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CLIMATE CHANGE AND RISK MANAGEMENT IN VITICULTURE (using the example of Vayots Dzor Region)

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The article discusses the issues of managing the risks of climate change impacts on viticulture in mountainous areas, the complexity of which requires a spatio-temporal study. The article chooses Vayots Dzor as an example, which is a typical mountainous area and is considered an ancient region rich in viticultural traditions. Here, there is a variety of interconnected agroclimatic conditions necessary for viticulture and obvious risks of climate change manifestations, which together make Vayots Dzor a typical object of geoecological research. Such research is not only of scientific and methodological interest and is useful for studying the agroclimatic conditions of other mountainous viticultural areas, but also, with its practical orientation, can contribute to the scientific understanding of the climate change problem observed in Vayots Dzor and risk management.

The article presents the results of the calculation and analysis of the spatial-temporal distribution of agroclimatic resources in Vayots Dzor. The following main agroclimatic indices were used: the sum of active temperatures, the number of days with temperatures above 30°C, the average of absolute minimum temperatures, and the amount of precipitation during the vegetation period. As a result of the study, some changes in the agroclimatic conditions of the area over the past decades have been revealed, and agroclimatic areas favorable for viticulture have been identified. It has been found that within the scope of climate change resistance and adaptation risk management, there are new opportunities to expand the viticultural areas in Vayots Dzor and to develop the cultivation of valuable grape varieties.

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Introduction. Agroclimatic conditions are one of the primary ecological factors for the development of viticulture. Due to global climate change, agroclimatic conditions in general and in Vayots Dzor in particular are also changing. The diversity and uniqueness of the Vayots Dzor relief create a great variety of climatic conditions, giving rise to microclimatic separations, which differ in light intensity, thermal regime, amount of atmospheric precipitation and humidity conditions. Agroclimatic conditions directly affect the growth and yield of grapes, determine the grape cultivation zone, the specialization of viticulture and the distribution of

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varieties, the cultivation system and care of vineyards. Climate directly affects the growth and yield of the vine, characterizing the duration of its stages, the ripening of fruits, and the effective accumulation of sugar and acids in them. The main viticultural areas of Vayots Dzor are located in the semi-desert and dry mountain steppe zone, reaching an altitude of up to 2000 *m* a.s.l. on the Southern and Southwestern mountain slopes.

Adverse weather events also have a significant impact on viticulture in Vayots Dzor. Recently, due to global climate change, the probability and intensity of adverse weather events have increased. Comprehensive agro-climatic studies are required to confront global climate change, reduce dangerous risks, and develop the adaptation of agricultural sectors to the current situation.

The aim of the study is to assess the agroclimatic conditions necessary for grape cultivation in the context of global climate change, taking Vayots Dzor Region as an example. To achieve this goal, agroclimatic indicators were determined and the agroclimatic characteristics of the viticultural areas were analyzed.

Materials and Methods. The methodological basis for assessing the adaptability of viticulture in the natural environment is the comparison of the combination of individual agroclimatic factors and weather conditions with the ecological niche of the grapevine. To compile the agroclimatic characteristics of the Vayots Dzor viticultural areas, the following evaluation indices were used: the sum of active temperatures, the number of days with temperatures above 30°C, the average of absolute minimum temperatures, and the amount of precipitation during the vegetation period.

The assessment of microclimatic conditions for the expansion of viticultural areas in Vayots Dzor due to climate change was carried out using mathematical modeling based on absolute altitude, slope orientation, and slope. The baseline data for the calculations – solar radiation energy, air temperature, and precipitation – are taken from the bulletins developed by the "Hydrometeorology and Monitoring Center" SNCO, as well as from the bulletins of previously conducted observations [1–3]. The multi-year indicators of hydrothermal observations of former and currently operating hydrometeorological stations in Vayots Dzor Region were studied. The work widely used international experience in calculating and assessing microclimatic indicators [4–10]. The occupied surfaces of Vayots Dzor relief elevation, slopes and orientations were calculated and mapped with the ArcGIS software package.

In the conditions of the mountainous relief of Vayots Dzor, the illumination of the valleys and adjacent mountain slopes is due to the direction of the valleys and the closedness of the horizon. In this regard, during the vegetation period, the East-West-oriented valleys of Vayots Dzor and their adjacent South-facing mountain slopes are best. Calculations show that the illumination of valleys and mountain slopes extending from East to West is about 2 *h* more during the day than that of valleys extending from North to South.

To calculate the intensity of direct radiation on different slopes of individual orientations of mountain slopes, the formula proposed by M.I. Sherban was used:

$$S_{cn} = S_m \sin h \cos\alpha + S_m \cos h \cos(A - A_n)\sin\alpha, \qquad (1)$$

where α is the slope of the mountain slope in degrees; S_m is the intensity of direct solar radiation on the surface perpendicular to the rays, *cal*·c*m*²/*min*; h is the altitude of the sun in degrees; A is the azimuth of the sun in degrees; A_n is the horizontal projection of the sun relative to the orientation of the mountain slopes in degrees [11].

To determine the value of total evaporation in the mountainous terrain of Vayots Dzor, we used the formula developed by A. Mkhitaryan and H. Hakobyan:

$$E = (r + a)\exp[-b(T - t)^2], \tag{2}$$

where E is the average monthly value of total evaporation, *mm*; r is the monthly amount of atmospheric precipitation, *mm*; T is the average monthly maximum temperature; t is the average monthly temperature; a, b are coefficients [11].

The calculation of thermal conditions in Vayots Dzor region according to orientations and slopes was performed using the following formula:

$$(\theta_\omega - \theta) = \frac{R_0 - \mathrm{LE} - \mathrm{B}}{\rho C_\mathrm{p} - 4s\sigma\theta^3}, \tag{3}$$

where $\theta_\omega - \theta$ is the difference between the slope temperatures at the active surface and in the air, °C; R_0 is the slope radiation balance; LE is the heat lost during evaporation; B is the heat transfer in the soil; ρ is the density of air; C_p is the specific heat capacity of air at constant pressure; S is the coefficient characterizing the radiating surface (taken to be 0.95); σ is the Stefan-Boltzmann constant (σ = 5.670373(21)·10^{-8} $Wm^{-2}K^{-4}$), θ is the air temperature at the flat surface [8].

The sum of temperatures above 10°C and the hydrothermal coefficient of Selyaninov served as the main index for the separation of agroclimatic zones:

$$\mathrm{HTC} = \frac{\sum r}{\sum t > 10^\circ} \cdot 10, \tag{4}$$

i.e. the ratio of the amount of precipitation over a period with a temperature above 10°C to the total amount of possible evaporation over the same period [5].

In order to predict the possible intra-annual change in temperature and precipitation, we have used the Fourier series method. The calculations were made using the following formulas:

$$f(X) = \overline{X} + \sum_{r=1}^{r=N/2} (a_r \sin(2\pi_r X/P) + b_r \cos(2\pi_r X/P)), \tag{5}$$
$$a_r = 2/N[f(X)\sin(2\pi_r X/P)]_{X=1}^{X=N}, \quad b_r = 2/N[f(X)\cos(2\pi_r X/P)]_{X=1}^{X=N},$$

where P is the number of steps; N is the number of data; $\overline{X}$ is the annual average of the data, X is the monthly average of the data; r is the number of steps; a_r, b_r are coefficients [11].

The obtained results were extrapolated and interpolated for individual orientations and slopes of different elevation zones through correlation. The results of the calculations are included in the climate characteristic tables.

Results and Discussion. According to an assessment by the World Bank, Armenia is one of the most vulnerable countries in the Europe and Central Asia region to climate change [1]. Rising temperatures and decreasing precipitation are accelerating desertification processes, which will have a negative impact on sectors that depend on climate and natural resources. The agricultural sector is most vulnerable to climate change. Viticulture represents one of the most ancient and significant sectors of Armenia's agriculture, whose spatial development is predominantly shaped by climatic conditions. Therefore, there is a need to develop a roadmap for viticulture adaptation, reduce the risks caused by climate change, and make this branch of agriculture more resilient.

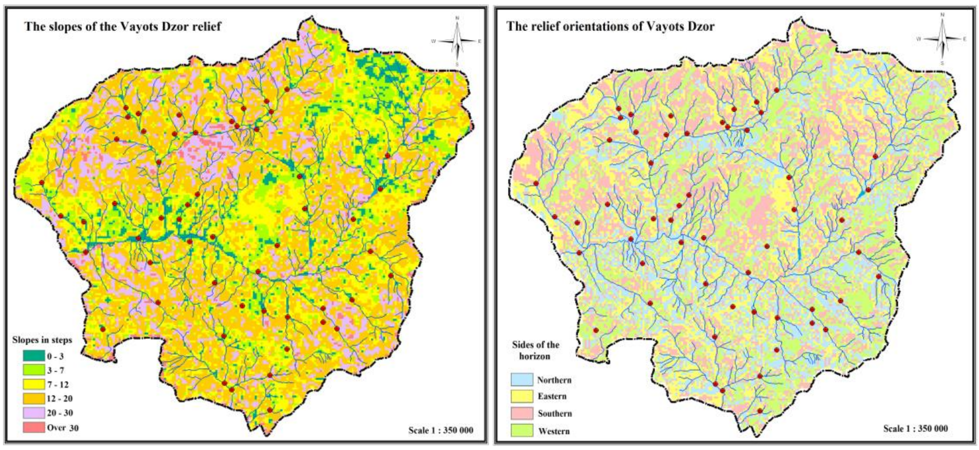
Vayots Dzor is one of the regions in Armenia known for its viticulture. In mountainous countries such as Vayots Dzor, the large differences in altitude, the various slopes and orientations have created conditions for diverse manifestations of climatic factors. The territory of Vayots Dzor has a typical mid-mountainous character, as the low mountain zone (up to 1400 *m*) occupies 11.3% of the entire territory, the mid-mountain zone (1400–2500 *m*) – 63.3%, and the high mountain zone (over 2500 *m*) – 25.4% (Tab. 1).

Table 1

The occupied surfaces of the height zones and subzones of Vayots Dzor Region

Height zones, *m*	Surface		Height subzones, *m*	Surface	
	km^2	%		*km*^{2}	%
Low mountainous (Until 1400)	262.5	11.3	Until 1000 1000–1200 1200–1400	17.5 80.0 165.0	0.7 3.5 7.1
Middle mountainous (1400–2500)	1456.2	63.3	1400–1600 1600–1800 1800–2000 2000–2250 2250–2500	235.3 269.3 282.8 333.5 335.3	10.2 11.6 12.2 14.5 14.8
High mountainous (2500 and more)	589.3	25.4	2500–2750 2750–3000 3000–3250 3250–3500 3500 and more	243.0 187.0 140.8 17.5 1.0	10.5 8.1 6.1 0.7 –
Total	2308	100	Total	2308	100

Vayots Dzor, with its average height, exceeds the corresponding indicator of the republic by 450 *m*, and with its altimeter outline of the orography resembles a unique amphitheater, where the highest mountain peaks are located in the watershed areas, and towards the central, axial zone, the heights decrease from all sides, except for the Southwest. Such a mountain structure leaves its deep imprint on the formation of the microclimate. Due to the decrease in atmospheric air density with altitude, the intensity of direct solar radiation and radiation from the earth's surface increases, as a result of which daily temperature fluctuations increase, and the average air temperature decreases, contributing to an increase in relative air humidity.



The slopes and orientations of the Vayots Dzor Region relief.

Vayots Dzor is characterized by a great variety of slopes and a very uneven distribution of slopes (see Figure, Tab. 2). The role of the slopes of mountains is particularly important in the distribution of energy received from direct solar radiation. On mountain sides with the same orientation but different slopes, quite large differences in the received solar radiation are observed (Tab. 3). The degree of closure of the mountain valleys is also determined by the slopes, which affects the duration of the area’s sunshine.

Table 2

Surfaces of different slopes in Vayots Dzor Region

The nature of the surface	Slopes, in degrees	Surface	
		km^2	%
Flat, horizontal, not eroded	until 1	4.3	0.2
Gently sloping, undulating, slightly eroded	1–3	18.5	0.9
Slightly steep, mounded, slightly eroded	3–5	149.9	6.5
Steep, moderately eroded	5–10	638.5	27.6
Strongly steep, fairly eroded	10–15	865.3	37.5
Steep slope, heavily eroded	15–20	312.5	13.6
Very steep, very heavily eroded	20–30	247.4	10.7
Directional slope, highly eroded	30–40	17.3	0.7
Almost vertical slope, completely eroded	40 and more	54.3	2.3
– “ – – “ –	Total	2308	100

Orientations, like slopes, are the reason for the formation of different microclimatic conditions in mountainous areas. Differences in the intensity of solar radiation, as well as the water-heat balance of the soil, which are characteristic of mountain slopes with different orientations, also find their expression within the boundaries of upwelling zones. The orientation of the slopes affects the intensity of illumination, as well as the temperatures of the soil cover. In Vayots Dzor, during the year, the north slopes receive a smaller amount of direct solar radiation than flat surfaces, while on the South slopes it is greater (Tab. 3). The land cover, due to the different orientations of the hillsides, absorbs different amounts of heat energy through solar radiation. The temperature difference between the Northern and Southern slopes, other things being equal, is 6°C to 7°C in the air near the ground layer, and 5°C to 7°C in the soil cover at a depth of 1 *m*, the Southern slopes not only heat up well, but also evaporate about twice as much water as the Northern ones [12].

Table 3

Average monthly direct solar radiation in Vayots Dzor region on slopes of 5° and 20° (kcal/cm²)

Month	Sides of the horizon	Height, *m* a.s.l.							
		1000		1400		1800		2200	
		5°	20°	5°	20°	5°	20°	5°	20°
A	S	11.92	8.87	11.76	8.74	11.60	8.60	11.44	8.47
	N	13.34	14.15	13.14	13.94	12.94	13.73	12.75	13.52
M	S	15.03	11.36	15.19	11.49	15.34	11.62	15.50	11.75
	N	16.14	15.86	16.34	16.02	16.54	16.18	16.74	16.34
J	S	15.94	12.34	16.08	12.45	16.22	12.56	16.36	12.66
	N	16.84	15.73	17.01	15.90	17.17	16.06	17.34	16.23
J	S	15.53	11.78	15.86	12.03	16.18	12.28	16.51	12.53
	N	16.62	15.69	16.97	16.01	17.32	16.33	17.66	16.64
A	S	13.86	9.83	14.23	10.08	14.59	10.34	14.96	10.59
	N	15.31	14.72	15.68	15.09	16.04	15.46	16.41	15.84
S	S	10.42	7.36	10.70	7.54	10.99	7.72	11.27	7.89
	N	12.09	13.45	12.37	13.77	12.66	14.10	12.94	14.42
O	S	7.42	3.25	7.66	3.33	7.91	3.41	8.15	3.49
	N	9.13	8.12	9.43	8.36	9.72	8.61	10.02	8.85

According to illumination and warming, the area of Vayots Dzor mountain slopes can be classified into the following groups: illuminated significantly warming mountain slopes (with Southern, Southeastern, Southwestern orientations), shady insufficiently warming mountain slopes (with Northern, Northeastern, Northwestern orientations), sufficiently illuminated warming mountain slopes (with Eastern and Western orientations) (see Figure, Tab. 4).

Table 4

The surfaces of the mountain slopes of different orientations in Vayots Dzor Region

Orientations	Until 1400		1400–2000		2000–2500		2500 and more		Total	
	*km*²	%	*km*²	%	*km*²	%	*km*²	%	*km*²	%
Northern	32.8	1.42	41.0	1.77	24.33	1.05	21.85	0.95	119.98	5.16
Northeastern	42.5	1.84	152.95	6.62	182.16	7.9	49.35	2.14	426.96	18.2
Northwestern	7.0	0.3	51.5	2.22	69.4	3.0	57.85	2.51	185.75	8.02
Southern	6.0	0.25	24.0	1.03	49.16	2.23	53.15	2.31	132.31	5.8
Southeastern	35.5	1.54	228.29	9.89	137.06	6.06	156.5	6.77	557.35	24.23
Southwestern	83.5	3.62	207.0	8.96	136.49	5.9	116.35	5.05	543.34	23.5
Eastern	31.1	1.34	49.99	2.15	15.85	0.96	65.23	2.84	162.1	7.25
Western	24.1	1.04	32.2	1.36	54.65	2.47	69.32	3.02	180.21	7.85
Total	262.5	11.3	786.8	34.0	669.1	29.3	589.6	25.4	2308	100

The differences in air humidity and temperature on South and North slopes are greater than in two successive altitudinal zones, which is why it is more correct to assess the agroclimatic conditions of the environment not only according to the altitudinal zonality but also according to the orientations.

In the mountainous terrain of Vayots Dzor, the closure of the horizon significantly reduces the duration of sunlight on the mountain slopes. The illumination of valleys and adjacent mountain slopes is determined by the direction of the valleys and the closure of the horizon. In this regard, during the vegetation period, the East-West valleys of Vayots Dzor and their adjacent South-facing mountain slopes are best illuminated. Calculations show that the illumination of valleys and mountain slopes extending from East to West is about 2 *h* more during the day than the illumination of valleys and mountain slopes extending from North to South with the same closure. This means that the conditions for the intensity and duration of photosynthesis are more favorable on valley slopes extending from East to West. It should be noted that well-lit mountain slopes have a high intensity of infrared rays and are characterized by high temperatures and a high rate of evaporation, therefore, the intensity of photosynthesis is determined not only by lighting, but also by the water supply of plants, which is small on well-lit slopes. Therefore, in the process of formation of agroecosystems in Vayots Dzor, air temperature and moisture deficiency act mainly as limiting ecological factors.

The annual duration of sunshine varies from 2700–2800 *h* in the low mountain zone, 2300–2600 *h* in the middle mountain zone, and 2200–2300 *h* in the high mountain zone. Calculations show that the duration of sunshine during the vegetation period is 82–87% of the annual duration, with the maximum (350–370 *h*/month) observed in July–August. During the year, depending on the altitude, an increase in the number of sunless days is observed, which has a direct impact on the quantitative ratio of direct and scattered solar rays [3].

In the Vayots Dzor region, the values of direct solar radiation were determined by us using correlation curves and are based mainly on calculations. The calculations also used the results of research on the intensity of direct solar radiation in the Republic of Armenia by R. Kartashyan and A. Mkhitaryan [7].

The daily amount of direct solar radiation at different orientations depends on the degree of horizon occlusion and the duration of insolation of the mountain slopes. Therefore, a large amount of direct solar radiation energy is received by the gently sloping south-facing mountain slopes of Vayots Dzor, whose degree of horizon occlusion is small and the duration of insolation is long (Tab. 3). The intensity of direct radiation on different orientations and slopes of mountain slopes was calculated using Sherban's formula (1).

When quantitatively characterizing the water factor of the microclimatic conditions of the area, a complex indicator reflecting the situation is used, which takes into account the moisture content of the air and soil. The saturation of air and soil with moisture and the peculiarities of their distribution during the vegetation of the grapevine are of vital importance and determine the quality of the harvest. The total evaporation value (Tab. 5) in the mountainous relief of Vayots Dzor was determined by formula (3) developed by A. Mkhitaryan and H. Hakobyan.

As can be seen from Tab. 5, the total evaporation value increases slightly with increasing altitude (up to 1800 *m* in the dry season and 2000 *m* in the humid season), then it decreases regularly. The maximum value of total evaporation is observed on the South-facing slopes of the middle mountain zone of the northeastern humid district of the region (434 *mm*), and the minimum is observed on the North-facing slopes of the high mountain zone of the dry season (188 *mm*).

Table 5

Total evaporation on the slopes of Vayots Dzor Region with different orientations, mm

Height, *m* a.s.l.	Dry region			Humid region		
	Slope orientations			Slope orientations		
	North	South	East, West	North	South	East, West
1000–1200	346	375	358	346	375	358
1200–1400	348	380	369	348	380	369
1400–1600	353	385	376	353	397	376
1600–1800	362	392	380	368	427	403
1800–2000	358	388	377	382	434	422

The spatiotemporal features of the thermal regime of Vayots Dzor are determined by the balance of solar radiation energy, atmospheric circulation and the nature of the relief. Our calculations have shown that at the same altitude of the terrain, the difference in air temperature between the South and North slopes is on average 3°C to 4°C, therefore, the same isotherm passes on the South slopes 800 *m* higher in winter and 600 *m* higher in summer than on the North slopes. It has also been found that the average annual air temperature on the North slopes in the lowland zone is 8.2°C to 10.3°C, and in the middle mountain zone 2.0°C to 8.2°C. The average annual air temperature on the South mountain slopes in the lowland zone is 11.2°C to 13.3°C, and in the middle mountain zone 5.0°C to 11.2°C. The calculation of thermal conditions according to orientations and slopes (Tab. 6) was performed using formula (3).

To determine the impact of air temperature on viticulture, it is necessary to take into account the biological minimum and active temperature requirements of grapevines. For the main grape varieties cultivated in Vayots Dzor, the biological minimum temperature almost coincides with the average daily air temperature of 10°C. It has been proven that within the active temperature range, the process of grapevine growth and development occurs more quickly not in the case of constant, but in the case of variable day and night temperatures, which is specific to the studied area.

Taking into account the above, we have analyzed the transition periods of 10°C average daily air temperatures in spring and autumn, as well as the amount and duration of active temperatures accumulated during the specified periods (Tab. 6). In the case of sufficient availability of the required agroecological factors, the possibilities and terms of grapevine growth and development in the area are determined by active temperature indicators. Therefore, the specified analysis has important agroecological significance.

In Vayots Dzor, the sum of active temperatures, which characterizes the vegetation period, is quite large and decreases with altitude. The sum of temperatures above 10℃ decreases by 220℃ to 230℃ for every 100 *m* of altitude.

Table 6

Thermal conditions on slopes of different inclinations in Vayots Dzor Region

Height, *m* a.s.l.	0–7° Inclination					20–30° Inclination				
	T℃	∑*t*℃>10℃				*T*℃	∑*t*℃>10℃			
	VII	year	IV–IX	IX	X	VII	year	IV–IX	IX	X
South										
900–1000	27.8	4567	4085	689	482	29.2	4833	4323	729	510
1000–1100	26.9	4387	3931	664	457	28.2	4643	4160	703	483
1100–1200	26.0	4224	3789	643	434	27.2	4470	4010	680	460
1200–1300	25.1	4050	3638	618	412	26.4	4286	3850	654	436
1300–1400	24.2	3880	3488	593	393	25.4	4106	3691	628	416
1400–1500	23.3	3420	3046	572	374	24.4	3920	3524	605	395
1500–1600	22.5	3278	2926	550	351	23.5	3468	3097	582	372
1600–1700	21.4	3120	2791	525	329	22.5	3301	2953	556	348
1700–1800	20.5	2655	2655	501	–	21.5	3134	2810	530	324
1800–1900	19.6	2526	2526	476	–	20.5	2673	2673	504	–
1900–2000	18.5	2387	2387	451	–	19.4	2526	2526	477	–
North										
900–1000	25.9	4257	3807	642	449	24.3	3991	3569	602	421
1000–1100	25.1	4089	3664	619	426	23.5	3834	3435	581	399
1100–1200	24.2	3936	3532	599	405	22.7	3690	3311	562	379
1200–1300	23.4	3775	3391	576	384	22.0	3250	2890	540	360
1300–1400	22.6	3329	2963	553	366	21.2	3121	2777	518	343
1400–1500	21.7	3187	2839	533	348	20.3	2988	2662	500	326
1500–1600	20.9	3055	2727	513	327	19.6	2557	2557	481	–
1600–1700	20.0	2601	2601	490	–	18.7	2438	2438	459	–
1700–1800	19.1	2475	2475	467	–	17.9	2320	2320	437	–
1800–1900	18.2	2354	2354	444	–	17.1	2207	2207	416	–
1900–2000	17.4	2225	2225	420	–	16.2	1798	1798	394	–
East and West										
900–1000	27.4	4501	4025	679	475	28.1	4634	4144	699	489
1000–1100	26.5	4324	3874	655	450	27.1	4451	3988	674	463
1100–1200	25.6	4162	3734	633	428	26.2	4285	3844	652	441
1200–1300	24.8	3991	3585	609	406	25.4	4109	3691	627	418
1300–1400	23.9	3824	3437	585	387	24.4	3937	3538	602	398
1400–1500	22.9	3370	3002	563	368	23.5	3470	3090	580	379
1500–1600	22.1	3230	2884	542	346	22.7	3325	2969	558	356
1600–1700	21.1	3074	2750	518	324	21.6	3165	2831	533	334
1700–1800	20.2	2616	2616	493	–	20.7	2694	2694	508	–
1800–1900	19.3	2489	2489	469	–	19.8	2563	2563	483	–
1900–2000	18.3	2352	2352	445	–	18.7	2422	2422	458	–

The calculations performed show (Tab. 6) that in Vayots Dzor, the South, as well as the horizontally flat, and East and West mountain slopes have a significant predominance of active temperatures compared to the North mountain slopes, the magnitude of which, although decreasing with height, retains its inadequacy. The sum of active temperatures is one of the primary agro-ecological factors determining the lower and upper limits of the spread of viticulture, and its disproportionate distribution in mountainous relief conditions affects the quantitative and qualitative indicators of the grape harvest. Obviously, the upper limits of the spread of viticulture on the South mountain slopes are 300–500 *m* higher than on the north mountain slopes. It should be noted that in Vayots Dzor, high-value agro-ecosystems for viticulture have been formed on areas with high indicators of active temperatures.

Table 7

Some factors of the microclimate of Vayots Dzor Region

Height, *m* a.s.l.	Number of days with temperatures above 30°C, IV–IX						Average absolute min *T*, °C	Precipitation amount, *mm*		
	South		North		East and West			month		
	0–7°C	20–30°C	0–7°C	20–30°C	0–7°C	20–30°C		IV–IX	IX	X
900–1000	3.2	3.3	3.0	2.8	3.1	3.2	–14.8	180	11	34
1000–1100	2.8	2.9	2.6	2.4	2.7	2.8	–15.3	197	12	35
1100–1200	1.8	1.8	1.6	1.5	1.7	1.8	–16.0	211	13	36
1200–1300	0.8	0.9	0.8	0.7	0.8	0.8	–16.7	224	14	38
1300–1400	0.3	0.3	0.3	0.3	0.3	0.3	–17.2	236	15	40
1400–1500	0.1	0.1	0.1	0.1	0.1	0,1	–17.9	248	16	42
1500–1600	0.0	0.0	0.0	0.0	0.0	0.0	–18.5	263	17	44
1600–1700	0.0	0.0	0.0	0.0	0.0	0.0	–19.0	277	18	46
1700–1800	0.0	0.0	0.0	0.0	0.0	0.0	–19.7	294	19	48
1800–1900	0.0	0.0	0.0	0.0	0.0	0.0	–20.3	310	20	52
1900–2000	0.0	0.0	0.0	0.0	0.0	0.0	–21.0	330	22	56

The main source of moisture in Vayots Dzor is atmospheric precipitation. Therefore, the seasonal variability of humidity depends on the annual course of atmospheric precipitation. The spatiotemporal nature of precipitation is largely determined by the general and local circulation of the atmosphere, relief height, orientations and other conditions. In Vayots Dzor, the maximum precipitation is received by the windward slopes of the marginal mountain ranges, and the amount of precipitation increases with altitude. This explains the fact that the maximum precipitation values are observed on the Southern windward slopes of the Vardenis, Texar mountain ranges and the Jermuk plateau, partly also in the high-mountainous summit zone of the Vayk mountain range, and the minimum values are observed in the internal closed depressions.

In the mountainous terrain and high-mountainous regions of the Republic, with few precipitation observation points, accurate assessment of the value of atmospheric precipitation is a rather difficult task. Therefore, we considered it appropriate to use the calculations made by B. Mnatsakanyan [9]. The average annual precipitation in Vayots Dzor varies with altitude, ranging from approximately 350 to 930 *mm*. On average, precipitation increases by 20–25 *mm* for every 100-meter rise in elevation. Data on the amount of atmospheric precipitation during the grape growing season are presented in Tab. 7.

During the vegetation period, the amount of precipitation in Vayots Dzor makes up 57–59% of the annual precipitation. It should be noted that the highest precipitation during this period occurs in April–June, and the lowest in July–August.

From November to March, a constant snow cover prevails in most of the territory of Vayots Dzor, while in the lowland zone it occurs not every year. The average thickness of the snow cover varies from 14 *cm* (in the lowland zone) to 126 *cm* (in the highland zone), and the duration is respectively from about 40 to 176 days. The upward gradient of the periods of formation and removal of snow cover in the low and middle mountain zones is 2–3 days, in the highland zone – 4–5 days, and the thickness of the snow layer increases by 2–4 *cm* and 10–12 *cm* per 100 *m*, respectively. On the southern slopes, the stable snow cover is established and disappears, with an average difference of 20 days, that is, the duration of the snow cover on the northern slopes is 40 days longer than on the southern slopes [3].

In Vayots Dzor, due to global climate change, the average monthly and annual sum of temperature and precipitation is subject to significant fluctuations over many years. The prediction of possible changes in temperature and precipitation during the grapevine vegetation period was made using the Fourier series method (5). Using this method, we have calculated the harmonics of the intra-annual distribution of temperatures and precipitation at Areni, Yeghenadzor, Martiros and Jermuk meteorological stations. As a result of the calculations, it becomes clear that the harmonic coefficient of temperature is equal to 0.1, and for precipitation it is 0.5. This shows that the probability of a possible change in the intra-annual distribution of air temperature is much smaller than that of atmospheric precipitation. Moreover, during the period of grape vegetation, the average monthly air temperatures tend to increase, and atmospheric precipitation tends to decrease.

The main viticultural areas in Vayots Dzor are located at altitudes of 1000 *m* to 1600 *m*, but due to climate change, grapevines can also be grown in higher zones, as evidenced by our agroclimatic calculations. The eastern, southern, and western slopes of the mountains, which are up to 2000 *m* a.s.l., have great potential for grape cultivation, accounting for about 30% of the total area of the region. Climate change has created new opportunities for viticulture in Vayots Dzor. However, climate change poses certain risks that need to be assessed in order to obtain high-quality crops. Climate has a direct impact not only on grape growth, but also on the quantitative and qualitative indicators of the harvest. In Vayots Dzor, during the grapevine vegetation, high air temperatures and low humidity create favorable conditions for the production of dessert wines. Viticulture is greatly damaged by adverse weather phenomena observed in the region, the intensity and frequency of which have become more active under climate change.

Conclusion. Due to climate change, the opportunities for expanding viticulture in Vayots Dzor have increased. Agroclimatic studies conducted indicate that conditions exist for growing grapes and obtaining quality harvests on sunny mountain slopes up to 2000 *m* a.s.l. In order to reduce and manage the risks of the prospective development of viticulture in the Vayots Dzor region due to the impact of climate change, the following measures need to be implemented:

- choose the most resistant grape varieties with high sugar content;
- implement clear protective measures to withstand adverse weather phenomena;
- develop and implement spatiotemporal management of water resources with an efficient water use component;

- climate change risk assessment and introduction of an insurance system;
- increasing the range of food products derived from grapes.

Thus, we can argue that establishing intensive grape orchards and increasing grape procurement volumes can be among the beneficial programs for climate change resilience and agricultural adaptation in Vayots Dzor.

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Ն. Ա. ՀԱՐՈՒԹՅՈՒՆՅԱՆ

ԿԼԻՄԱՅԻ ՓՈՓՈԽՈՒԹՅՈՒՆԸ ԵՎ ՌԻՍԿԵՐԻ ԿԱՌԱՎԱՐՈՒՄԸ ԽԱՂՈՂԱԳՈՐԾՈՒԹՅԱՆ ՄԵՋ
(Վայոց ձորի մարզի օրինակով)

Ամփոփում

Հոդվածում քննարկվում են լեռնային տեղանքում՝ խաղողագործության վրա կլիմայի փոփոխության ազդեցության ռիսկերի կառավարման խնդիրները, որոնց բարդությունը պահանջում է տարածաժամանակային ուսումնասիրություն: Հոդվածում որպես օրինակ ընտրվել է Վայոց ձորը, որը տիպիկ լեռնային տարածք է և համարվում է խաղողագործական ավանդույթներով հարուստ հնագույն շրջան: Այստեղ առկա են խաղողագործության համար անհրաժեշտ փոխկապակցված ագրոկլիմայական պայմանների բազմազանությունը ու կլիմայի փոփոխության դրսևորումների ակնհայտ ռիսկերը, որոնք միասին Վայոց ձորը դարձնում են տիպիկ գեոէկոլոգիական հետազոտության օբյեկտ: Նման հետազոտությունը ոչ միայն գիտական և մեթոդական հետաքրքրություն է ներկայացնում և օգտակար է այլ լեռնային խաղողագործական տարածքների ագրոկլիմայական պայմանների ուսումնասիրության համար, այլև իր գործնական ուղղվածությամբ կարող է նպաստել Վայոց ձորում դիտվող կլիմայի փոփոխության խնդրի գիտական ըմբռնմանը և ռիսկերի կառավարմանը:

Հոդվածում ներկայացված են Վայոց ձորի ագրոկլիմայական ռեսուրսների տարածաժամանակային բաշխման հաշվարկի և վերլուծության արդյունքները: Որպես հիմնական ագրոկլիմայական ցուցանիշներ օգտագործվել են՝ ակտիվ ջերմաստիճանների գումարը, 30°C և ավելի ջերմաստիճաններով օրերի թիվը, բացարձակ նվազագույն ջերմաստիճանների միջինը և վեգետացիայի ընթացքում տեղումների քանակը:

Ուսումնասիրության արդյունքում բացահայտվել են վերջին տասնամյակների ընթացքում տարածքի ագրոկլիմայական պայմանների որոշ փոփոխություններ, առանձնացվել են խաղողագործության համար ագրոկլիմայական նպաստավոր տարածքներ: Պարզվել է, որ կլիմայի փոփոխությանը դիմակայելու և ռիսկերի կառավարման շրջանակներում նոր հնարավորություններ կան Վայոց ձորում ընդլայնելու խաղողագործական տարածքներն ու զարգացնելու խաղողի արժեքավոր տեսակների աճեցումը:

Н. А. АРУТЮНЯН

ИЗМЕНЕНИЕ КЛИМАТА И УПРАВЛЕНИЕ РИСКАМИ В ВИНОГРАДАРСТВЕ
(на примере Вайоц Дзорского марза)

Резюме

В статье рассматриваются вопросы управления рисками от воздействия изменения климата на виноградарство в горной местности, сложность которых требует пространственно-временного изучения. В качестве примера в статье выбран регион Вайоц Дзор, который является типичной горной местностью и считается древним регионом, богатым традициями виноделия. Здесь есть многообразие взаимосвязанных агроклиматических условий, необходимых для виноградарства, и очевидные риски проявления изменений климата, что в совокупности делает Вайоц Дзор типичным объектом геоэкологических исследований. Такие исследования представляют не только научный и

методический интерес и полезны для изучения агроклиматических условий других горных виноградарских зон, но и благодаря своей практической направленности могут способствовать научному пониманию проблемы изменения климата, наблюдаемой в Вайоц Дзоре, и управлению рисками.

В статье представлены результаты расчета и анализа пространственно-временного распределения агроклиматических ресурсов Вайоц Дзора. В качестве основных агроклиматических показателей использовались: сумма активных температур, количество дней с температурой выше 30°C, средняя из абсолютных минимальных температур, количество осадков за вегетационный период. В результате исследования выявлены некоторые изменения агроклиматических условий территории за последние десятилетия и выделены агроклиматические зоны, благоприятные для виноградарства. Установлено, что в рамках адаптации к изменению климата и управления рисками открываются новые возможности для расширения виноградарских площадей в Вайоц Дзоре и развития выращивания ценных сортов винограда.