area in China, forests and grasslands are important vegetation types in Qilian Mountains, which have an irreplaceable role in regional ecological security, water resource regulation, biodiversity protection and human social development. The current studies on water-heat fluxes in the Qilian Mountains mainly focus on single vegetation types grassland, desert, and forest [29-31], and there is a lack of comparative studies on the water-heat fluxes of different vegetation types, and the studies on the differences in water-heat fluxes between forests and grasslands are still unclear. In view of this, based on the data of water-heat fluxes and environmental factors, this paper takes typical forests and grasslands on the northern slopes of the Qilian Mountains as the research objects to explore the characteristics of water-heat fluxes changes and the relationship with environmental factors. Main objectives: (1) Comparative analysis of the characteristics of daily and seasonal changes in water-heat fluxes in forests and grasslands; (2) Explore the differences in the effects of environmental factors on water-heat fluxes between forests and grasslands.

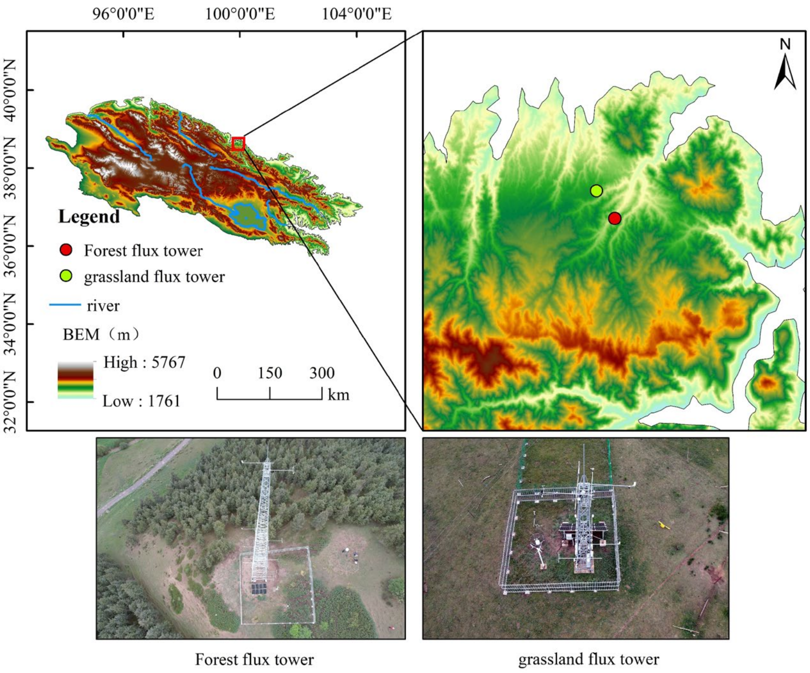

Figure 1: Forest flux towers and grassland flux towers on the northern slopes of the Qilian Mountains in 2023.

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2. Study area

The selected flux tower of the study is located in a typical forest and grassland area in the middle of the northern slope of the Qilian Mountains (Figure 1), which belongs to the plateau continental climate, with an average annual temperature of 5.4°C and an average multi-year precipitation of 300-500 mm, which is mainly concentrated in the months of June-September.

Da Caotan (38°47′8.51″N, 99°54′41.86″E) is a forest flux tower, elevation 2774 m, growing vegetation mainly with Qinghai spruce (*Picea crassifolia Kom*) as the main, the soil type for the Alpine meadow soil as the main; Jiu Paisong(38°48′25.26″N , 99°53′37.41″E) is a grassland flux tower with an elevation of 2962 m. Herbs such as yellow-flowering echinoderma (*Oxytropis ochrocephala Bunge*), ice grass (*Agropyron cristatum*), and marram grass (*Iris lactea Pall*) are common. Gray cinnamon soil is the dominant soil type.

3. Research Methodology

3.1 Observation instrument

The height of the forest flux tower was 30 m and the height of the grassland flux tower was 10 m. Information on the model, observation elements, and mounting height of the observation instruments is shown in Table 1, and the data were collected and stored by the data collector CR6 (Campbell Scientific, Logan, USA) at a frequency of 10 Hz, and a set of averaged data was output every 30 min.

Table 1:Basic information of forest flux tower and grassland flux tower instruments on the north slope of Qilian Mountains in 2023.

observation instrument	model number	Observational elements	Mounting height	
			Forest flux tower	grassland flux tower
Closed Circuit CO_2/H_2O Gas Analyzer	EC155	Water and carbon dioxide concentration	30	10
Three-dimensional ultrasonic anemomete	CSAT3A	Three-dimensional wind speed	30	10
Wind Speed Sensor	W10	u	10	10
Air temperature and humidity sensors	HMP155	Ta, RH	10	10
Four-component radiation sensors	FS-JI	Rn, PAR	10	10
Weighing Rain and Snow Gauge	T200B3	P	0	0
Soil temperature, humidity and salt three-parameter sensor	SM926	Ts, VWC	-0.1	-0.1

3.2 Flux data processing

The acquired 10 Hz raw data were pre-processed by the EasyFlux™ DL online flux calculation program from Campbell, U.S.A. The processing includes: outlier checking and elimination, elimination of delay, coordinate rotation (quadratic coordinate rotation), computation of raw fluxes, ultrasonic false temperature correction, frequency response correction, and at the same time, the flux data were subjected to a data quality check, which was categorized into nine levels (1-3 levels of good data quality; 4-6 levels of good data quality; 7-8 levels of poor data quality; 9 levels of poor data quality need to be considered according to the actual situation. 3 data quality is good; 4-6 data quality is good; 7-8 data quality is poor, according to the actual situation to consider whether to reject, sometimes part of the data is better than interpolated data; 9 data quality is poor, need to be rejected). The data were then sliced and diced into 30 min flux data using LoggnerNet 4.0 software, and the data format was converted from TOA5 to TOB1.

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After preprocessing, the data need to be further processed, and in this study, flux data with a nighttime friction wind speed of less than 0.18 m/s was considered as an outlier to be excluded. The REddyProc package of R4.4.1 software was used to interpolate the data using the look-up table method of interpolation (LUT method), the mean daily change curve method (MDC method), and the sample margin distribution sampling method (MDS method) [32-34].

3.3 Parameter calculation

The latent heat flux, sensible heat flux, and Bowen ratio are calculated as follows[35-36]:

$$LE = \lambda \rho_a \overline{w'q'} \tag{1}$$

$$H = C_p \rho_a \overline{w'T'} \tag{2}$$

$$\beta = H / LE \tag{3}$$

where LE(W/m^{-2})is the latent heat flux; H(W/m^{-2})is the sensible heat flux; and β is the Bowen ratio; (kJ·g^{-1}) is the latent heat of vaporization coefficient of water, which is taken as 2.45 kJ·g^{-1}; ρ_a(kg·m^{-3})is the density of air, which is taken as 1.2 kg·m^{-3}; w'(m·s^{-1}) is the vertical wind speed; q'(g·kg^{-1})is the specific humidity pulsation of air; C_p(J·kg^{-1}·k^{-1})is the specific heat of constant pressure, taken as 1.003 J·kg^{-1}·k^{-1}; T'(k)is the ultrasonic temperature pulsation value.

3.4 Flux Contribution Source Area Calculation

To ensure whether the acquired flux data are spatially representative, the Kormann and Meixner model [37] and the Kljun model [38] were used in this study to simulate the source area for each half-hourly wind direction and 90% contribution at the corresponding moment.

3.5 Data analysis methods

In this study, Pearson correlation analysis was utilized to determine the correlation between water-heat fluxes and environmental factors. With the help of AMOS software, structural equation modeling (SEM) was used to explore the direct and indirect effects of environmental factors on the water-heat fluxes, and when the ratio of degrees of freedom of the chi-square value of the model developed(χ^2/df)<5, comparative goodness of fit (CFI) >0.9, goodness-of-fit index (GFI)>0.9, and root-mean-square error (RMSEA) <0.05 indicate a good model fit and a reasonable model structure [39]. When considering seasonal variations, May to October was selected as the growing season, and the rest of the months were the non-growing season [40,41].

4. Results and analysis

4.1 Flux contribution source area analysis

In order to further determine the source range of flux observation data in the target study area, flux contribution source area analysis was carried out for the forest flux tower and grassland flux tower. The forest flux tower mainly takes the southwest wind as the main wind direction and the northeast wind as the second main wind direction, with an average wind speed of 5.82 m/s during the whole observation time; the grassland flux tower takes the northwest wind and southwest wind as the main wind direction and the east wind as the second main wind direction, with an average wind speed of 5.48 m/s during the whole observation period. The average wind speed during the whole observation period was 5.48 m/s. The source area range of 90% flux contribution from forests is larger than that of grasslands, ranging from 0 to 1200 m for forests and from 0 to 900 m for grasslands. Changes in flux contribution zones are closely related to changes in wind speed, and the 90% flux accumulation contribution points correspond to the main wind direction, with the 90% flux accumulation contribution points in forests mainly distributed in the southwest and northeast directions, and the 90% flux accumulation contribution points in grasslands mainly distributed in the northwest, southwest, and east directions (Figure 2). The forest flux towers and the grassland flux towers are located in locations with large areas of forest and grassland in both the upwind and downwind directions of the prevailing wind direction, so it can be determined that the flux data source range for this eddy observation is within the target study area.

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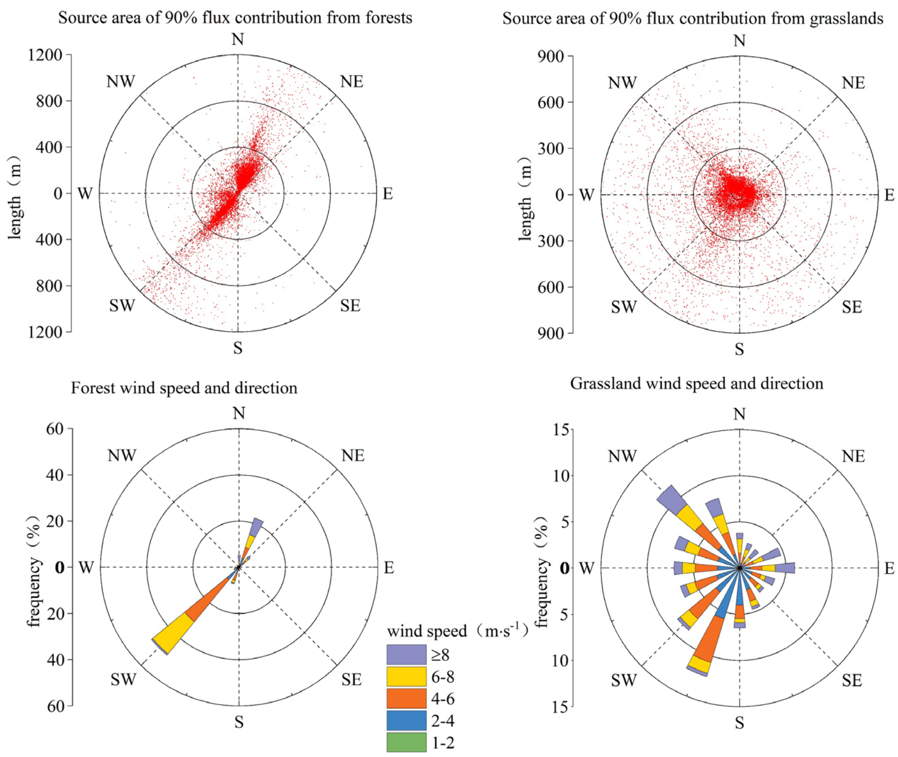

Figure 2: Source area and wind speed and direction distribution of 90% flux contribution from forest towers and grassland towers on the north slope of Qilian Mountains in 2023.

4.2 Comparison of the characterization of changes in water-heat fluxes in forests and grasslands

4.2.1 Daily variation

Both forest and grassland water-heat flux daily changes showed obvious single-peak type characteristics (Figure 3). During the daytime, the water heat flux is mainly controlled by solar radiation and reaches its peak at 12:00~15:00, and then decreases after 15:00; during the nighttime, the change in water heat flux is small, with LE close to zero and H negative. The daily variation of LE was the largest in July, with maximum values of 223.33 $W \cdot m^{-2}$ for forests and 135.74 $W \cdot m^{-2}$ for grasslands, while the daily variation of H was the largest in June, with maximum values of 140.88 $W \cdot m^{-2}$ for forests and 158.09 $W \cdot m^{-2}$ for grasslands.The daily mean of LE was higher for forests than for grasslands, and that for grassland H was higher than for forests.

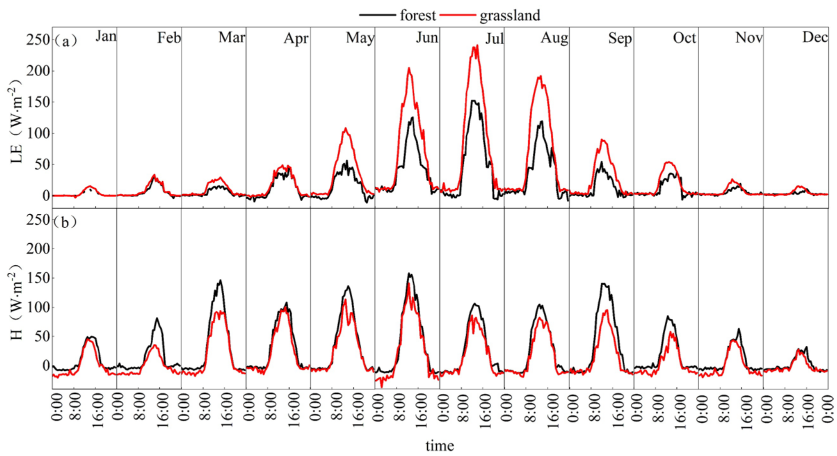

Figure 3: Characteristics of daily changes in water and heat fluxes in forests and grasslands on the northern slopes of the Qilian Mountains in 2023.

Note: (a) latent heat flux, (b) sensible heat flux.

4.2.2 Seasonal changes

Seasonal changes in forest and grassland LE were characterized by a single-peaked pattern, and seasonal changes in H were characterized by a bimodal pattern (Figure 4). Forest and grassland LE was higher than H in summer, and H was higher than LE in other seasons, the monthly mean of LE was maximum in July, 76.37 W·m^{-2}, 43.65 W·m^{-2} for forest and grassland, respectively, and monthly mean of H was maximum in June, 26.74 W·m^{-2} for forest and grassland, respectively , 38.35 W·m^{-2}, the monthly mean value of LE was higher in forest than in grassland, and the monthly mean value of H was higher in grassland than in forest.Seasonal changes of forest and grassland β showed U-shaped characteristics (Figure 5), the monthly mean value of grassland was higher than that of forest, the monthly mean value of β was less than 1 in summer and greater than 1 in the rest of the seasons, the smallest value of β was in July, and the forest and grassland were 0.26 and 0.53, respectively, and the largest value of β was in March, and the forest and Grassland were 2.88 and 5.28 respectively, and the annual mean values of forest and grassland β were 1.16 and 2.33 respectively, indicating that heat was mainly transferred to the atmosphere in latent form in summer, and in sensible form in the rest of the seasons, and in general, heat exchange between the earth and the air throughout the year was dominated by sensible form.

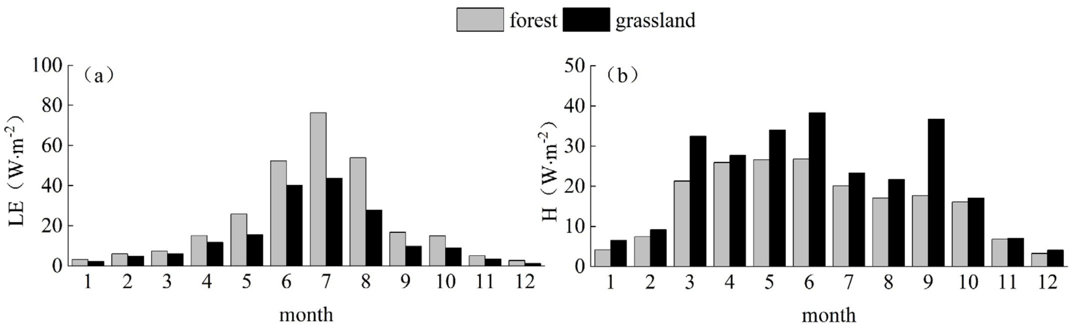

Figure 4: Characteristics of seasonal changes in water-heat fluxes in forests and grasslands on the northern slopes of the Qilian Mountains in 2023.

Note: (a) latent heat flux, (b) sensible heat flux.

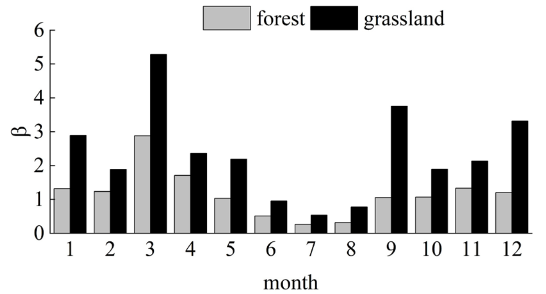

Figure 5: Characteristics of seasonal changes in forest and grassland Bowen ratio on the north slope of Qilian Mountains in 2023.

4.3 Comparison of environmental factors in forests and grasslands

Seasonal changes of forest and grassland Rn, Ta, P, VPD, Ts, and VWC were similarly characterized, with high in summer and fall, and low in winter and spring. u and RH were relatively stable within a year, and seasonal changes were not clearly characterized (Figure 6), with the amplitude of changes of u and RH ranging from 0.81 to 2.58 m·s^{-1} and 11.21 to 92.58% for forests, and from 0.62 to 5.60 m·s^{-1} for grasslands, respectively, 15.80~96.32%. The differences in Ta, P, RH, and VPD between forest and grassland were small due to their close geographical locations. Ta, P, and VPD reached their maximum values in summer, and the maximum values of Ta, P, and VPD were 21.95°C, 38.89 mm, and 20.11 hPa for forests and 21.57°C, 31.20 mm, and 18.15 hPa for grasslands, respectively.RH reaches its maximum value in spring, which is 92.58% and 96.32% for forests and grasslands, respectively. The difference between forest and grassland Rn, u, Ts, VWC is obvious, the forest vegetation is dense, the trees are tall, which can absorb and scatter solar radiation in large quantities, and have a blocking effect on the wind, and the canopy of the trees can block the direct scouring of the soil by the rain, which is conducive to the infiltration and storage of water. The grassland vegetation is low, the solar radiation can reach the ground directly, the terrain is open to the wind blocking effect is small, the plant root system is shallow, the soil moisture retention capacity is weak, resulting in the grassland Rn, Ts, u is higher than the forest, the forest VWC is higher than the grassland, the summer Rn, Ts, VWC reaches the maximum, the forest is 224.57 $W \cdot m^{-2}$, 20.60 °C, 0.24 $m^3 \cdot m^{-3}$, the grassland is respectively 400.31 $W \cdot m^{-2}$, 22.43°C, 0.20 $m^3 \cdot m^{-3}$. u reached its maximum value in spring with 2.58 $m \cdot s^{-1}$ and 5.60 $m \cdot s^{-1}$ for forest and grassland, respectively.

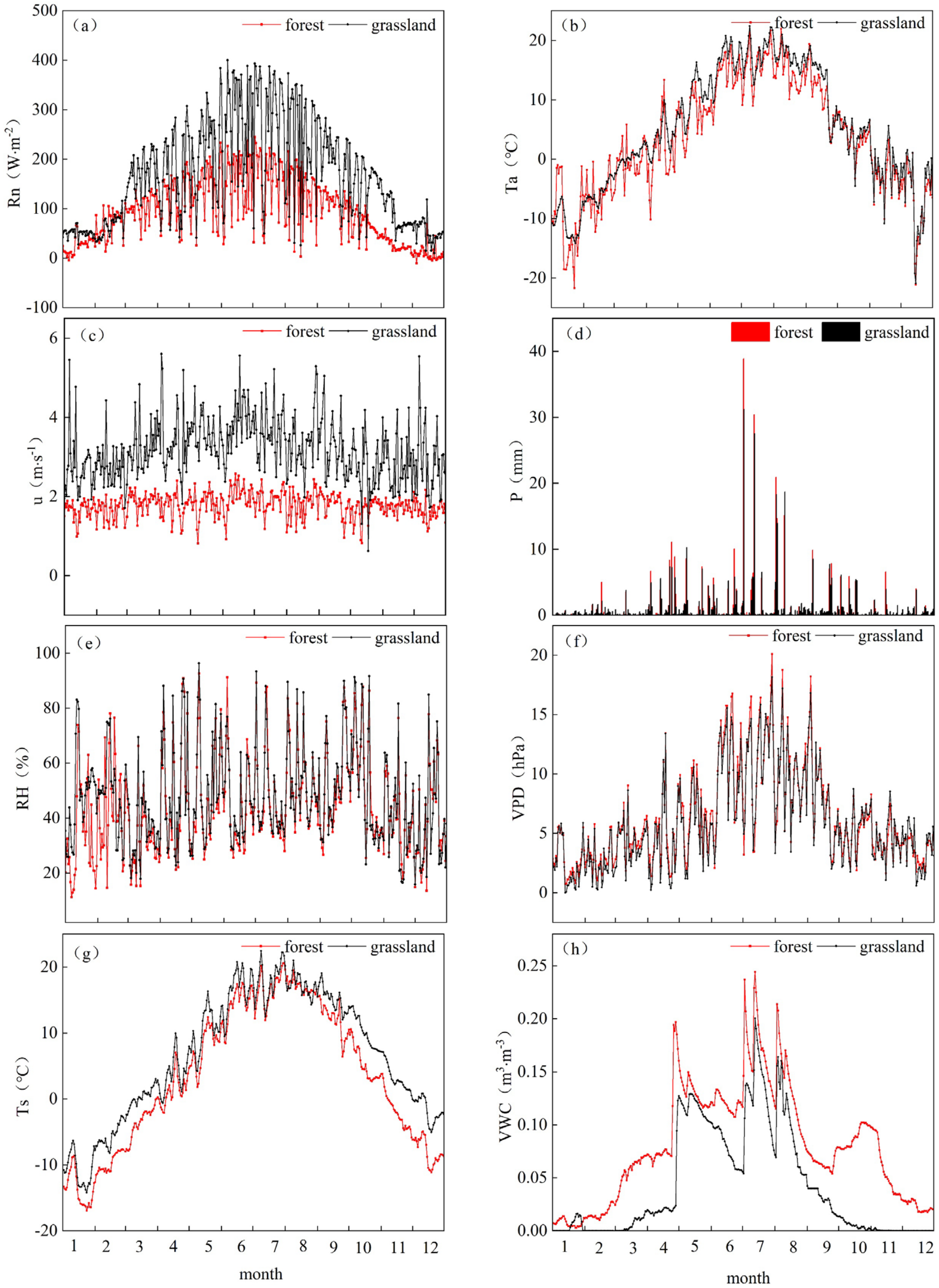

Figure 6: Characterization of seasonal changes in environmental factors of water-heat fluxes in forests and grasslands on the northern slopes of the Qilian Mountains in 2023.

Note: (a) Net radiation, (b) Air temperature, (c) Wind speed, (d) Rainfall, (e) Relative humidity, (f) Saturated vapor pressure difference, (g) Soil temperature, (h) Soil volumetric moisture content.

4.4 Comparison of the effects of forest and grassland environmental factors on water-heat fluxes

4.4.1 Correlation between environmental factors and water-heat fluxes

During the growing season, forest and grassland water-heat fluxes were influenced by Rn, Ta, u, P, VPD, RH, Ts, and VWC (Figure 7), all of which reached highly significant levels ($P<0.001$). Where LE was negatively correlated with RH and positively correlated with Rn, Ta, u, P, VPD, Ts, and VWC; H was positively correlated with Rn, Ta, u, VPD, and Ts, and negatively correlated with P, RH, and VWC. Forest and grassland β were affected by Rn, Ta, u, P, VPD, RH, Ts, and VWC at highly significant levels ($P<0.001$), where β was positively correlated with u and VPD, and negatively correlated with Rn, Ta, P, RH, Ts, and VWC. The correlations between forest and grassland water-heat fluxes and environmental factors were the same in direction, but there were differences in the degree of correlation, with the dominant factor affecting water-heat fluxes being Rn and the dominant factor affecting β the VPD, with grassland water-heat fluxes being more strongly correlated than forests, and grassland β being more strongly correlated with environmental factors than forests.

In the non-growing season, forest and grassland water and heat fluxes were mainly affected by Rn, Ta, u, VPD, RH, and Ts (Figure 7), which all reached highly significant levels ($P<0.001$), where LE was positively correlated with Rn, Ta, u, VPD, and Ts, and negatively correlated with RH; H was positively correlated with Rn, Ta, u, VPD, and Ts, and negatively correlated with RH; forest and grassland β were affected by Rn, Ta, u, VPD, RH, and Ts, all of which reached highly significant levels ($P<0.001$), where β was positively correlated with Rn, Ta, u, VPD, and Ts, and negatively correlated with RH. The degree of influence of grassland environmental factors on water heat fluxes and β was stronger than that of forests, and there were differences in the influence of environmental factors on water heat fluxes at different stages of plant growth, with a stronger influence in the growing season than in the non-growing season, and a correlation between water heat fluxes in the growing season and all eight environmental factors, whereas there was no correlation between water heat fluxes in the non-growing season and P and VWC.

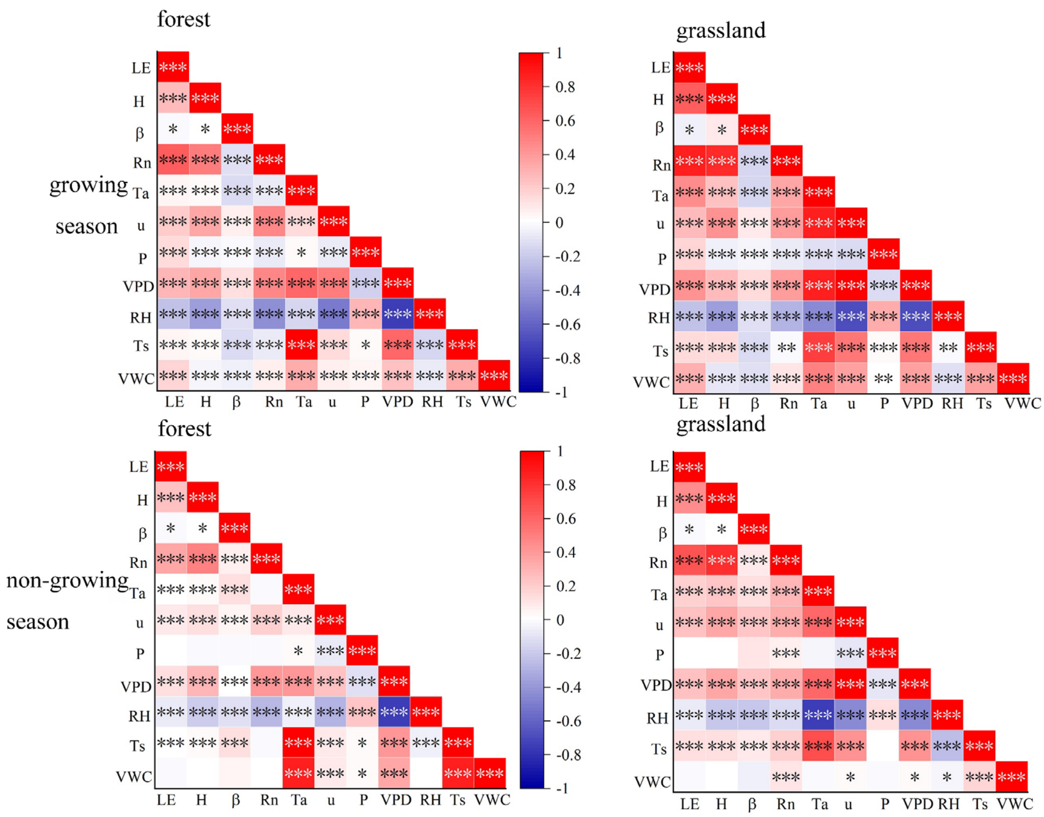

Figure 7: Correlation of forest and grassland water-heat fluxes with environmental factors during growing and non-growing seasons on the north slope of Qilian Mountains in 2023.

*Note: ***represents $p<0.001$, **represents $P<0.01$, *represents $P<0.05$.*

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4.4.2 Pathways of environmental factors on water-heat fluxes

Based on the results of correlation analysis between forest and grassland hydrothermal fluxes and environmental factors in the growing and non-growing seasons, we selected the environmental factors that affect water-heat fluxes to a stronger extent throughout the year: Rn, u, RH, and VPD to construct a structural equation model (SEM), and explored the relative contributions and influence paths of the environmental factors on the water-heat fluxes and the β The model fitting process χ^2/df, CFI, GFI, and RMSEA all met the criteria, and the model fit was good.The results showed that the environmental factors of forests and grasslands had similar pathways of influence on water-heat fluxes and β, and water-heat fluxes and β were directly positively influenced by Rn, u, and VPD, and directly negatively influenced by RH. In addition, Rn indirectly affects water-heat fluxes and β by influencing u, RH, and VPD pairs, and VPD also indirectly affects water-heat fluxes and β by influencing u and RH. Environmental factors explained 45%, 51%, and 20% of LE, H, and β for forests and 71%, 72%, and 27% for grasslands, respectively. Overall the path coefficients and explanatory rates of grassland environmental factors influencing water-heat flux and β were higher than those of forests (Figure 8).

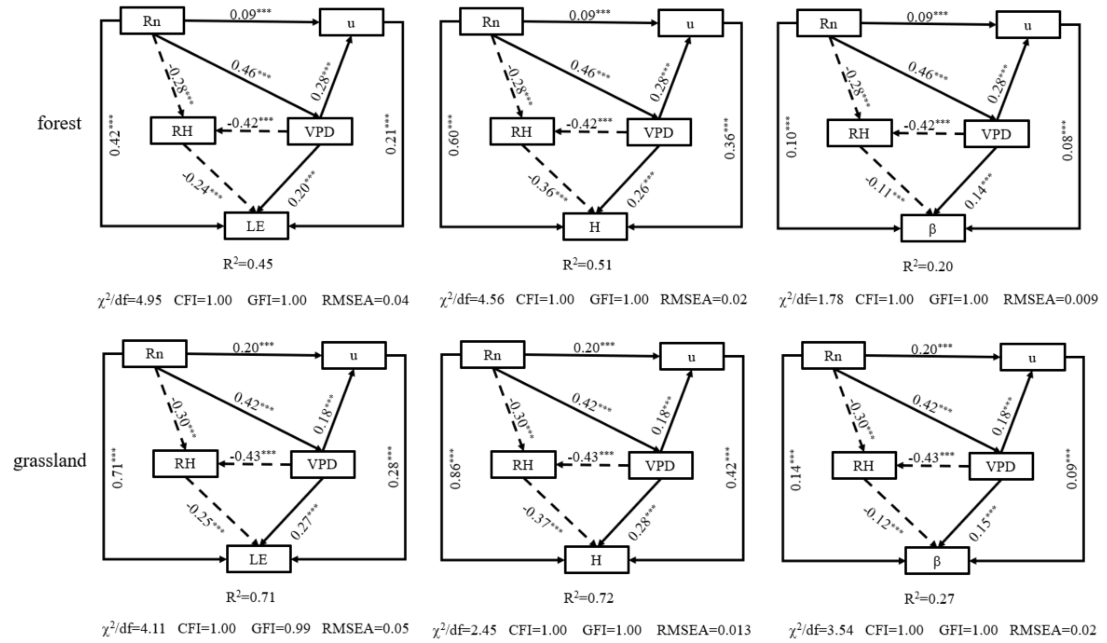

Figure 8: Structural equation modeling of the effects of forest and grassland environmental factors on water-heat fluxes on the northern slopes of the Qilian Mountains in 2023.

Note: The solid line represents the positive impact, the dashed line represents the negative impact, and the coefficients on the arrows represent the path coefficients.
****represents p<0.001, **represents P<0.01, *represents P<0.05.*

5. Discussion

5.1 Comparison of the characterization of changes in water-heat fluxes in forests and grasslands

Both forest and grassland LE and H showed obvious unimodal daily variation characteristics, and solar radiation was the main driving force of the process [26], with positive values during the daytime, peaking at 12:00~15:00, and near-zero values of LE during the nighttime, mainly because of the decrease in nighttime temperatures, weakening of evaporation of water vapor, and reduction of evaporation of water from the surface; and negative values of H during the nighttime, mainly because of the decrease in nighttime surface temperatures, and reduction of heat transfer from the atmosphere to the surface [42], which is consistent with the results obtained by many scholars [28-29, 43-44] on different ecosystems.

In terms of seasonal changes, forest and grassland LE was higher than H in summer, and the opposite in other seasons, mainly due to the vigorous growth of vegetation in summer, high precipitation, strong radiation, high temperature, which is favorable for transpiration of plants and evaporation of soil, and the energy exchange between the earth's air in summer is dominated by latent heat, and other seasons are

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dominated by sensible heat, which is similar to the results of Liu Xuanwo et al [21]. Forests and grasslands differ in their ecosystem characteristics, leading to differences in energy exchange and water utilization, with higher monthly mean LE for forests than for grasslands, and higher monthly mean H for grasslands than for forests, mainly due to the fact that forests have higher vegetation cover and biomass, which allows them to absorb and utilize solar energy more efficiently, and to have significant evapotranspiration and evapotranspiration, and thus a higher LE. Grasslands, on the other hand, have higher H due to low vegetation cover and the soil surface is more susceptible to direct heating by solar radiation. The seasonal variation of H and LE is further characterized by a U-shaped seasonal variation of β, with grasslands being higher than forests, which is the same as that of Songyu Huang et al [45] and Huiqing et al.

5.2 Comparison of the effects of forest and grassland environmental factors on water-heat fluxes

Material cycling and energy flow between the earth and air are affected by a variety of environmental factors[44], and forest and grassland LE and H are positively correlated with Rn, Ta, u, VPD, and Ts, and negatively correlated with RH during the growing and non-growing seasons, with Rn having the strongest positive effect, mainly due to the fact that solar radiation, as the main energy input, causes the surface temperature to rise, and vegetation consumes water through photosynthesis and transpiration. LE increased in this process. At the same time, H also increases due to the enhanced heat exchange between the surface and the lower atmosphere;Higher VPD increases the transpiration rate of plants, which leads to more water evaporation from the soil and vegetation, increasing LE, and the process of water evaporation, which consumes surface heat, thus increasing H; Ts and Ta promote water evaporation and energy exchange between the ground and air, which increases the water heat flux; the water vapor content of the air increases when RH is increased, which lowers the water vapor gradient, thus decreasing the evaporation and transpiration rates, the LE decreases, and under high RH conditions, the heat capacity of air increases, heat transfer efficiency decreases, and H decreases; an increase in u increases the turbulent motion of air, which promotes the exchange of heat and water vapor, resulting in an increase in the water-heat flux. Growing season forest and grassland P and VWC are positively correlated with LE and negatively correlated with H. This is mainly due to the fact that in the growing season, an increase in P leads to a rise in VWC, more water is available for evapotranspiration, and LE increases, and on the contrary, when P decreases and the soil dries out, the surface temperature increases and H increases, in agreement with the results of Xia Lu et al. In the non-growing season, vegetation cover is low, precipitation is low, soil is dry, evaporation of water and transpiration of plants are inhibited, and there is no correlation between P and VWC contributing little to LE and H.

The correlations of forest and grassland environmental factors on water heat fluxes and β were higher in the growing season than in the non-growing season, mainly due to the greater variation of environmental factors in the growing season, and the more vigorous physiological activities of plants, which made them more sensitive to changes in environmental factors. The degree of influence of grassland environmental factors on water-heat flux and β was higher than that of forests, mainly due to the relatively low vegetation cover and relatively simple vegetation structure of grasslands, which made the surface of grasslands more susceptible to the influence of environmental factors. In contrast, forests have high vegetation cover and complex vegetation structure, which can effectively block and absorb solar radiation and reduce the fluctuation of surface temperature, thus exerting a certain buffering effect on water-heat flux.

6. Conclusion

In this paper, flux data of forest and grassland on the north slope of Qilian Mountains in 2023 were obtained based on eddy correlation technique, and the daily and seasonal changes of water-heat fluxes of forests and grasslands were analyzed comparatively and the differences in the impacts of environmental factors of forests and grasslands on water-heat fluxes were explored. The following conclusions were drawn:

(1) Daily changes in water-heat fluxes in forests and grasslands were unimodal, with daily changes in LE being the largest in July and daily changes in H being the largest in June, with daily means of LE higher in forests than in grasslands, and daily means of H higher in grasslands than in forests.

(2) The seasonal changes of LE in both forests and grasslands are of a single-peak type, the seasonal changes of H are of a double-peak type, and the seasonal changes of β are of a U-shape. The monthly mean value of forest LE is higher than that of grassland, the monthly mean value of grassland H and β is

higher than that of forest, and the heat exchange between forest and grassland land and air in summer is dominated by latent heat, and the rest of the seasons are dominated by sensible heat, and the annual average β of forest and grassland is 1.16 and 2.33, respectively, with sensible heat as the main form of heat exchange throughout the year.

(3) Forest and grassland hydrothermal fluxes and β were correlated with Rn, Ta, u, P, VPD, RH, Ts, and VWC in the growing season, while water-heat fluxes and β were not correlated with P and VWC in the non-growing season, and the effects of environmental factors on water-heat fluxes and β existed in different growth stages, with the degree of influence of environmental factors on water-heat fluxes and β stronger than that of forests in the growing season. differences, the degree of influence of environmental factors on water-heat fluxes and β was stronger in the growing season than in the non-growing season, and the degree of influence of environmental factors on water-heat fluxes and β was stronger in the grassland than in the forest, and through the path analysis of the structural equation modeling, the environmental factors that had a stronger influence on water-heat fluxes and β throughout the year were Rn, u, and RH, VPD, these four environmental factors not only have direct influence on water heat flux and β, but Rn also indirectly influences water heat flux and β by influencing u, RH, and VPD, and VPD indirectly influences water heat flux and β by influencing u and RH.

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