

Dust storms as a factor of atmospheric air pollution in the Aral Sea basin

L. Orlovsky¹, G. Tolkacheva², N. Orlovsky¹ & B. Mamedov³

¹*J. Blaustein Institute for Desert Research, Ben-Gurion University, Israel*

²*Central Asian Hydrometeorological Institute, Tashkent, Uzbekistan*

³*National Institute of the Deserts, Flora and Fauna, Ashgabat, Turkmenistan*

Abstract

The Aral Sea Basin is considered as a region with increased rates of atmospheric air pollution by aerosols of arid origin. It is conditioned by the aridity of the climate and the presence of a great number of natural sources of aerosols emission to the atmosphere. The average annual number of days with dust storms varies from 20 to 67, while the maximum reaches up to 108-146 days with dust storms in separate years. The dusty and salty aerosol is the indispensable component and satellite of the dust storms in the region. The solonchaks (salty pans), secondary salinized irrigated lands and exposed bottom of the Aral Sea serve as natural sources of such kind of atmospheric pollution. Solonchaks, occupying the area of about 150 thousand km² of the Aral Basin, create the powerful basis for development of aeolian processes, and, consequently, salty-dust emission.

This paper presents the climatic characteristics of the dust storms in the Aral Sea region, and quantitative assessment of salty-dust emission from the Aral Sea surface, its dried off bottom and surrounding solonchaks. Distribution of components of aerosols by the height and remoteness from the sources of emission, routes and distance of transportation of atmospheric aerosols from the dried bottom of the Aral Sea to the adjacent areas are studied.

Keywords: Aral Sea, dust storm, air pollution, salt and dust emission, aerosol composition, transportation and deposition.

1 Introduction

One of the most dangerous consequences of the ecological crisis in Central Asia is significant increase of atmospheric dustiness and development of the powerful



dust and salt storms during the last decades [8]. Peculiarities of atmospheric circulation and landscapes of the Aral Basin favor the formation of dust storms. Sandy, sandy-gypseous, loess-clayey and solonchak deserts, occupying more than 70% of the area, serve as potential sources of dust in the lower atmosphere. Long dry season, unstable atmospheric stratification, and frequent strong winds call forth the accumulation of huge amount of dust in the surface air above the dust emission sites and its transportation to significant distances. According to the observations, dust here contains salts dangerous for the health of humans and animals, and for environment in whole [9, 16].

The main factors of dust storms rise are recurrence of strong winds and vast area of dust emission sites, where the latter is the subject of change. During the last decades owing to the crisis situation in the Aral region the total area of dust emission sites increased significantly because of the shrinking of the Aral Sea and consequent drying of its exposed bottom and deltaic areas of Amudarya and Syrdarya Rivers.

The problem of salty dust emission from the dried bottom of the Aral Sea and quantitative and qualitative properties of salty dust, routes of transportation and areas of deposition of salty dust are the most important and the least studied ecological problems of the Basin. There is a lack of information both on the mechanism of dust formation and its temporal and spatial distribution, and on quantity of the dust in the atmosphere and its chemical, dispersive and sedimentation properties.

The purpose of the paper is to present some data on quantity and quality of the natural aerosols from the emission sources in the Aral Sea Basin.

2 Study site and methodology

The Aral Sea Basin administratively includes all the territory of Uzbekistan (448,000 km²), Tadjikistan (142,000 km²) and Turkmenistan (491,000 km²), and parts of the territory of Kazakhstan (Kzylorda and Chimkent districts, south of Aktyubinsk district – 369,000 km²) and Kyrghizstan (Osh and Naryn districts – 115,000 km²). The large part of the land is under agricultural use (1123,000 km²) and is divided as follows: plough-land – 82,000 km², permanent plantations – 5,000 km², hayfields - 5,000 km², rangelands – 892,000 km², others – 139,000 km².

Atmospheric precipitation is an integrated indicator of atmospheric pollution; it is divided into wet precipitation and dry atmospheric fallings. Rain, snow and hail are wet atmospheric precipitation, while depositing dust particles are dry atmospheric precipitation. The permanent network for sampling of atmospheric precipitation was established in a way encompassing all the geographic and climatic natural zones of the region, affected by anthropogenic influence at different rates. Sampling of the wet precipitation and dry deposits was carried out according to the methodology developed by Central Asian Hydrometeorological Institute (SANIGMI) and Main Geophysics Observatory [4,5]. Sampling of dry atmospheric depositions was carried out by two ways: on the medicinal gauze with polyethylene substrate and on the plastic



dish with glycerin. Wet precipitation was collected in clean dishes. The extraction of collected dry deposits has been done twice a month in the first and sixteenth of each month; wet precipitation was extracted after each event. Samples were tested on quantitative and qualitative content of mineral components, pH and electric conductivity. Electric conductivity of the studied samples was determined by conductance-measuring method; concentration of hydrogen ions (pH) – by electrometric method with pH-meter, HCO_3^- – by micro-titration, sulphate-ions were defined by colorimetric barium-sulphate method; chloride ions – by mercurimetric method. To determine nitrate ions the photolorimetric method with salicylic acid was applied, for NH_4^+ -ions – photolorimetric method with Nessler reagent. Cations Ca^{2+} , K^+ , Na^+ were defined by flame photometric method, Mg^{2+} - by difference between the hardness of the probe and Ca^{2+} ions content, hardness – by micro-titration with black chromogen indicator. Toxic elements were determined by neutron-activation method. Macro-components' content of aqueous extract of soils samples was detected by methods of ionic chromatography, atomic-absorptive spectrometry, photometric and classic chemical methods. Approximate estimate of the volume of aeolian transportation was calculated by Orlova's balance equation [6].

3 Results and discussion

3.1 Dust storms characteristics

Dust storms in Central Asia are the natural phenomena typical for the arid and semi-arid environment. Systematic observations on dust storms in the meteorological stations have been carried out since 1936. These observations are limited by visual estimation of duration, intensity and horizontal visibility.

The first summarizing papers were published in 1960s-70s [7,11]. The new phase in dust storms studies in the Aral Sea Basin, connected with beginnings of the Aral crisis, started in 1980s [2, 3, 8, 17].

The spatial distribution of the average annual number of days with dust storms differs in the northern and southern provinces of the area under research. In the northern province the distribution of the annual average number of days with dust storms has significant spottiness and varies from 10 to 40 days per annum. It has two local maxima – in the Eastern Aral region and Syrdarya River valley. Oblongness of the Aral dust emission site from the northwest to the southeast is connected with strong northwestern winds by the intrusions of the cold air masses and strong southeastern winds that precede the exit of the southern cyclones.

To the south of 42°N , where the vast sandy Karakum desert is situated, there is the zonal distribution of the average annual number of days with dust storms. The average number of days with dust storms increases from 20 days in the north to 70 days in the south. The area of the highest frequency of dust storms confined with Central Karakum desert and also has two local maxima. The axis between the local maxima in the Karakum desert is oriented latitudinally and



conforms to the prevailing here western and eastern strong winds. The average number of days with dust storms in the eastern local maximum site (corresponding to the area of sand dunes in the Central Karakum desert) reaches 62 days/year; the average of 67 days with dust storms per year is observed in the western site presented by the complex of sand dunes and solonchaks. In some unfavorable years 106-146 days with dust storms were registered in the Karakum desert. Comparison of the annual frequency of dust storms in 1936-1965 and 1966-1985 reveals some distinguishing features in geographic distribution of dust storms [24]. First, there are two large emission sources - in the Karakum desert and eastern Aral region. Second, there is a decrease in frequency of dust storms in the most of the area in 1966-1985. Significant decrease was observed in the Karakum desert, in the western Kazakhstan, and in the central parts of the area under research (excluding the north-eastern, eastern and south-western coastal areas of the Aral Sea). The frequency of the dust storms in the area of dried bottom of the Aral Sea increased during the same period more than twice [8]. Observations from the satellites confirm the conclusion made above. The unusually strong dust storms were not observed here till 1975. For the first time a dust storm in the northeastern coast (to the south of Syrdarya River delta) was recorded by satellite imagery in 1975 [3]. To this day, a dry sandy surface with a width of 20-25 km and a length of 100 km was formed here. Eight dust storms were recorded here in April-June of 1975: 5 events from April 2-May, and 1 in June (29 large dust removals with a distance of 200-450 km towards the west and southwest were recorded by satellite imagery from 1975-81). During the next five years (1985-90) an increase in the number of dust storms to 5.5 events a year was observed by satellite imagery together with revelations of new large dust-raising sites on the dried bottom near Vozrozhdenie Island and the Kulandy Peninsula. However, the low spatial and temporal resolution of the images and high cloudiness does not allow recording of all dust storms. On the whole, the number of events should be much higher than was recorded [3]. Nevertheless, further observation from space made it possible to reveal the main sites of salt- and dust cloud formation, their size and main directions of salt and dust transportation [2, 3]. Also the intensity of salt and dust blowouts changed with time. For instance, on May 22nd 1975, the dusty cloud over the Aral Sea had an area of 14,000 km². The dusty cloud observed on May 6 1979, by the same synoptic situation, had an area of 45,000 km². Analysis of the satellite images [3] demonstrated that the structure of the dust flow depends on the moisture content of the underlying surface. In 1975 the dust flow over the Aral Sea in most cases was divided into two big streams 30-40 km wide. Such division was determined by the structure of the dust-raising site. Both streams originated in places with dry sands. In 1976 the structure of dust removal changed; division into two streams is not experienced any more, and the dust is blown evenly from the whole coastal area.

Dust storms in the area under research may occur during all the year. There is no stable snow cover here, precipitation occur in winter-spring period in the most of area. Summer is dry and hot. Minimal frequency of number of days with dust storms is marked in January and December. In the plain area, the maximal



frequency of days with dust storms is observed mainly in summer (June-July), in some areas the peak shifts to autumn (August-September) or has two maxima – spring-autumn and summer-winter. Maximum of dust storms in the diurnal variation occurs as a rule during the daylight time. After 0500 the number of dust storms events increases reaching the maximum at 1100-1200 or 1500, and decreases gradually later on [8].

3.2 Sources of the salt and dust emission

Weakly stabilized sands, solonchaks, secondary salinized irrigated lands, dried off bottom of the Aral and Caspian Seas serve as natural sources of the atmospheric pollution in the Aral Sea Basin. Solonchaks (salty pans) are typical for the Central Asian deserts; they occupy the area of more than 150,000 km² [14]. Solonchaks are the main salts accumulators, and, therefore, sources of aeolian emission of the salts. Amount of readily soluble salts in the upper layer (0-10 cm) of meadow crusty-puffy solonchaks in spring and autumn exceeds 50% of total amount of salts in the half-meter layer. Friability of the upper accumulative salty horizon and weak fixedness by vegetation favor the emission of the salts. Solonchaks occupy more than 12% of 40,300 km² of the exposed bottom of the Aral Sea [1]. Morphologically, most of them are presented by crusty and puffy solonchaks. By chemical composition the soils of dried bottom are sulphate-chloride and chloride-sulphate ones, formed on sandy and loamy sandy coastal soils. They are heavily salinized with 8-10 % and more of Na⁺, Cl⁻, SO₄²⁻. For the “old dry zone” relatively low salinization rate of the soils is characteristic with sulphates, hydrocarbonates and calcium. In the surface layer of soils of the “newly-dried zone” the sulphates, chlorides and sodium dominate. The macro-component composition of the soils farther from the Aral Sea slightly changes: the sulphates content is decreasing, concentration of hydrocarbonates, calcium and magnesium – typical components of arid zone soils – is increasing [15]. Predominance of the soils with light texture favors the intensive development of aeolian processes and formation of aeolian forms of relief. In small sand-dune massifs amount of sulphate and chloride salts in the zone of aeration is 180,000-270,000 kg/ha, while in the high sand dunes this amount is 104,000 kg/ha. Salts content in the barchans doesn't exceed 0.1-0.3%, dust fraction is about 4-6% [12].

3.3 Distribution of dust transportation

Transfers of salt and dust are usually directed to the south-south-west towards the Amudarya River delta and the Ustyurt plateau, but in some cases they stretch to the east-south-east towards the Syrdarya River delta [3]. Analysis of space images for 1975-81 revealed that in 60% of all cases the salt and dust blowouts were moving to the south-west to oases in the Amudarya delta, in 25% of events to the west to the Ustyurt plateau, and in the rest of the cases to the south and southeast. In 1975 salt-dust transfers were mainly spread over the Aral Sea and rarely over adjacent coastal zones. In 1975 only one dust storm from the 8 recorded storms reached the opposite seaside. In 1979, by contrast, in 6 events



from the recorded 7 salt-dust storms, dust reached the western and southwestern coasts of the sea. The average length of the salt-dust flow in 1975 was 180 km; in 1979 it increased to 300 km. On May 6 1979 a strong salt-dust transfer over the Aral Sea and Ustyurt with a length of more than 500 km was registered. The area of salt and dust deflation comes to 20,000-30,000 km²; raised and transported salt and dust affects the surrounding territory – more than 500,000 km². It should be recognized that the satellite images register only cases with very strong atmospheric turbidity so in reality dust and salt could be transported to a far longer distance than can be observed from space. Based on this assumption, Grigor'ev and Lipatov [3] supposed that salt from the Aral region reaches the Caspian shore and spreads all over the Aral-Caspian lowland.

3.4 Range of salty dust transfer

The quantity and quality of salty dust transfer from the dried bottom of the Aral Sea, its transportation routes and areas of deposition are of significant scientific and public interest. Such an interest is conditioned by negative influence of salty dust storms on the environment and human activities. Processes of sandy, dust and salt aerosols transfer by air fluxes are complicate for both experimental and theoretical research. Hence, the present study estimates only the scale of aerosols amount and distances of their transportation. The expert estimation of the possible salty dust transfer from the water area of the Aral Sea, zones of “old” and “new” dried bottom and adjacent solonchaks has been done. Approximate volume of aeolian transfer was calculated by the balance equation [6], where the following parameters were taken into account: 1) statistical capacity of the salts on the surface soil layer (0-30 cm) undergone by aeolian transfer; 2) annual income of salts by hydrochemical way, with atmospheric precipitation and other ways, mln.t; 3) salts outcome by hydrochemical way, mln.t; 4) aeolian emission of salts from the area, mln.t; 5) time of salts accumulation. The calculated estimations of aeolian salty dust emission from different underlying surfaces are presented in the Table 1.

The following dynamics was revealed: in 1957-1990 transfer of the salts from the water area of the sea increased in average by 6 times considering the input of dry atmospheric fallings and by 300 times considering the input of wet atmospheric precipitation. Salty dust emission from the dried bottom increased during the same period by 5 times taking into account the dry atmospheric fallings, and from solonchaks it increased by 12 times.

Comparison of three sources of aerosol emission in the Aral region confirms that there is an increase of the estimated weight of salts transported from the water area. It is connected, obviously, with increase of salinity of seawater. Increase of the salty dust emission from the dried bottom and solonchaks is caused by increase of their area.

In 1957 an aeolian emission of aerosols was observed only from the water area of the Sea, since the process of shrinking didn't start yet, and there were no dried bottom and solonchaks in the area. In 1977 emission of aerosols from the water area still prevailed on that from the solonchaks and dried bottom, and only in 1982 emission from the solonchaks increased significantly, and in 1990



emission from the dried off zone also increased. With appearance of the solonchaks in the dried zone the emission of aerosols from them dominated over all the other sources. In 1990 the total amount of salty dust emission reached 7,048.1 t/km².

Table 1: Calculated estimates of salty dust emission from the water area of the Aral Sea and dried bottom.

Year	Input	Aerosol emission from					
		Water area		Dried bottom		solonchaks	
		T/km ²	Mln t/year	T/km ²	Mln t/year	T/km ²	Mln t/year
1957	D*	277.0	17.0	-	0.0	-	0.0
	W**	0.9		-		-	
1977	D	861.3	47.7	352.9	5.5	394.9	0.2
	W	9.0		-		-	
1982	D	991.9	51.2	471.0	21.0	1102.9	0.52
	W	81.3		-		-	
1990	D	1274.3	53.0	1764.8	57.0	4645.8	12.6
	W	263.2		-		-	

*D – dry fallings; **W – wet precipitation.

Preliminary estimates show that amount of emitted aerosols from the water area and dried bottom comes to 123 mln. tonnes per year. The calculated estimates of salty dust transfer from the dried bottom are close to those obtained earlier by the other researchers [3, 12].

Systematic observations on chemical composition of dry atmospheric fallings in the Aral region were carried out in 1982-1995. The experimental data allow defining the actual rate of aeolian emission from the dried bottom of the Aral Sea, which varies from 300-400 to 5,000-6,000 t/km² according to obtained data. These figures are less than calculated by the balance model (7,048.1 t/km²), but significantly higher than estimates calculated by hydrodynamic model [13]. Discrepancies in different estimates of amount of salty dust emission, and between experimental and empiric data confirm the necessity of the further experimental study of quantity and quality of aerosols and improvement of the existing models.

3.5 Aerosols deposition

Volume of aerosol deposits was calculated based on the experimental observations from 12 meteorological stations located at different distances from



the Aral Sea. Maximal values for aerosols deposits were registered on the dried bottom of the Aral Sea – 2,400-2,700 kg/ha per year. Farther from the dried bottom zone the dry atmospheric fallings decrease and at the distance of 600 km from the dried strip they come to 100-150 kg/ha per year. Nature of atmospheric fallings varies within the years and has a seasonal character. Deposition of the largest portion of aerosols occurs during the summer dust storms. Thus, in Uyaly area (15 km from the Sea) deposition of sand and dust during the dust storm event in July may vary from 450 to 1,800 kg/ha [14].

Ten-years observations on salty dust transfer in 43 points of the Aral region revealed that deposition of salty dust aerosols depended significantly on topography of the area, prevailing winds, nature of vegetation, soil moisture etc., and reaches the value of 1,500-6,000 t/ha, where the portion of soluble salts are 170-800 kg/ha. According to the authors on the dried bottom this figure reaches 1,600 kg/ha [10].

Similar data for aerosol deposits were obtained at 16 observation points in Karakalpakstan for the period of May-October 2000 by Wiggs et al. [16]. Deposition rates were highly variable throughout this period, with values ranging from less than 500 kg/ha at Nukus (200 km from the Sea) to nearly 2,500 kg/ha at Kyzyl-Djar located on the Aral Sea shore. Agricultural sites experienced variable rates (170-270 kg/ha) throughout May-August before declining to 120 kg/ha in October. The agricultural sites adjacent to the former shore of the Aral Sea showed the rates of 560 kg/ha in July and August before declining to 380 kg/ha in September. These results indicate high levels of dust deposition throughout the southern Aral region in the summer months, but with particularly high rates of deposition in the north of the region close to the shore of the former Aral Sea in July, August and September.

Based on experimental observations and model calculations it is possible to distinguish three main zones affected by salty dust emission from the Aral Sea and its dried bottom: 1) 100 km- zone from the Aral Sea with 1,500-2,500 kg/ha of deposited salty dust aerosols; 2) 100-400 km- zone where 1,000-500 kg are deposited annually; 3) 400-500 km- zone with <100 kg/ha of salty dust aerosols are deposited per year.

Analysis of the chemical composition of samples of atmospheric precipitation gives the impression on the rate of atmospheric pollution by toxic ingredients. Samples of atmospheric precipitation and dry deposits contain ions and cations of Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Al^{3+} , Fe^{3+} , Br^- , SO_4^{2-} , NH_4^+ , Cl^- , NO_3^- , HCO_3^- . Ions in the probes of atmospheric falling were classified into the following groups: soil (Ca^{2+} , HCO_3^- , K^+ , silicates), marine (Na^+ , SO_4^{2-} , Cl^- , Mg^{2+}), anthropogenic (SO_4^{2-} , NO_3^- , NH_4^+ , Cl^- , H^+), and biogenic (NH_4^+ , NO_3^-) [14].

Annual average mineralization of the atmospheric precipitation at the background stations was relatively low (37.9 mg/l). Comparing with European part of Russia, where the average mineralization of deposits varies from 10 to 20 mg/l, and the figures for the area under research is relatively high even at the background stations. Prevailing cations at the background stations were $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{2+} > \text{K}^+ > \text{NH}_4^+$, and anions – $\text{NO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$. Therefore, in precipitation collected at the background stations prevail the soil components,



which means the influence of the local sources and primary abundance of aerosols of soil origin in the atmospheric air of the region.

Average annual mineralization of samples of atmospheric precipitation at the stations located in the zone of influence of the sea and deserts exceeds 86 mg/l. Prevailing cations in precipitation collected at the sea stations were $\text{Na}^+ > \text{Mg}^{2+} > \text{Ca}^{2+} > \text{K}^+ > \text{NH}_4^+$, and anions – $\text{NCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$.

Average mineralization of samples in the industrial areas is 81.7 mg/l, which is higher than at the background stations and lower than in the zone of influence of the sea and deserts. The prevailing cations at the “industrial” stations are $\text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+ > \text{Na}^+ > \text{NH}_4^+$, anions - $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^-$. Content of nitrates-ions at anthropogenic stations is significantly higher than at background and sea/desert stations. Atmospheric air in the industrial areas contains more soil pollutants, dust and anthropogenic components.

4 Conclusion

Central Asia is one of the regions with a high frequency of dust and salt storms. It is characterized by the presence of the vast areas of sandy and solonchak deserts of natural and anthropogenic origin. Resulting from the Aral Sea crisis the powerful basis of aeolian processes has been formed favoring the development of salt and dust removal from the dried-up bottom of the Aral Sea and distribution of salt and dust over a significant part of the basin. Preliminary estimations showed the average transfer of salt and dust aerosol from the dried bottom varying between 500 thousand tonnes to 57 million tonnes. Deposition of salt-dust aerosols to a certain extent depends on the topography of the landscape, wind intensity, and distance from the emission source. Three major zones experiencing significant influence of salt-dust transfer could be defined: 0-100 km from the sea, a 100-400 km zone, and a 400-500 km zone. Air sensing permitted to define the height where the transportation of the mineral components takes place. Two layers different by chemical composition of aerosols were distinguished. The first layer (up to 600 m) is characterized by complex aerosols composition, while in the 2000-2500 m layer transportation of aerosols by air masses takes place. The emission of the salts is one of the most negative manifestations of the Aral disaster. It affects the living conditions of the local population, biodiversity and biological productivity of environment, and agricultural and pastoral productivity.

References

- [1] Breckle, Z.-V., Wukherer, V., Agakhanyantz, O. E. & Gel'dyev B. The Aral Sea crisis region. In: Z.-V. Breckle, M. Veste and V. Wucherer (Eds). *Sustainable land use in deserts*, Springer-Verlag, Berlin, pp.27-37, 2001.
- [2] Grigor'ev, Al. A. & Djogova, M. L. Strong dust blowouts in Aral region in 1985-1990. *Proc. of the Russian Academy of Sciences*, **325(3)**, pp. 672-675, 1992. (in Russian)



- [3] Grigor'ev, Al. A. & Lipatov, V.B. Distribution of the dust pollutions in the Aral region by space observations. *Proc. of the Academy of Sciences of USSR, geographical series*, **4**, pp.73-77, 1983. (in Russian)
- [4] *Guidance for sampling of atmospheric precipitation*, Tashkent, SANII, 1983.
- [5] *Methodic approach on determining the chemical composition of precipitation*. Leningrad, GGO, 1980.
- [6] Orlova, M.A. *The role of aeolian factor in the salt regime*. Alma-Ata: Nauka, 230 p., 1983
- [7] Orlovsky, N. S. Some data on dust storms in Turkmenistan. *Proc. of Ashgabat hydrometeorological observatory*, Ashgabat, **3**, pp. 17-42, 1962.
- [8] Orlovsky, N. & Orlovsky, L. White sandstorms in Central Asia. In Yang Youlin, V. Squires and Lu Qi (Eds.). *Global Alarm: Dust and Sandstorms from the World's Drylands*. Bangkok: UN, pp.172-204, 2002
- [9] Orlovsky, N., Radzinsky, V. & Orlovsky, L. Desertification and population health in the Turkmenistan part of the Aral Sea region.- In Brebbia C.A. and Fajzieva D. (Eds.). *Environmental Health Risk*. WIT press, pp.267-276, 2001.
- [10] Razakov, R. M. & Kosnazarov, K. A. Dust and salt transfer from the exposed bed of the Aral Sea and measures to decrease its environmental impact. *The Aral Sea Basin, NATO ASI series*, Berlin, **12**, pp. 95-102, 1996.
- [11] Romanov, N. N. *Dust storms in Central Asia*. Tashkent, 198 p., 1961. (in Russian)
- [12] Rubanov, I. V. & Bogdanova, N.M. Quantitative estimation of salts emission on the drying bottom of the Aral Sea. *Problems of Desert Development*, **3**, pp.31-37, 1987.
- [13] Semenov, O. E. Estimation of the scale of the Aral aerosol transfer. *Hydrometeorology and ecology*, **1**, pp. 117-130 , 1995. (in Russian)
- [14] Tolkacheva, G.A. Guidance for monitoring of dry atmospheric fallings in the Central Asian region. Tashkent, SANIGMI, 2000.
- [15] Tolkacheva, G.A. Assessment of the rate of aeolian emission from the dried bottom and water area of the Aral Sea. *Proc. of SANIGMI*, **151(232)**, pp. 13-18, 1995
- [16] Wiggs, G., O'Hara, S., Wegerdt, J., Van Der Meer, J., Small, I. & Hubbard, R. The dynamics and characteristics of aeolian dust in dryland Central Asia: possible impacts on human exposure and respiratory health in the Aral Sea basin. *Geographical Journal*, **169(2)**, pp. 142-157, 2003.
- [17] Zolotokrylin, A.N. *Dust storms in the Turan lowland*. Izvestiya RAN, seriya geographicheskaya, **6**, pp. 48-54, 1996

