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Rainfall Distribution in the Srepok River Basin (Vietnam)

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Srepok is an international river basin in the Central Highlands in Vietnam with an area of about 18,230 km², and is divided into ten irrigation sub-basins. This study applies the statistical method to assess the distribution of rainfall in the past using observed data (1981–2020) and the downscaling method to predict for the periods 2021–2040, 2041–2060, 2061–2080, and 2081–2100 under the medium and high emission scenarios (SSP2-4.5 and SSP3-7.0). Based on observed data, the annual rainfall in 1981–2020 decreased gradually from the North and South to the center and decreased from the West to the East of the basin. Rainfall (May to October) in the rainy season reached 1,494 mm, accounting for 84.4% of annual rainfall. Under both SSP2-4.5 and SSP3-7.0 scenarios, the annual rainfall in the basin and the irrigation sub-basins tends to decrease. The low rainfall area tends to expand every 2 decades to the end of the 21st century. The rainfall amounts do not change between the periods in the dry season but tend to decrease in the rainy season. The rainfall tends to increase from the East to the West of the basin in the rainy season and from the North to the South in the dry season. However, monthly and annual rainfall between periods is relatively stable under the SSP2-4.5 scenario.

Keywords: Rainfall, distribution, Srepok river basin and CMIP6.

Introduction

Global warming, rising sea levels, and extreme events have made the effects of climate change evident worldwide. Changes in precipitation, one consequence of global warming, directly affect World agriculture, especially tropical agriculture. Recent erratic changes in rainfall distribution, including floods, droughts, and famines, lead to reduced agricultural yields and growing food insecurity.

The distribution of rainfall depends on the geographical zone and seasonal characteristics. The tropical region receives more rainfall than deserts.

More extraordinary places like the poles do not receive rain because it is transferred to snow before landing on the ground. The planning of agriculture in the world is built based on the distribution characteristics of rainfall. The reservoirs, irrigation networks, and urban water supply systems are designed according to the average annual rainfall. Heavy and continuous rainfall for an extended period is a reason for flooding and subsequent disaster to the infrastructure. Light or no rainfall for an extended period in an inhabited area can lead to drought and famine.

The planning of agriculture in the world is built primarily based on the distribution characteristics

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Table 1. Rainfall stations in the Srepok river basin

No.	Rainfall Station	Latitude	Longitude	No.	Rainfall Station	Latitude	Longitude
1	Ban Don	12°54'N	107°46'E	8	Ea Knop	12°48'N	108°27'E
2	Buon Ho	12°55'N	108°16'E	9	Ea Soup	13°04'N	107°53'E
3	Buon Ma Thuot	12°40'N	108°03'E	10	Giang Son	12°30'N	108°12'E
4	Cau 14	12°36'N	107°56'E	11	Krong Bong	12°33'N	108°24'E
5	Cau 42	12°45'N	108°26'E	12	Lak	12°22'N	108°12'E
6	Ea Hding	12°54'N	108°07'E	13	Dak Mil	12°27'N	107°37'E
7	EA Hleo	13°13'N	108°12'E	14	Duc Xuyen	12°17'N	107°59'E

of rainfall, which depend on the geographical zone and seasonal factors. While the tropical region receives more rainfall than the deserts, more extraordinary places like the poles do not receive rain because it is transferred to snow before landing on the ground. The reservoirs, irrigation networks, and urban water supply systems are designed according to the average annual rainfall. Heavy and continuous rainfall for an extended period is a reason for flooding and subsequent disaster to the infrastructure. Light or no rainfall for an extended period in an inhabited area can lead to drought and famine.

Previous studies on temporal and spatial rainfall distribution often used observed data [1–4]. Recently, data from the World Climate Research Program has been used with diverse scenarios and forecast periods to predict future rainfall distribution [5–7]. The Coupled Model Intercomparison Project, started in 1995 under the support of the World Climate Research Program (WCRP), is currently in phase six (CMIP6) [8].

To date, there are some studies on the rainfall distribution of the Srepok River basin and the part of the river basin in the territory of Vietnam [9–13]. Vietnam has also developed climate change scenarios [14]. However, past climate changes were only considered with the series of observed data up to 2018 and other scenarios were built with development scenarios from the CMIP5 phase. This study will assess the distribution of rainfall in the period 2001 to 2020 by using statistical and GIS methods. To evaluate and predict the future rainfall distribution, this study extracts data from the ACCESS-ESM1-5 model (Australia) of CMIP6 with a resolution of 1km. With this resolution, the study can calculate the rainfall for the sub-basins to manage and exploit water resources in the basin. Calculation results are performed for 2021–2040, 2041–2060, 2061–2080,

and 2081–2100 under SSP2-4.5 (medium emission) and SSP3-7.0 (high emission) scenarios. The study results are the scientific basis for the integrated management of water resources for the basin.

Study area and Methodology

The Srepok River originates from Dak Lak—Vietnam, and flows through Monduliri province in Cambodia's territory. The basin's total area is 30,100 km², and the length of the main river is 371 km. The basin part of Vietnam's territory has an area of 18,230 km², accounting for 60.5% of the whole basin. In the territory of Vietnam, the Srepok River is located in four provinces (**Fig. 1**): Dak Lak (10,420 km²), Dak Nong (3,610 km²), Gia Lai (2,900 km²), Lam Dong (1,300 km²). The area of agricultural land in the Srepok River basin is 758,897 ha [15]. The annual crop area is around 404,829 ha, of which the area for winter-spring rice is 49,467 ha, summer rice is 81,512 ha, corn is 170,741 ha, sweet potatoes is 12,524 ha, cassava is 58,693 ha, and sugarcane is 31,128 ha. The perennial crop area is around 354,265 ha, of which the area for coffee cultivation is 330,714 ha, and fruit tree cultivation is 23,268 ha. The entire Srepok River basin is divided into 10 irrigation sub-basins (Krong Pach, Krong Bong, Dak R'mang, Dak Krong No, Lower Srepok, Krong Buk, Krong Ana, Dak Pri, Ea Lop, and Ea Sup) and illustrated in **Fig. 2** [16]. In the case of a large basin, the division into 10 irrigation sub-basins is suitable for water resource management. Some irrigation sub-basins do not have gauging stations, therefore the prediction of the spatial distribution of rainfall will support the allocation of water resources in the basin in the most reasonable way.

This study uses the observed data at the gauging stations to evaluate the rainfall distribution in the Srepok River basin in the past. Currently, there are 14 stations in the basin with rainfall data. The posi-

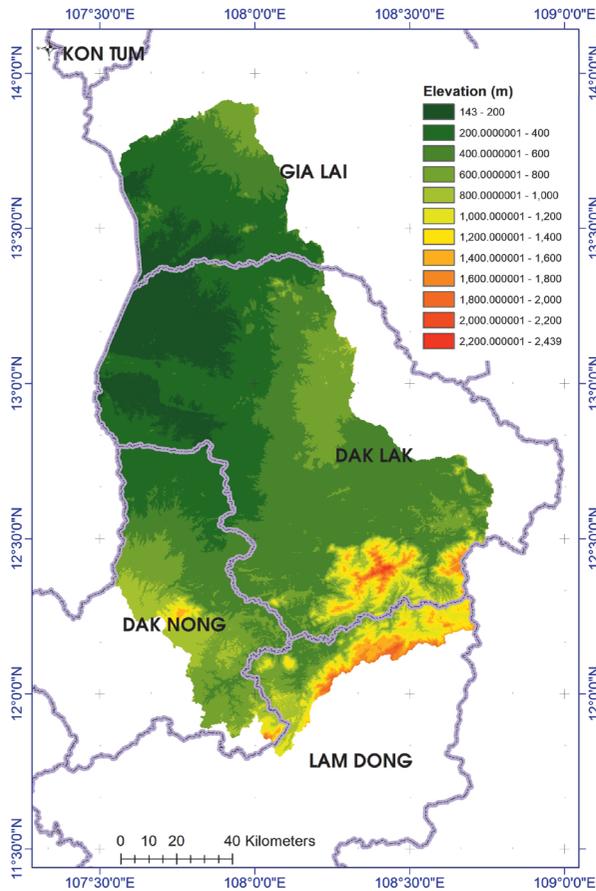


Fig. 1. Topographic map of Srepok River basin

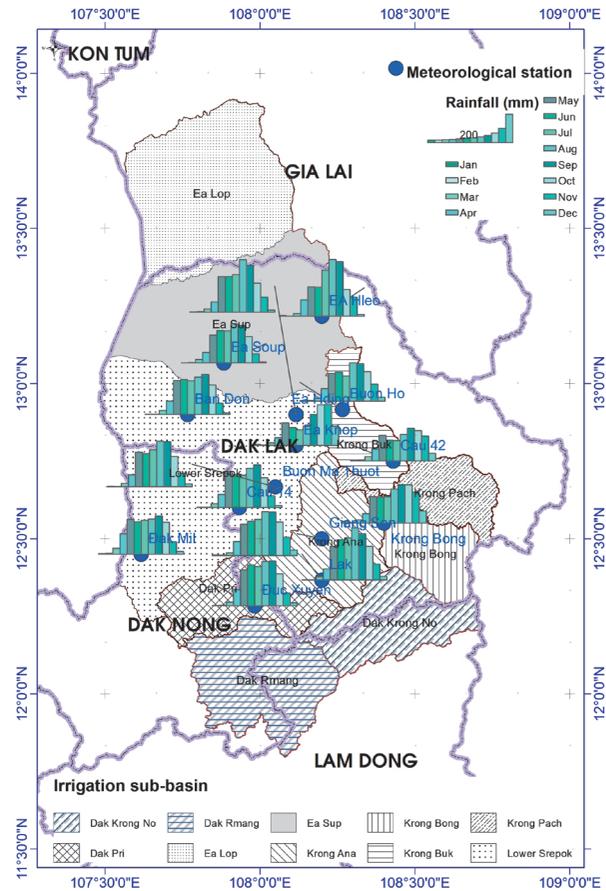


Fig. 2. Rainfall distribution at gauging stations in the Srepok River basin

tion of the rain gauge stations is presented in *Tab. 1* and illustrated in *Fig. 2*. This study applies statistical methods to calculate and evaluate the rainfall distribution in the past.

To predict the future rainfall distribution in the Srepok River basin, this study applies the downscaling method to get the data according to the Coupled Model Intercomparison Project (CMIP6) scenarios. The latest version of the scenarios in CMIP6 based on the Shared Socio-Economic Pathways (SSP) was outlined in the IPCC Sixth Assessment Report (AR6) [11]. The scenarios based on SSP are the most complex, from expected reductions to continued emissions growth. The precipitation data of CMIP6 was used in the research on rainfall in the islands of Vietnam [9]. The precipitation data from the ACCESS-ESM1-5 model (Australia) at a resolution of 1km under the medium and high emission scenarios (SSP2-4.5 and SSP3-7.0) for the study area was calculated to evaluate the future rainfall distribution in the periods of 2021–2040, 2041–2060, 2061–2080 and 2081–2100.

Results and Discussions

The Srepok River basin is located in the middle of the Central Highlands. The rainfall amount in the South of the basin is smaller than in the northern Central Highlands, as there are many high mountains, which are watersheds between the Srepok and Dong Nai rivers, to block the southwest wind. Rainfall in the Srepok River basin depends closely on its topographic characteristics.

The distribution of average monthly rainfall at gauging stations in the Srepok River basin is presented in *Fig. 2* using observed data from 1981–2020. The average rainfall in the basin reaches about 1,700–1,800 mm, ranging from 1,440 to 1,968 mm. Rainfall in the Easup, Krong Buk, and Krong Pack sub-basins is usually as low as 1,500 mm. Sub-basins in the Southwestern basin, such as Dak Pri, Krong Ana, Dak R'Mang, and Dak Krong No, typically have an annual rainfall of approximately 2,000 mm/year. The northern area of the basin in Gia Lai province also has high rainfall. Thus, the yearly rainfall tends to decrease gradually from North and South direc-

Table 2. The rainfall in months in rainy season under SSP2-4.5 scenario (mm)

Month	SSP2-4.5			
	2021–2040	2041–2060	2061–2080	2081–2100
May	168.3	129.3	124.9	121.9
June	192.1	167.9	161.0	159.2
July	290.8	286.1	286.6	281.9
August	284.0	272.1	267.7	263.1
September	321.5	293.9	297.2	295.0
October	253.0	232.7	236.2	241.7

Table 3. The rainfall in months in dry season under SSP2-4.5 scenario (mm)

Month	SSP2-4.5			
	2021–2040	2041–2060	2061–2080	2081–2100
November	114.5	102.0	107.7	110.1
December	33.2	31.6	31.2	32.2
January	5.6	5.5	5.5	5.5
February	7.6	7.6	7.6	7.6
March	25.6	24.8	24.6	24.3
April	69.8	73.9	73.0	71.7

Table 4. The rainfall in months in rainy season under SSP3-7.0 scenario (mm)

Month	SSP3-7.0			
	2021–2040	2041–2060	2061–2080	2081–2100
May	138.5	121.2	111.7	94.5
June	166.0	149.4	136.8	120.5
July	277.0	263.1	247.7	249.4
August	273.0	261.7	247.5	229.6
September	295.1	286.4	297.4	277.8
October	218.2	214.6	225.0	232.1

Table 5. The rainfall in months in dry season under SSP3-7.0 scenario (mm)

Month	SSP3-7.0			
	2021–2040	2041–2060	2061–2080	2081–2100
November	101.5	102.8	99.6	100.1
December	30.2	30.5	31.1	30.6
January	5.4	5.4	5.4	5.4
February	7.6	7.4	7.4	7.2
March	25.1	24.5	24.3	23.2
April	78.5	73.3	69.3	64.9

Table 6. Annual rainfall in the Srepok river basin (mm)

Scenario	2021–2040	2041–2060	2061–2080	2081–2100
SSP2-4.5	1766	1627	1623	1614
SSP3-7.0	1616	1540	1503	1435

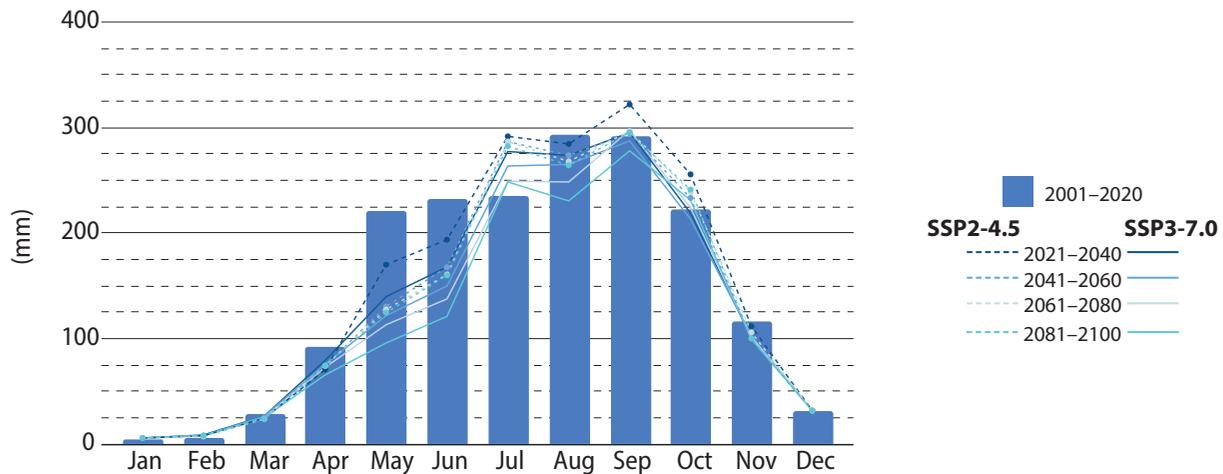


Fig. 3. Monthly rainfall of the Srepok River basin for the period of 2001–2020, 2021–2040, 2041–2060, 2061–2080 and 2081–2100 under SSP2-4.5 and SSP3-7.0 scenarios

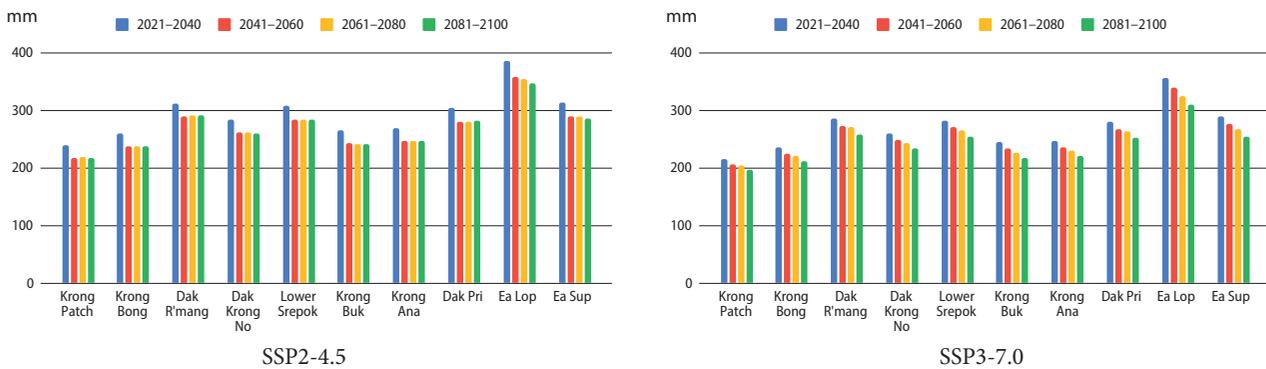


Fig. 4. Annual rainfall of irrigation sub-basins for the period of 2001–2020, 2001–2040, 2041–2060, 2061–2080 and 2081–2100 under SSP2-4.5 and SSP3-7.0 scenarios (mm)

tions to the center and tends to decrease from West to East of the basin.

Rainfall in the Srepok River basin is highly different between the rainy and dry seasons. The rainy season lasts 6 months, from May to October. Rainfall in the rainy season reaches 1,493.7 mm, accounting for about 84.4% of annual rainfall. The rainfall in the highest three months (July to September) is 819.9 mm, accounting for 46.3% of the total annual rainfall. September has the highest average monthly rainfall of 292.7 mm, accounting for 16.5% of yearly rainfall. The dry season lasts from November to April, reaching 276.5 mm, accounting for 15.6% of the annual rainfall. Rainfall in the dry season is concentrated in the transition month between the rainy season and the dry season, which is December, and the transition month from the dry season

to the rainy season, which is April. The rainfall in the lowest three months (January to March) reaches 38 mm, accounting for 2.1% of annual rainfall, and the lowest rainfall month is January, reaching 4.2 mm, accounting for 0.2% of yearly rainfall.

The uneven rainfall distribution between the two seasons causes difficulty in developing agriculture in the basin. Particularly in the years affected by El Nino, such as 1998, 2004, 2016, and 2023, water shortage occurred seriously, leading to heavy damage. Therefore, the predicted rainfall for 10 irrigation sub-basins in the Srepok basin based on climate change scenarios is very important in the Socioeconomic development of the Central Highland region of Vietnam. The Srepok River basin has an upper part belonging to Vietnam's territory and a lower part belonging to Cambodia's territory. There-

Table 7. Annual rainfall of irrigation sub-basins (mm)

Irrigation sub-basin	SSP2-4.5				SSP3-7.0			
	2021–2040	2041–2060	2061–2080	2081–2100	2021–2040	2041–2060	2061–2080	2081–2100
Krong Pach	1,372	1,248	1,250	1,249	1,242	1,188	1,167	1,124
Krong Bong	1,482	1,356	1,356	1,353	1,350	1,286	1,262	1,211
Dak R'mang	1,771	1,650	1,655	1,657	1,631	1,557	1,541	1,475
Dak Krong No	1,618	1,494	1,495	1,492	1,486	1,413	1,390	1,328
Lower Srepok	1,757	1,622	1,622	1,617	1,606	1,534	1,504	1,437
Krong Buk	1,514	1,391	1,388	1,379	1,386	1,321	1,288	1,233
Krong Ana	1,536	1,412	1,412	1,409	1,405	1,338	1,312	1,254
Dak Pri	1,730	1,602	1,604	1,605	1,586	1,514	1,493	1,428
Ea Lop	2,216	2,038	2,011	1,981	2,024	1,924	1,844	1,752
Ea Sup	1,793	1,653	1,643	1,629	1,641	1,565	1,518	1,448

fore, the results of the study are also the scientific basis for reasonable water use and do not to affect downstream development activities.

By downscaling method from the global climate model with the selected scenarios of SSP2-4.5 and SSP3-7.0 for the Srepok River basin, the distribution of average monthly and yearly rainfall in 4 periods of 2041–2060, 2061–2080, and 2081–2100 was predicted. The monthly rainfall distributions in the rainy and dry seasons in the Srepok River basin under SSP2-4.5 scenario are shown in **Tab. 2 and 3**. The monthly rainfall distributions in the rainy and dry seasons in the Srepok River basin under the SSP3-7.0 scenario are shown in **Tab. 4 and 5**. Rainfall in the dry season tends to increase in the North-South direction. Rainfall in the rainy season tends to rise from East to West of the basin. In both scenarios, rainfall in April, May, June, and November change in different periods. Rainfall in the remaining months is relatively stable by the end of the 21st century.

Due to the large area of the Srepok River basin, the uneven rainfall distribution causes water exploitation and use difficulties. The area with low rainfall tends to increase. However, rainfall during the rainy season tends to decrease until the end of the 21st century (**Tab. 6**) in the SSP3-7.0 scenario. Based on the calculation results of monthly rainfall distribution, it is possible to calculate the amount of input monthly water in detail for irrigation sub-basins, which is the basis for allocating and managing water resources in the basin. Calculating the amount of input natural water in the basin is also the basis for allocating water resources in the basin because the upstream part of the Srepok River basin is in the

territory of Vietnam. The downstream part of the territory of Laos and Cambodia is approximately 30% of the basin area. The average annual rainfall in the whole basin tends to increase gradually from East to West and from South to North (**Tab. 6**). By the end of the 21st century, the area with low rainfall is also increasing.

Rainfall distribution (**Tab. 6**) according to the scenarios in the Srepok River basin is quite similar to the rain distribution according to observed data presented in Integrated Planning of the Srepok River basin for 2021–2030, vision to 2050 [15]. Annual rainfall has decreased by the end of the 21st century (**Fig. 3**). However, annual rainfall in SSP3-7.0 scenario will reduce more than in SSP2-4.5. This result is also the opposite of the study on the rainfall variation on the islands of Vietnam. The rainfall on the islands tends to increase towards the end of the 21st century [17].

Fig. 4 and Tab. 7 illustrate the results of calculating the average annual rainfall for the irrigated sub-basins under two scenarios, SSP2-4.5 and SSP3-7.0.

According to the SSP2-4.5 scenario, rainfall in the sub-basins ranges from 1372–2216 mm, 1248–2038 mm, 1250–2011 mm, and 1249–1981 mm in the periods of 2021–2040, 2041–2060, 2061–2080 and 2081–2100, respectively. According to the SSP3-7.0 scenario, rainfall in the sub-basins ranges from 1242–2024 mm, 1188–1924 mm, 1167–1844 mm, and 1124–1752 mm in the periods 2021–2040, 2041–2060, 2061–2080 and 2081–2100, respectively. Among the sub-basins, Krong Pach in the west of the basin has the most minor annual rainfall, and the Ealop sub-basin has the highest

annual rainfall. This rainfall distribution is also similar to the rainfall distribution in the basin [15]. As mentioned, agriculture is the primary economic sector in the region; therefore, the decreased trend of annual rainfall in the irrigated sub-basins also causes difficulties for agricultural development.

Conclusions

Based on the observed data from 1981–2020, the annual rainfall tends to decrease gradually from North and South to the center and decrease from West to East in the Srepok River basin. The rainy season lasts from May to October, reaching 1,494 mm, accounting for about 84.4% of annual rainfall. The concentrated rainfall in the 6 months of the rainy season causes difficulties for water supply in the dry season for irrigation sub-regions in the basin.

Rainfall in both SSP2-4.5 and SSP3-7.0 scenarios tends to decrease every two decades by the end of the 21st century. Annual rainfall in the SSP3-7.0 scenario will decrease more than in SSP2-4.5. The low rainfall area also tends to increase by the end of the 21st century. The average rainfall in the basin in the dry season months does not differ much be-

tween the periods, while the rainfall amount in the rainy season tends to decrease.

In summary, rainfall amounts in the Srepok River basin are not uniform in both temporal and spatial distribution. In the context of climate change, rainfall in the basin tends to decrease, causing difficulties for water use. The study's results will provide a scientific basis for managers to build a plan of water resource allocation for irrigation sub-basins in the basin.

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Розподіл дощових опадів в басейні річки Срепок (В'єтнам)

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Річка Срепок має транскордонний басейн в Центральному нагір'ї В'єтнаму, площа якого становить близько 18 тис. км² і поділяється на 10 іригаційних суббасейнів. У цьому дослідженні застосовано статистичний метод для оцінювання розподілу опадів в минулому з використанням даних спостережень (1981–2020 рр.), а також метод зменшення масштабу для прогнозування на періоди 2021–2040, 2041–2060, 2061–2080 та 2081–2100 рр. за сценаріями середнього та високого рівня викидів (SSP2-4.5 та SSP3-7.0). За даними спостережень річна кількість опадів у період 1981–2020 рр. поступово зменшувалась з півночі та півдня до центру, а також із заходу на схід басейну. Кількість опадів в сезон дощів (від травня до жовтня) досягла 1494 мм, що становить 84,4% річної кількості опадів. За сценаріями SSP2-4.5 і SSP3-7.0 річна кількість опадів у басейні, а також у зрошувальних суббасейнах, має помітну тенденцію до зменшення. Установлено, що площа області з низькою кількістю опадів має тенденцію до розширення кожні два десятиліття до кінця ХХІ ст. Помічено, що кількість опадів не змінюється між періодами в сухий сезон, але має тенденцію до зменшення в сезон дощів. Кількість опадів має тенденцію до збільшення зі сходу на захід басейну в сезон дощів і збільшення з півночі на південь в сухий сезон відповідно. Однак місячна і річна кількість опадів між періодами досить стабільна за сценарієм SSP2-4.5.

Ключові слова: кількість опадів, розподіл, басейн річки Срепок, СМІР6.

Цитування:

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