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SPATIAL AND TEMPORAL CHARACTERISTICS OF THE WIND REGIME FROM THE ARAL SEA IN THE SETTLEMENTS OF THE ARAL SEA REGION

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Abstract
The spatial and temporal features of the direction and speed of wind from the Aral Sea in the settlements located in ecological disaster zone of the Republic of Kazakhstan were analyzed. Ecological-hygienic and statistical methods were used. The results showed that during the cold period, the wind direction from Big Aral was registered in Aralsk at a speed of 5 m/s and remained for 45.8±2.12; CI 46.01 and 45.6% days per year, in Aiteke-bi – 6 m/s and for 45.8±2.33; CI 46.1 and 45.6% days, in Shalkar – 3 m/s and for 54.3±2.72; CI 54.5 and 53.9% days. In the warm period, the wind speed was higher than 3-5 m/s, and its direction from the Aral Sea remained in Aralsk for 33.3±2.01; CI 33.5 and 33.6% days per year, in Aitek-bi – for 15.8±1.71; CI 15.95 and 15.63% days. The duration of winds at a speed of 12 m/s remained in Shalkar for 70.8±2.48; CI 71.1 and 71.6% days per year. The wind strength on the Beaufort scale corresponded to a weak and moderate. According to the results, the occurrence of dust storms in Aralsk was registered >10.4 days per year. The maximum frequency moved from the spring-summer months to the spring months.
Key words: Aral Sea, population of the Aral Sea region, wind direction and speed, dust storms, influence

1. Introduction

One of the biggest global environmental disasters experienced by the countries and the population of Central Asia is the tragedy of the Aral Sea. This catastrophe with its ecological, climatic, socio-economic and humanitarian consequences poses a direct threat to the sustainable development of the region, the health, the gene pool and the future of people living in this zone (Samandar J.2021; Sitdikova N. K. et al.2017). The consequences of the Aral catastrophe have long gone beyond the region. Every year, more than 100 thousand tons of salt and fine dust with admixtures of various chemicals and poisons are carried from the dried-up water area of the sea, as from the crater of a volcano, adversely affecting all living things. The effect of pollution is enhanced by the fact that the Aral Sea is located on the path of a powerful jet stream of air from west to east, contributing to the removal of aerosols into the high layers of the atmosphere (Mukhametzhanova Z.T., et al.2015, Sakiyev K.Z.et al.2015; Margaryan V.G. 2020; Yessimbetov A. T. et al.2018, UNESCO, 2017).

In this regard, a comprehensive ecological-hygienic and climatic-geographic assessment of environmental factors with justification of the real environmental burden on the population of the Aral Sea region considering the zones of ecological disaster is a new approach to studying the changes occurring in the territory of the Aral Sea region. Therefore, there is a need to study the individual components of the climatic and ecological conditions of these territories, including the level of discomfort and climate variability, which determine the state and level of the local population health (Amreyeva K. Ye. et al.2017; Mamyrbayev A. A. et al. 2014; Sakiyev K. Z., . et al. 2015).

Previously, the Aral Sea acted as a kind of regulator softening the cold winds that came from Siberia in winter, and reducing, like a huge air conditioner, the heat in the summer months. With the tightening of the climate, summers in the region have become drier and shorter, and winters have become long and cold. The vegetative season has been reduced to 170 days. Precipitation decreased 10-fold in the coastal areas of the Aral Sea, air humidity decreased by 10 percent, air temperature decreased in winter and increased by +2-3 Celsius in summer (Hajek, A. et al.2022; Shadetova A. Zh. et al.2015; Novikova N. M. 2019).

A characteristic feature of the Aral Sea climate is the high frequency and significant duration of dust storms and snowdrifts. Strong winds often blow in the Aral Sea area. They are most intense and prolonged on the western coast of the sea – more than 50 days. The maximum wind speed can reach 20-25 m/s. The influence of the Aral Sea on the climate of

the territory is local. The decrease in the level of the Aral Sea entails a change in all components of the natural environment. The sea area has a special effect on the wind regime, mainly on their speed (Novikova N. M. 2019; Novikova N. M. 2020; Semyonov O. Ye. et al.2006; Tleumuratova B. S. et al.2015; Akhmetova S. T. et al.2016;).

The **aim** of our study was to analyze the spatial and temporal features of the wind regime from the Aral Sea to the settlements of the Aral Sea region located in the zone of ecological disaster of the Republic of Kazakhstan.

2. Materials and methods

2.1 Research area and sampling strategy

We have studied the main characteristics of wind in the conditions of Aralsk city, Aitek-bi township (the Kyzylorda region) and Shalkar city (the Aktobe region) of the Republic of Kazakhstan.

The object of the study was the territories of 2 cities and 1 township of the Aral Sea ecological zones according to the Law of the Republic of Kazakhstan dated June 30, 1992 No. 1468-XII «On social protection of citizens affected by an environmental disaster in the Aral Sea region» (with amendments and additions as of 03.07.2013): environmental disaster (Aralsk, Aiteke-bi, Shalkar) (https://online.zakon.kz/Document/?doc_id=1001259).

The studies were organized during the cold and warm periods of the year (2014-2015). The total volume of studies amounted to 38,400 measurements.

2.2. Analysis of microclimate parameters

The coordinates of the studied territories were determined using a GPS navigator. The assessment was carried out throughout the week, around the clock. Measurements of wind speed (m/s), wind direction and bearing were performed every 3 hours (6:00, 9:00, 12:00, 15:00, 18:00, 21:00, 00:00, 3:00). 8 wind directions were estimated – northern (N), north-western (NW), south-western (SW), western (W), southern (S), south-eastern (SE), eastern (E) and north-eastern (NE).

Registration of factors was carried out according to the Set of rules of the RK 2.04-01-2017 «Construction climatology» (Set of rules of the RK 2.04-01-2017) and the methodology approved at the meeting of the Scientific Council of the «National Center for Occupational Hygiene and Occupational Diseases» of the Ministry of Health of the Republic of Kazakhstan (Protocol No. 2 dated 27.02.2014). Monthly values of 92 meteorological parameters for 2004 – 2014 were obtained from the RSE «Kazhydromet» of the Kyzylorda

region. According to the obtained values, a retrospective analysis of weather and climatic data was carried out.

The wind speed was estimated on the Beaufort scale: 0-0.2 – calm (smoke rises up); 0.3-1.5 – quiet (smoke slightly deviates, leaves rustle, candle flame slightly deviates); 1.6-3.3 – light (wind movement is felt by the face, leaves rustle); 3.4-5.4 – weak (leaves and thin branches of trees wave all the time, the flag flyes); 5.5-7.9 – moderate (the wind picks up dust and papers, large branches swing).

2.3. Statistical analysis

Quantitative variables were checked for the normality of the distribution by statistical analysis (Statistica 10) using the Shapiro – Wilk criteria. Arithmetic mean, standard deviation, error and 95% confidence interval were calculated for quantitative variables with normal distribution. Median, 25% and 75% interquartile ranges were calculated for quantitative variables with abnormal distribution. Differences between sectors were revealed by methods of parametric Student's statistics for unrelated groups with statistical accuracy <0.05, when using the Bonferroni correction – with a significance <0.05 divided by the number of pairs of comparisons, with nonparametric statistics on the Man – Whitney test with sample ranking.

3. Research results

The wind regime is mainly determined by the seasonal features of the structure of the baric field according to the baric law of wind, as well as the shape of the relief, the nature of the underlying surface and the openness of the installation site of the devices.

The analysis of the average daily wind speed for the study period showed that the average value of the daytime wind speed during the warm season in Aralsk was 6.26±0.13 m/s; CI 6.0 and 6.52. Fluctuations in the night wind speed during the period were significant and ranged from complete calm to 12 m/s (3.67± 0.2; CI 3.28 and 4.06).

The indicators of the repeatability of the wind direction by points according to the results of average daily observations in the warm season are presented in Table 1. Thus, it is obvious that the winds of the south-western (33.3%), western (20.8%) and southern (15.5%) directions blew most often over the Aralsk territory.

Table 1 – Indicators of wind frequency by points in the warm season in Aralsk

Wind direction	Percent	Standard deviation	Standard error	Confidence interval	
				-95,000%	+95,000%
Aralsk, twenty four hours					
Calm	1,09	0,19	0,44	1,12	1,05
N	4,17	0,72	0,85	4,24	4,09
E	4,17	0,72	0,85	4,24	4,09
SE	4,17	0,72	0,85	4,24	4,09
S	15,58	2,38	1,54	15,71	15,45
SW	33,33	4,03	2,01	33,50	33,16
W	20,83	2,99	1,73	20,98	20,69
NW	16,67	2,52	1,59	16,80	16,53
Aralsk, day					
E	6,67	1,80	1,34	6,81	6,52
S	13,33	3,35	1,83	13,53	13,14
SW	40,00	6,96	2,64	40,28	39,72
W	20,00	4,64	2,15	20,23	19,77
NW	20,00	4,64	2,15	20,23	19,77
Aralsk, night					
Calm	2,90	1,36	1,17	3,06	2,74
N	11,11	4,77	2,18	11,42	10,81
SE	11,11	4,77	2,18	11,42	10,81
S	19,32	7,53	2,74	19,71	18,94
SW	22,22	8,35	2,89	22,63	21,82
W	22,22	8,35	2,89	22,63	21,82
NW	11,11	4,77	2,18	11,42	10,81

The studied period in Aralsk was characterized by winds of the southern and south-western directions with a speed from 1 to 12 m/s. Due to the southern location of the Aral Sea to the city and the general slope of the terrain to the sea, winds at a speed of 12 m/s brought sand from the bottom of the dried sea.

According to the measurements of wind speed in Aralsk, in the cold season in the studied area, the prevailing influence was exerted by winds of north-eastern and northern directions with a speed from 1 to 6 m/s (3.22±0.06; CI 3.10 and 3.34). The average wind speed for the study period showed that the daily wind speed in Aralsk was 3.28±0.09 m/s; CI 3.12 and 3.45. Fluctuations in night wind speed were insignificant and their average value was 3.11± 0.2; CI 2.94 and 3.28.

The results of the analysis of the average daily frequency of the wind direction by points in the cold season are presented in Table 2, from which it can be seen that the winds of the north-eastern (45.8%), northern (29.17%) and eastern (20.83%) directions blew most often over the territory of Aralsk, calm was recorded in 4.17%.

Table 2 – Indicators of wind frequency by points on the Aralsk territory in the cold season

Wind direction	Percent	Standard deviation	Standard error	Confidence interval	
				-95,000%	+95,000%
Aralsk, twenty four hours					
Calm	4,17	0,72	0,85	4,24	4,09
N	29,17	3,74	1,93	29,33	29,00
NE	45,83	4,50	2,12	46,01	45,65
E	20,83	2,99	1,73	20,98	20,69
Aralsk, day					
Calm	6,67	1,80	1,34	6,81	6,52
N	26,67	5,67	2,38	26,92	26,41
NE	33,33	6,44	2,54	33,61	33,06
E	33,33	6,44	2,54	33,61	33,06
Aralsk, night					
N	33,33	10,74	3,28	33,79	32,88
NE	66,67	10,74	3,28	67,12	66,21

According to short-term studies in the cold period of the year, during the study period, winds from the north-east, north and east directions with wind speeds from 1 to 6 m/s was characteristic for Aralsk.

The results of long-term observations of wind speed in Aralsk (2004 – 2014) indicate that the maximum average annual wind speed was observed in 2010 and was 4.6 m/s, the

minimum average annual wind speed was observed in 2004 and was 3.7 m/s. The maximum wind speed for January for Aralsk according to SP RK 2.04-01-2017 is 5.6 m/s.

The change of the prevailing wind points is clearly expressed in the annual course: north-eastern (25%), northern (21%), eastern (13%) and south-western (11%) winds, which is characteristic of the long-term climatic parameters of the cold (December-February) period of the year for the city of Aralsk (north-eastern wind) and warm (June-August) period (northern winds) according to the Set of rules of the Republic of Kazakhstan 2.04-01-2017.

Wind speed measurements have shown that the large presence of calm days and winds of north-western and north-eastern directions was characteristic for Aiteke-bi. The wind speed during the studied period was in the range from 1 to 5 m/s (1.77±0.07; CI 1.64 and 1.91) with a transition to calm. The maximum wind speed was usually observed during daytime hours (2.21±0.09; CI 2.03 and 2.39) and with frequently recurring north-western and north-eastern wind directions mainly in the warm season of the season. The night wind speed rose to 3 m/s at times (1.05±0.07; CI 0.91 and 1.19).

The analysis of the average daily frequency of wind directions by points is presented in Table 3, from which it can be seen that north-eastern (26.7%), north-western (26.3%) and south-western winds (15.79%) prevailed most often over the territory of Aiteke-bi during the warm season due to the weakening of the Siberian anticyclone, their repeatability was in the range from 15 to 27%. The frequency of winds from the western and northern directions ranged from 4 to 8%.

Table 3 – Indicators of wind repeatability by points in the territory of Aiteke-bi in the warm season

Wind direction	Percent	Standard deviation	Standard error	Confidence interval	
				-95,000%	+95,000%
Aiteke-bi, twenty-four hours					
Calm	18,64	3,33	1,82	18,81	18,47
N	8,33	1,68	1,29	8,45	8,21
SW	26,75	4,30	2,07	26,95	26,56
SE	15,79	2,92	1,71	15,95	15,63
E	4,17	0,88	0,94	4,25	4,08
NE	26,32	4,25	2,06	26,51	26,12
Aiteke-bi, day					

Calm	12,98	3,96	1,99	13,22	12,75
N	6,67	2,18	1,48	6,84	6,49
NE	30,53	7,44	2,73	30,85	30,20
SW	17,89	5,16	2,27	18,16	17,63
NW	31,93	7,63	2,76	32,26	31,60
Aiteke-bi, night					
Calm	28,07	11,81	3,44	28,60	27,55
N	11,11	5,78	2,40	11,48	10,75
NE	20,47	9,52	3,09	20,94	20,00
SW	12,28	6,30	2,51	12,67	11,90
W	11,11	5,78	2,40	11,48	10,75
NW	16,96	8,24	2,87	17,40	16,52

The results of short-term observations in the warm period of the year in Aiteke-bi showed that the studied period of the year was characterized by a low wind speed of up to 5 m/s.

Wind speed measurements have shown that there was a wind regime with a wind speed of up to 7 m/s with a transition to calm in the cold period of the year in Aiteke-bi. The average daily wind speed was 2.35±0.08; CI 2.20 and 2.50. The maximum wind speed was usually observed during daytime hours (2.59±0.11; CI 2.38 and 2.81) with a frequently recurring eastern wind direction, the night wind speed increased to 4 m/s (1.94±0.09; CI 1.76 and 2.12).

The analysis of the average daily frequency of wind directions by points is presented in Table 4, which indicates that the eastern (45.83±2.33; CI 46.05 and 45.61%), north-eastern (29.17±2.13; CI 29.37 and 28.97%), north-western (8.33%) and south-eastern (4.17%) winds with a transition to calm (12.5%) prevailed most often in the territory of Aiteke-bi during the cold season.

Table 4 – Indicators of wind repeatability by points in the territory of Aiteke-bi in the cold season

Wind direction	Percent	Standard deviation	Standard error	Confidence interval	
				-95,000%	-95,000%
Aiteke-bi, twenty-four hours					
Calm	12,50	2,40	1,55	12,65	12,36

NE	29,17	4,53	2,13	29,37	28,97
E	45,83	5,44	2,33	46,05	45,61
SE	4,17	0,88	0,94	4,25	4,08
NW	8,33	1,68	1,29	8,45	8,21
Aiteke-bi, day					
Calm	13,33	4,05	2,01	13,57	13,10
NE	13,33	4,05	2,01	13,57	13,10
E	53,33	8,73	2,96	53,68	52,98
SE	6,67	2,18	1,48	6,84	6,49
NW	13,33	4,05	2,01	13,57	13,10
Aiteke-bi, night					
Calm	11,11	5,78	2,40	11,48	10,75
NE	55,56	14,44	3,80	56,14	54,97
E	33,33	13,00	3,60	33,89	32,78

Thus, according to the results of short-term studies, during the cold period of the year, winds from eastern directions with a speed of 1 to 7 m/s (45.83%) prevailed in Aiteke-bi. All the obtained results confirm the expressed continentality of climatic factors.

According to the results of long-term observations of wind speed in Aiteke-bi (2004 – 2014), the maximum average annual wind speed in this area was observed in 2012 and 2013 and was 2.4 m/s. The minimum average annual wind speed was recorded in 2008 and was 1.9 m/s. The average monthly maximum wind speed was recorded in February and was 2.5 m/s, while the minimum average monthly wind speed was 2.03 m/s and was recorded in July.

According to the Set of rules of the Republic of Kazakhstan 2.04-01-2017, the maximum wind speed should normally be recorded in January and be 3 m/s, the minimum wind speed should be recorded in July and be 2.5 m/s. According to long-term observations, there were no deviations from the wind speed norms from 2004 to 2014 in Aiteke-bi.

The results of retrospective data on the repeatability of wind directions, calms and wind roses over 10 years indicate that north-eastern (27%), north-western (14%), northern and eastern (13%), western (11%) and south-western (10%) winds prevailed in Aiteke-bi, and calm was recorded in 19%. The study of the repeatability of wind directions and calms by month showed that north-eastern (28.3%), eastern (16%), south-western (12.3%), northern (12%) and south-eastern (9.7%) winds and calms (21%) prevailed during the warm season.

And north-eastern (26.3%), north-western (21%), northern (16.3%), western (13.3%) and eastern (9%) winds and calm (17.7%) prevailed in the cold season. These data correlate with the climatic parameters determined by the Joint Venture of the Republic of Kazakhstan 2.04-01-2017 «Construction climatology» for the cold season (north-eastern winds) and the warm season (north-western winds).

In the warm season, the Shalkar territory is characterized by winds with an increase in speed from 4 to 15 m/s, sometimes with a transition to a storm (according to the Beaufort scale). The average daily values of wind speed at this time of the year were in the range of 6.46±0.13 m/s; CI 6.2 and 6.71. The maximum wind speed (from 4 to 15 m/s) in Shalkar was recorded during the daytime with an average daily wind speed of 7.45±0.17 m/s; CI 7.10 and 7.79. The night wind speed (from 4 to 7 m/s) on the Beaufort scale ranged from moderate to a wind that is capable of lifting dust from the ground. The average wind speed at night was 4.8±0.06; CI 4.67 and 4.93.

According to the results of average daily observations, in 70.83% cases in the territory of Shalkar during the warm season, the south-western wind direction was recorded, in 29.17% – the western wind direction. In the daytime, winds from the south-western direction were recorded in 66.67% cases, and from the west – In 33.33%. At night, the winds of the south-western direction (77.78%) and the western direction (22.22%) prevailed (Table 5).

Table 5– Indicators of wind frequency by points in the territory of Shalkar in the warm season

Wind direction	Percent	Standard deviation	Standard error	Confidence interval	
				-95,000%	+95,000%
Shalkar, twenty-four hours					
SW	70,83	6,15	2,48	71,10	70,56
W	29,17	6,15	2,48	29,44	28,90
Shalkar, day					
SW	66,67	10,58	3,25	67,11	66,22
W	33,33	10,58	3,25	33,78	32,89
Shalkar, night					

SW	77,78	13,72	3,70	78,43	77,11
W	22,22	13,72	3,70	22,89	21,57

Short-term studies showed that the south-western (70.83%) and western (29.17%) winds with a high speed from 4 to 15 m/s prevailed in the territory of Shalkar in the warm period of the year. Winds with such characteristics increase the dustiness of the Shalkar air basin.

Wind speed measurements in Shalkar indicated that winds of the southern and north-eastern directions with a speed of 1 to 5 m/s were more often recorded (2.54±0.07; CI 2.41 and 2.68) during the cold season in the studied area The average value of the daily wind speed in Shalkar during the study period was 2.46=0.09 m/s; CI 2.27 and 2.64. Fluctuations in the night wind speed were insignificant with an average value of 2.68± 0.1; CI 2.49 and 2.87.

The analysis of the frequency of wind directions by points in the cold season showed that the winds of the southern (54.17%), north-eastern (25%), eastern, south-eastern and south-western (4.17%) directions blew most often over the territory of Shalkar. The complete absence of wind (calm) was noted in 8.33%. Winds from the southern (46.67%), north-eastern (26.67%), eastern and south-western (6.67% each) directions were recorded during the daytime, complete calm was observed in 13.33% cases (Table 6).

Table 6 – Indicators of wind frequency by points in the territory of Shalkar in the cold season

Wind direction	Percent	Standard deviation	Standard error	Confidence interval	
				-95,000%	+95,000%
1	2	3	4	5	6
Shalkar, twenty-four hours					
Calm	8,33	2,27	1,51	8,50	8,17
NE	25,00	5,58	2,36	25,26	24,74
E	4,17	1,19	1,09	4,29	4,05
SE	4,17	1,19	1,09	4,29	4,05
S	54,17	7,39	2,72	54,46	53,87
SW	4,17	1,19	1,09	4,29	4,05

Shalkar, day					
Calm	13,33	5,50	2,35	13,66	13,01
NE	26,67	9,31	3,05	27,09	26,25
E	6,67	2,96	1,72	6,91	6,43
S	46,67	11,85	3,44	47,14	46,19
SW	6,67	2,96	1,72	6,91	6,43
Shalkar, night					
NE	22,22	13,72	3,70	22,89	21,57
SE	11,11	7,84	2,80	11,61	10,62
S	66,67	17,64	4,20	67,41	65,92

At night, winds from the southern (66.67%), north-eastern (22.22%) and south-eastern (11.11%) directions prevailed.

Thus, the results of short-term studies of the climate parameters of Shalkar showed that the winds of the north-eastern directions prevailed in the cold period of the year (25%). The occurrence of southern winds with a wind speed from 1 to 5 m/s was 54.17%.

The results of the study of retrospective data of wind speed in Shalkar showed that the maximum average annual wind speed (4 m/s) was observed in 2006, 2010, 2012 and 2013. The minimum average annual wind speed (3.6 m/s) was recorded in 2014. According to monthly averages, the maximum wind speed (5.9 m/s) was registered in March 2005. The minimum wind speed (1.7 m/s) was registered in October 2007. The maximum wind speed according to the Joint Venture of the Republic of Kazakhstan 2.04-01-2017 in Shalkar is 6.2 m/s in January. Minimum wind speed according to the Joint Venture of the Republic of Kazakhstan 2.04-01-2017 is registered in July and is equal to 4.3 m/s. According to the data of RSE «Kazhydromet», the excess of the norm wind speed was not noted in Shalkar in the cold period of the year. The excess (by 0.2 m/s) in the warm period of the year was registered in June in 2008.

Long-term observations of the repeatability of wind direction, calm and wind roses indicate that eastern (16%), north-eastern and western (15%), northern (14%), south-western (12%) and southern (11%) winds prevailed in Shalkar. The analysis of the frequency of calms and wind directions by season showed that the north-eastern (20%), northern (18%), eastern (15%), south-western (14%) and southern (13%) winds prevailed in the cold period of the

year. During the warm season, the western (18%), northern, eastern, north-western (15%) and north-eastern (13%) winds prevailed.

Studies have shown that the wind direction from the Big Aral with a wind speed of 4 m/s was recorded 45.8% days per year in Aralsk during the cold season. The wind direction from the Small Aral at a speed of 6 m/s was recorded 46% days per year in Aiteke-bi during the cold season. In Shalkar, the wind direction from the Small Aral at a speed of 3 m/s was recorded 54% days per year during the cold season (Figure 1).

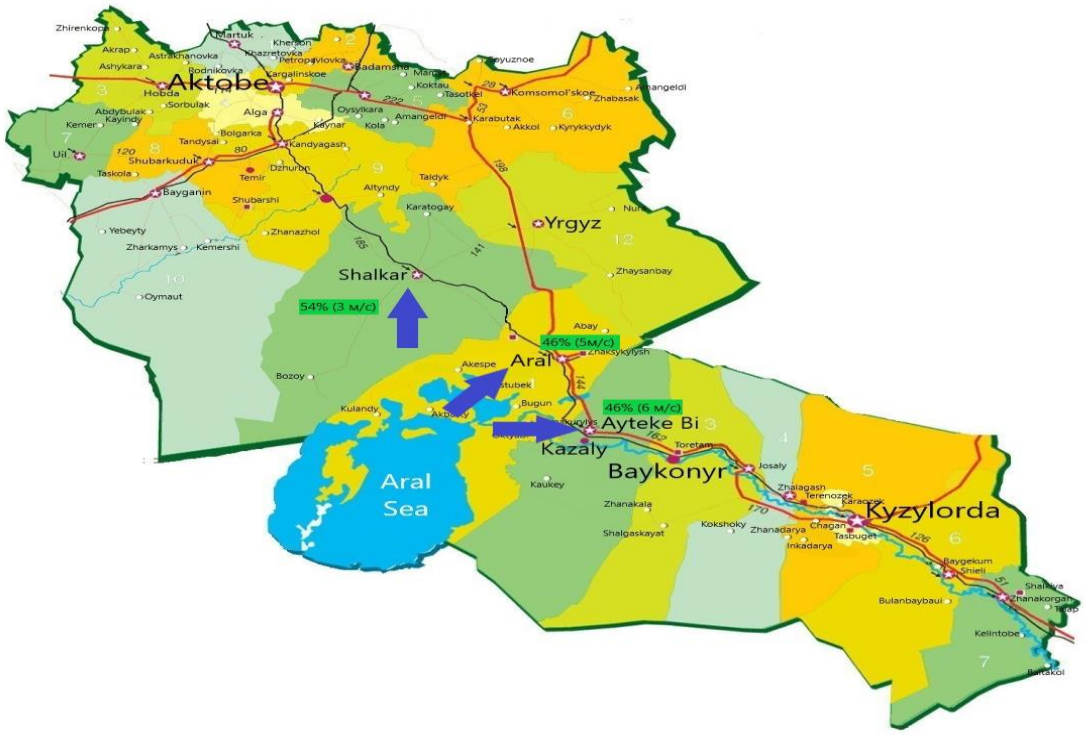

Figure 1 – Wind direction (from the Aral Sea) in the Aral Sea region during the cold season

The analysis of the regularity of the wind direction in the territory of the Aral Sea region showed that the wind direction from the Big Aral with a speed of 5 m/s was recorded 33% days per year in Aralsk during the warm season. At the same season, the wind direction from the Big Aral at a speed of 2 m/s was recorded 16% days per year in Aiteke-bi. The wind direction from the Big Aral at a speed of 12 m/s was recorded 71% days per year in the warm season in Shalkar (Figure 2).

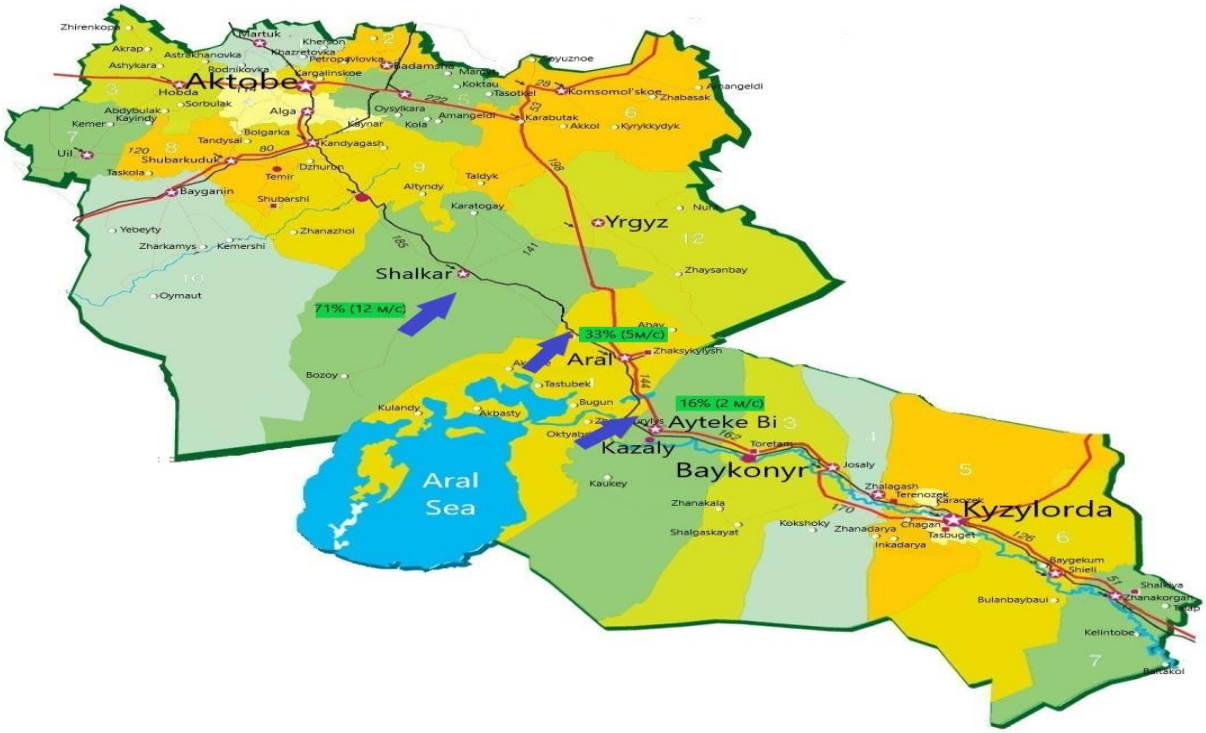

Figure 2 – Wind direction (from the Aral Sea) in the Aral Sea region during the warm season

The results of a long-term study of wind directions in the Aral Sea region indicate that the wind direction from the Big Aral with a speed of 4 m/s was recorded 11% days per year in Aralsk. The wind direction from the Big Aral at a speed of 2 m/s was recorded 12% days per year in Aiteke-bi. The wind direction from the Big Aral at a speed of 4 m/s was recorded 11% days per year in Shalkar (Figure 3).

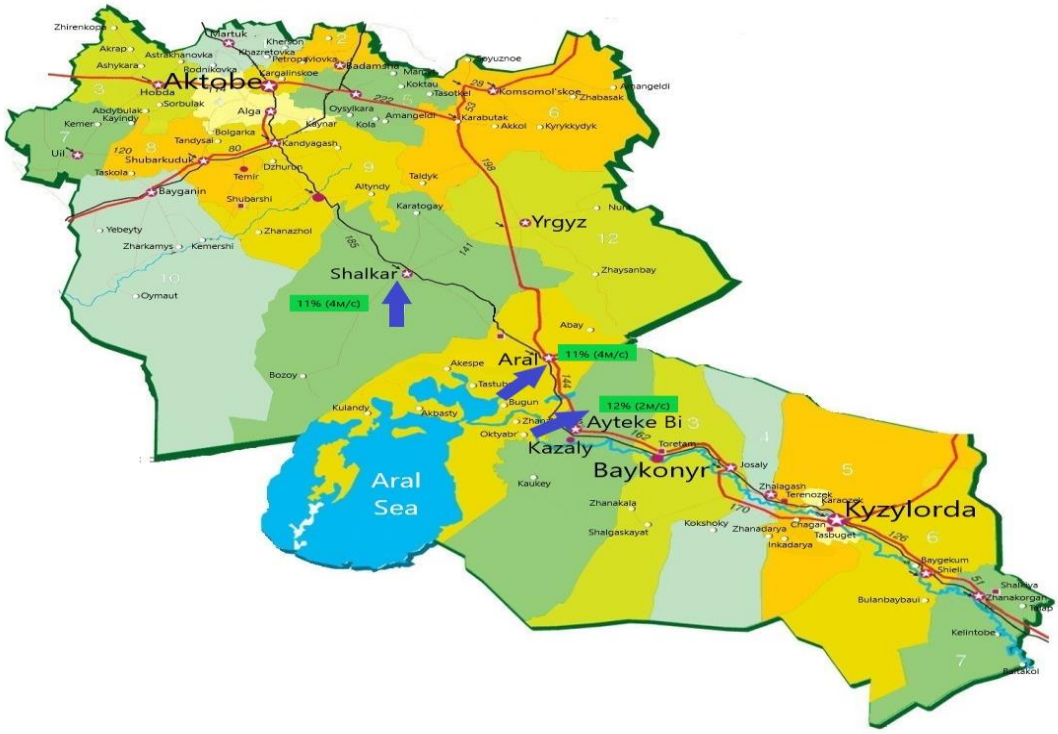

Figure 3 – Retrospective data of wind direction in the Aral Sea region (from the Aral Sea)

4. Discussion

4.1. Main findings

Changes in atmospheric pressure in the settlements of the Aral Sea region determine a rapid increase in wind speed of more than 5-6 m/s, causing the occurrence of dust storms. But in addition to the intensity of the wind, it is important to analyze the stability of the wind direction from the Aral Sea, which determines the formation of sand-salt aerosols over the territories of cities and towns. Sand-salt aerosols make breathing difficult and cause health problems (Margaryan, V. G. 2020; Breitner, S., et al. 2014; Margaryan V. G. et al. 2021; Margaryan V. G. 2020; Danova T. Ye. 2017; Mezentseva L. I., et al. 2017).

It should be noted that maximum wind speeds are also important for agriculture, construction and other human activities. Strong winds under certain conditions can cause significant damage to the population and economic activity. Such phenomena as wind erosion and dry winds are especially unfavorable for agriculture (Surkova G. V. et al. 2018; Perevedentsev Yu. P. et al. 2014; Noskova Ye. V. et al. 2015; Yagafarova G. A. et al. 2018).

The position of the settlements of the Aral Sea region territory to the Aral Sea largely determines the direction and speed of winds in the region. The results of short-term studies showed that during the cold period of the year, the wind direction from the Big Aral was recorded more often in Aralsk (5 m/s) and remained 45.8 ±2.12; CI 46.01 and 45.6% days per year. The wind direction from the Small Aral at a speed of 6 m/s remained in Aiteke-bi 45.8±2.33; CI 46.1 and 45.6% days per year. The wind direction from the Small Aral at a speed of 3 m/s remained in Shalkar 54.3±2.72; CI 54.5 and 53.9% days per year.

In the warm season, the wind speed in the territory of the Aral Sea region was higher than 3-5 m/s, and its direction from the Big Aral remained in Aralsk 33.3±2.01; CI 33.5 and 33.6% days per year. The wind direction from the Small Aral remained in Aiteke-bi 15.8±1.71; CI 15.95 and 15.63% days per year. The wind direction from the Small Aral at a speed of 12 m/s remained in Shalkar 70.8±2.48; CI 71.1 and 71.6% days per year.

According to retrospective data, the average annual wind speed was 2-5 m/s, and the frequency of days with wind direction from the Big and Small Aral in Aralsk and Shalkar was 11% days per year, in Aiteke-bi – 12%. Dust storms occurred >10.4% days per year per, rain and fog were recorded on >7.7% days per year.

There are numerous studies that prove that even minor exceedances of the maximum permissible concentrations of pollutants in the atmosphere can lead to an increase in the frequency of diseases of the respiratory and cardiovascular systems (Shadetova A. Zh. et al. 2016; Tleumuratova, B. S., et al. 2020; Mashina T. F. et al. 2018; Gazizova A. O. et al. 2017;).

The present study showed that in the studied areas the wind blew from the direction of the Big and Small Aral spreading salts over long distances. Salt particles get into the air both from the bottom of the dried part of the sea, when the sea is agitated and sea water is sprayed with subsequent evaporation of droplets in the air. Salt condensation also occurs on hygroscopic solid particles and droplets that are products of combustion or organic decomposition (Khaibullina Zh. et al. 2022; Ou, C. et al. 2023; D'Amato, G. et al. 2023;).

According to retrospective data, the average annual wind speed during the study period varied within 5-6 m/s with the predominance of winds in the north-eastern points. Their repeatability ranged from 20-25% cases, respectively. In January, the frequency of north-eastern winds was 24-32%. Winds from other directions were rarely observed, their frequency did not exceed 10-14%. Winds reached especially great strength during the occurrence of a storm cyclone over the Aral Sea during the north-western incursions of cold air masses. Breezes were often observed in the coastal zone. V. Ye. Chub et al. indicates that

the reduction of the sea water surface affected the wind regime of the Aral Sea region. Namely, there was a weakening of the breeze circulation mainly due to a reduction in daytime northeast breezes (Novikova N. M. 2020; Semyonov O. Ye. et al.2006).

In spring, mainly north-easterly winds prevailed in the north-eastern part of the sea and on the coast. But their frequency decreased to 20-22% with a simultaneous increase in the frequency of winds of the western points. The average wind speeds of the prevailing directions were 5-7 m/s. In summer, northern winds with an average speed of 4-5-6 m/s prevailed in the middle part of the east coast and on the islands. In autumn, north-eastern and eastern winds prevailed over a larger area, the speed of which was higher compared to summer. Thus, it was found that the average wind strength in the territory of the Aral Sea corresponded to a weak and moderate category of wind strength by the Beaufort scale.

According to the results of retrospective data, the following changes were noted: dust storms in Aralsk were recorded >10.4 days per year. The greatest number of dust storms and snowdrifts occurred in the spring and summer period. But it should be noted that in recent years, the maximum frequency of dust storms and snowstorms has shifted from the spring-summer months to the spring months.

Salt dust transfer is one of the most significant negative consequences of the drying up of the Aral Sea. When the surface dries, it becomes a source of salt and dust removal in the form of snowdrifts and dust storms. The total amount of aerosol removed from the foci is 1.17 million tons per year, including up to 2-3%salts. With one dust storm, up to 12% of the substance mass from the annual amount can be removed. The bulk of the removed material falls directly on the seabed, but a small part (no more than 15%) is spread to a distance of 10-15 km (Kublanov Zh. Zh. et al.2023; Novikova N. M. 2020; Semyonov O. Ye. et al.2006).

Analysis of the various experimental studies has shown that chronic exposure to salt-dust aerosol of the Aral Sea contributes to the strengthening of oxidative metabolism with an increase in catabolites of lipid peroxidation and an imbalance of antioxidant protection. Chronic exposure of salt-dust aerosol leads to damage of cell membranes and the growth of extracellular nucleic acids, to the development of T-cell immunity depression, increased expression of inflammatory cytokine IL6. And pathomorphological changes in the bronchopulmonary system are characterized by massive reactive lymphoid hyperplasia with predominant involvement in the process of interstitial lung, perivascular and peribronchial zones (Otarbayeva, M.B. et al.2018; Dyusembayeva N. K. 2015; Akbarkhodzhayeva Kh. N. et al.2016; Gazizova A. O. et al.2017; Muhammetgulyeva, O.S. et al.2023).

It should be noted that at present, storms have become less frequent due to the general weakening of the wind in Central Asia, which caused a sharp decrease in dust and salt precipitation.

4.2. Strengths and Limitations

The territories of Aralsk, Aiteke-bi, Shalkar were classified as an environmental disaster zone in the Law of the Republic of Kazakhstan dated June 30, 1992 No. 1468-XII «On social protection of citizens affected by an environmental disaster in the Aral Sea region» (https://online.zakon.kz/Document/?doc_id=1001259). According to our research, the natural and climatic factors of Aralsk and Shalkar can be attributed to the 4 zone with highly irritating weather conditions, and Aitek-bi can be attributed to the 2 zone with mildly irritating weather conditions (Ibrayeva L. K. et al.2016; Khanturina, G.R. et al.2017).

Scientists have found that the main route of ecotoxicants entry into the body of residents is the inhalation route, which determines the high dust load caused by the arid climate and semi-desert-desert landscape. A study of the air in the territory of Aiteke-bi (Kyzylorda region) in 2015 revealed a high content of suspended solids (42.0±4.0 (CI 95% 33-50) micrograms/m^3 with a range of fluctuations 6-78). The same level of fine suspended particles in the territory of the Aral Sea region was determined by WHO in 2005, and the average annual concentrations were more than 35 micrograms/m^3 (Shadetova A. Zh. et al.2015; Khanturina, G.R. et al.2017).

The effects of prolonged inhalation exposure to dust aerosol on the human body can lead to diseases of the respiratory and cardiovascular systems, gastrointestinal diseases and diseases of the excretory systems (Ferrari, U., et al.2012; Urban, Aleš 2018; Chergizova B.T. et al. 2021; Milushkina O. Yu. et al. 2022; Zhao, New Zealand; 2018).

Thus, according to research data, a relationship between air temperature and wind speed was revealed in all the studied settlements of the Aral Sea region in the warm period of the year. With a decrease in wind speed on hot days, this led to stagnation of air over populated areas and difficulty in heat regulation of the body, to discomfort, especially with low humidity, particularly in Shalkar. Such dry and still air (49.3%) forms tension in the body, can lead to meteotropic reactions and the development of cardiovascular diseases. In the warm season, the high range of wind speed fluctuations in Aralsk may have been associated with cyclonic activity over the Aral Sea (Khanturina, G.R. et al.2017; Dzhumanov S. A. 2015).

5. Conclusion

1. The climatic indicators of Aralsk and Aiteke-bi in the warm period are characterized by the predominance of winds from the southern and south-western directions at a speed of 1 to 12 m/s. Due to the southern location of the Aral Sea to the city and the general slope of the terrain to the sea, winds at a speed of 12 m/s brought sand from the bottom of the dried sea. During the cold period of the year, the wind direction from the Aral Sea at a speed of 3 m/s was more often recorded in Shalkar and remained up to 54% of the days. It was found that the wind strength on the Beaufort scale corresponded to a weak and moderate category of wind strength.

2. Dust storms were recorded in Aralsk >10.4 days per year, their maximum frequency shifted from the spring-summer months to the spring months. Winds of north-eastern directions prevailed in Aralsk in 25%, in Aiteke-bi in 27%. The winds of the western directions prevailed in Shalkar in 18%.

Unconditionally, it is promising to conduct such studies using remote sensing materials, while simultaneously conducting ground-based observations in monitoring mode. It is important to study the connection of these phenomena with the change of cyclonic epochs, since they are accompanied by changes in wind speed – one of the important reasons for the formation of dust storms and salt-dust drifts.

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Authors' contribution

Conceptualization: MZ, AK; methodology: MZ, AK; verification: DZ; formal analysis: AK; investigation: KK, DZ, AS, TG, SG, PI, KT, resources: MZ, AK; data supervision: MZ, AK; writing – preparation of the initial project: MZ, AK; writing – review and editing: AK, SG; visualization: KK, DZ, AS; supervision: SG; project administration: MZ; all authors have read and agreed with the current version of the manuscript.

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Conflict of interest

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