Research progress on influence factors and models of rainfall redistribution under the action of vegetation

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Abstract: Vegetation redistribution of rainfall is an important hydrological phenomenon in the hydrological cycle, and has been paid attention to for a long time. Based on the systematic analysis of the influence factors of rainfall redistribution, the research progress of vegetation under the action of rainfall redistribution model was summarized, and the problems existing in the research and further research issues are discussed.

Introduction

Vegetation on the process of rainfall redistribution is the process of the interception and shunt of the parts of the plant. It can be divided into canopy interception, additional rainfall, falling rain, rainfall, trunk absorption and stem flow [1-4]. Vegetation on the process of rainfall redistribution as an important hydrological process, not only changed the number of basin water inputs, output, the distribution of time and space, but also changed the energy of rainwater falling to the ground, which in turn affected the water balance and soil erosion in the basin [5-10].In this process, the canopy interception reduces the actual amount of rain reaching the ground and reduces the actual rainfall in the woodland [5-6]; The formation of stem flow, resulting in the formation of local areas of the source of full flow, which has an important impact on nutrients and mineral elements of the transfer in the forest ecosystem [5-8].Therefore, the redistribution of vegetation to rainfall has a very important ecological function in vegetation ecosystem [11].With the improvement of ecological environment construction and the improvement of forest coverage, it is very important to summarize the existing achievements in the research of rainfall redistribution, which is of great significance to the future ecological environment construction and forest ecological water cycle.

1. Effects of vegetation structure on rainfall redistribution

At present, the research on rainfall redistribution of vegetation at home and abroad is mainly concentrated in tropical rain forest area, coniferous forest area and arbor irrigation area of Loess Plateau, mainly discussing the effect of vegetation on the distribution and spatial distribution of rainfall and seeing more small scale research, large-scale research are rare [12 - 16]. The general interception of canopy in a rainfall is between3-10 cm [14-16].

Vegetation types grown in different regions have different effects on rainfall redistribution. It can be seen from Table 1 that the canopy interception rate of pine forest is about 25%, the Canopy penetration rate is about 75%, the stem flow rate is about 1%; the canopy interception rate of Birch forest is about 15%, the Canopy penetration rate is about 85%, the stem flow rate is about 0.5%; the canopy interception rate of Shrub is about 25%, the Canopy penetration rate is about 80%, the stem flow rate is about 2%. Can be drawn, canopy interception rate coniferous forest> broadleaf forest> shrub; canopy penetration rate broadleaf forest> shrub> coniferous forest; stem flow rate broadleaf forest> shrub> coniferous forest. This conclusion is the same as that of Wang Chaohua [17] and Wang Sufang [18]. The reason is that the coniferous forest is lush, the vertical directions are many levels, and the unit leaf area is larger, so the canopy interception is relatively large and the Canopy penetration is relatively small. The stem flow rate is closely related to the height of the canopy, the vertical angle of the branches, the percentage of the branches, and the size of the leaves. In general, the greater the height of the canopy, the smaller the vertical angles of the branches, the greater the proportion of branches, the smaller the leaves, the greater the stem flow.

Table 1 Rainfall redistribution characteristics under different vegetation types.

Vegetation type	Rainfall /mm	Research cite	Research period (Month)	Canopy interception /mm	Canopy interception rate /%	Penetrate the rainfall /mm	Penetrate the rainfall rate/%	Stem flow /mm	Stem flow rate /%
Larch forest	396.01	Mohe	7-8	92.23	23.29	303.20	76.57	0.56	0.14
Larch forest	262.19	Root river	6-9	40.25	15.35	213.39	81.39	8.55	3.26
Natural Pinussylvestris forest	493.12	Mohe	7-9	123.48	25.04	362.85	73.58	6.79	1.38
Deciduous Artificial Pine forest	236.62	Jiagedaqi	5-9	94.40	39.89	141.40	59.76	0.82	0.35
Pinussylvestris plantation	236.62	Jiagedaqi	5-9	73.23	30.95	162.11	68.51	1.28	0.54
Salix shrub	136.75	Yulin	5-11	33.97	24.90	98.50	72.20	4.00	2.94
Larch forest	727.75	LiuPanShan	5-10	123.90	17.03	602.00	82.75	1.40	0.22
Birch forest	727.75	LiuPanShan	5-10	100.10	13.76	625.00	85.91	2.40	0.33

2. Rainfall distribution model under vegetation

The redistribution of vegetation to rainfall is a complicated process with many factors. Many researchers try to use the knowledge of hydrology and hydraulics to construct the empirical simulation and semi-empirical semi-theoretical model of canopy interception.

2.1 Canopy interception model

Calculation of canopy interception usually uses the principle of water balance [16-17]. During rainfall, the relationship between canopy interception and rainfall redistribution is as follows:

$$\boldsymbol{IC=P—TF—SF} \tag{1}$$

There—the rainfall; ***TF*** — penetrating rainfall; ***SF*** — the stem flow; ***IC*** —the canopy interception. By collecting the data after rainfall, the rainfall and the stem flow were obtained, and then the empirical formula of canopy interception was obtained by substitution of formula (1). This empirical formula has the advantage of eliminating the need for complex theoretical deductions, but ignoring rainfall characteristics such as rainfall, rainfall intensity, rainfall duration and vegetation characteristics such as vegetation type, canopy thickness, leaf area index and temperature and other factors, and lacks of rainfall characteristics and vegetation characteristics of the conditions of constraints, likely to cause greater error.

Cash [20] analytical model divides the canopy interception process into three stages: the canopy humidification, the canopy saturation, and the canopy after the rain is stopped, and assumes that canopy is dry degree before every rainfall events. The model only considers the case of canopy closure, and think that the vegetation interception evaporation has nothing to do with the vegetation interception, so when the stand is not closed, the canopy interception will be overestimated. The modified Gash model [21] introduced the vegetation coverage parameter and assumed that the vegetation-free area did not evaporate. The modified Gash model is as follows

$$\sum_{j=1}^{n+m} I_j = ncP' + (c\overline{E_c}/\overline{R})\sum_{j=1}^{n}(P_{Gj} - P'_G) + c\sum_{j=1}^{m} P_{Gj} + qSc + P^t\sum_{j=1}^{n-q} Pq \tag{2}$$

$$P'_G = \left(-\frac{\overline{R}Sc}{\overline{E_c}}\right)\ln\left[1 - \frac{c\overline{E_c}}{\overline{R}}\right] \tag{3}$$

There,I_j—Interception; S—Maximum interception; $\overline{R}$—Average rain intensity; Pt—Interception factor;P'_G—the canopy reaches the saturation of the rainfall;P_{Gj}—the total rainfall in the j the field; n, m, q—Number of times of rainfall; j—Serial number; c—area; $\overline{E_c}$—the average evaporation rate of saturated canopy.

Fan Shixiang [22] learns from the theory of "full runoff", and the forest canopy interception model was proposed with which the forest is completely closed and the forest is not completely under the condition of the case. The stand is completely closed down: If the amount of rainfall is P, The canopy of the stranded formula is as follows：

$$I = \frac{H}{\beta + 1}\left[1 - \left(1 - \frac{P}{H}\right)^{\beta+1}\right] \tag{4}$$

If $W = \frac{H}{\beta+1}$ (5)

So $I = W\left[1 - \left(1 - \frac{P}{H}\right)^{\beta+1}\right]$ (6)

The stand is not completely closed down:

If $P<H$， $I = \alpha W\left[1 - \left(1 - \frac{P}{H}\right)^{\beta+1}\right]$ (7)

If $P\geq H$， $I = \alpha W$ (8)

There, H—Saturated interception in the thickest canopy;β—comprehensive parameter, which is closely related to the stand characteristics such as the uniformity of the canopy layer thickness, the forest species, the age of the tree.α —Canopy density; The formulas (6) and (7) are the canopy interception ability models of the general stand with the canopy density of α; The model is not affected by meteorological factors such as rainfall characteristics, and the physical meaning of the parameters is clear, which can be used to compare the size of the canopy interception rainfall between different forest types. However, the model can't fully reflect the other basic characteristics of forest stands, such as leaf area index, tree species composition and age, and still need to be summarized by the three parameters (β, W and H) in the model. In addition, the parameters of the model need to refer to the measured data, for the absence of measured data area, the application of the model is restrictive.

2.2 Penetration rainfall model

Liu Jiagang [23] proposed a semi-theoretical model of penetrating rain rate based on canopy destiny in 2000. YouZhen [2] think canopy drip formation needs certain rainfall, and the penetration rate of the formula is improved:

$$T_T = \begin{cases} 1 - S + Se^{-BDG}(P \geq P_0) & (9) \\ 1 - S \qquad (P < P_0) & (10) \end{cases}$$

There,T_T—Penetrate the rainfall rate, ％; S— Canopy destiny, ％;B —Forest leaf area index; D—Canopy dryness; G— Projection ratio on foliage ground; P —the rainfall, mm;P_0—Penetrate the critical rainfall; The advantages of this model can reflect the time variation of rainfall in the forest, the disadvantage is that the parameters are not easy to determine, especially penetrating the critical rainfall, likely to cause greater error.

2.3 stem flow model

PeiTiefan [25] studied the runoff process of trunk by simulation experiment, and revealed the mechanism and regularity of stem flow. Formula is as follows：

$$\begin{cases} \dfrac{\partial H(x,t)}{\partial t} = B(x,t) - \dfrac{\partial F(x,t)}{\partial x} & (11) \\ F(x,t) = f\big(H(x,t)\big) & (12) \\ f\big(H(x,t)\big) = \begin{cases} 0 & (H \le H_0) \\ K((H-H_0)\sin A)^5 & (H > H_0) \end{cases} & \begin{matrix}(13)\\(14)\end{matrix} \\ B = 2PIQ\sin\beta\cos\beta & (15) \end{cases}$$

There, ***X***—One-dimensional branches on the coordinates of the location; ***t***—time; ***H***—Branch unit surface area of water;H_0—The minimum depth of water required for the branches to produce water; ***B***—The net inflow on the surface of the branch unit; ***F***—Branch surface flow; ***K***—Flow coefficient; ***P***—Scale factor; ***A***—Branch and horizontal angle; β—Branch angle; ***Q***—Leaf area index; ***I***—Rain strong; ***H***, ***F***, and ***B*** are functions of coordinate x and time ***T***.

You Zhen [2] and Dang Hongzhong [19] think that the emergence of the stem flow need to reach a certain amount of rainfall and the stem flow and rainfall and rain intensity has a significant positive correlation. So the stem flow function can be expressed by the following formula:

$$\begin{cases} Q = 0 & P < P_1 & (16) \\ Q = kM(U,L) & P \ge P_1 & (17) \end{cases}$$

There, ***Q***—Stem flow, mm; ***k***—Rainfall characteristics; ***M (U，L)*** —The function of the branch characteristic;P_1—Produce the critical rainfall required for the stem flow, mm;

3. Problems and Prospects

In summary, the effect of vegetation on the redistribution of rainfall has been comprehensive understanding, and trying to construct the canopy interception, penetrate the rainfall, the stem flow model, to explain the vegetation on the role of redistribution mechanism and law. However, there are still many problems that need to be further studied in view of the complexity of vegetation redistribution and the diversity of influencing factors. Combined with the seasonal variation and growing age of the vegetation, it is feasible to strengthen the application of remote sensing in determining the characteristics of forest by features by using the similarity theory to describe the spatial structure of vegetation. Enhancing the application of seamless continuous observation of remote sensing data with high spectral resolution and high spatial resolution can be used to improve model accuracy and parameter availability, and to extend the scope of application of the model. While the leaf area index as an important parameter of vegetation characteristics need to further strengthen the study.

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