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GROUND-BASED ASSESSMENT OF PM2.5 AND PM10 DYNAMICS DURING A TYPICAL DUST STORM IN THE SOUTHERN ARAL SEA REGION

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Abstract: Dust storms originating from the dried Aral Sea bed have become one of the major environmental threats in Central Asia, significantly affecting regional air quality and public health. This study evaluates the impact of a typical salt dust storm on atmospheric particulate matter in the Southern Aral Sea region using field observations conducted in Nukus and its suburban area. Airborne particles were monitored with an aerosol particle counter (AZ-10-03, 0.3–5.0 μm), while satellite imagery and synoptic meteorological data were used to identify dust sources and characterize transport conditions. The results revealed that the total dust mass concentration in suburban areas was approximately 20% higher than in the urban environment. During the dust storm, PM10 and PM2.5 concentrations exceeded the permissible daily limits by up to 7.2 and 13.5 times, respectively. Fine particles exhibited prolonged atmospheric residence times, remaining suspended for several days, whereas submicron particles persisted for up to two weeks. These findings demonstrate the considerable environmental and health risks associated with typical dust storms in the Southern Aral Sea region and emphasize the importance of continuous air-quality monitoring and timely public health advisories.

Keywords: dust storms; Southern Aral Sea region; PM_{10}; $PM_{2.5}$; air quality; aerosol monitoring; salt dust; environmental monitoring.

Introduction. The frequency and intensity of dust storms have increased across the global desert belt, including North Africa, the Middle East, Central Asia, and East Asia, making atmospheric dust one of the major environmental challenges in arid and semi-arid regions [6]. Dust storms adversely affect air quality, ecosystem functioning, transportation safety, and human health. Fine particulate matter transported over long distances is recognized as one of the most hazardous components of atmospheric pollution because of its ability to penetrate deep into the respiratory system and to transport salts, heavy metals, microorganisms, and other toxic substances [1, 8, 12].

To reduce health risks associated with particulate pollution, the World Health Organization (WHO) has established guideline values for airborne particulate matter, including PM10 and PM2.5 [11]. Particular attention has recently been focused on PM2.5 because of its stronger association with respiratory and cardiovascular diseases [8, 12]. In the Southern Aral Sea region, where the desiccation of the Aral Sea has created the extensive Aralkum Desert, salt-dust emissions have become a dominant source of atmospheric aerosol pollution, substantially increasing the frequency and spatial extent of dust storm events.

Most previous studies have investigated dust storms using satellite remote sensing or numerical modeling, primarily focusing on dust plume trajectories, atmospheric dust loading, and large-scale transport processes [6, 9]. Although these approaches provide valuable regional information, they offer limited insight into near-surface air quality and human exposure during typical dust storms. Furthermore, previous research has mainly addressed extreme dust events, whereas moderate dust storms, which occur much more frequently and therefore contribute more substantially to cumulative environmental and health impacts, remain insufficiently studied.

This study presents the results of ground-based monitoring of a representative dust storm that occurred on 22 August 2025 in the Southern Aral Sea region. Based on a statistical analysis of dust storms observed during 2021–2025, this event was selected as typical of medium-intensity regional dust storms. The investigation combines field measurements of particulate matter concentrations, meteorological observations, satellite imagery, and synoptic analyses to characterize the temporal evolution of the event and the dynamics of atmospheric aerosol pollution.

The novelty of this study lies in quantifying the relationship between particulate matter concentrations and air-quality standards during a typical dust storm, estimating the atmospheric persistence of different particle-size fractions, and introducing the concept of dust storm relaxation time, defined as the period required for PM concentrations to decrease below the applicable air-quality guideline values. The results provide new insights into dust storm impacts on air quality and support the development of operational monitoring systems and public health warning strategies for the Southern Aral Sea region.

Materials and Methods. The meteorological conditions and evolution of the dust storm that occurred on 22 August 2025 were investigated in Nukus using satellite imagery, synoptic weather charts, and field measurements of airborne particulate matter. Dust concentrations were measured with a Sorhis SX-L301T aerosol particle counter, while wind speed, air temperature, and relative humidity were recorded simultaneously throughout the observation period. The dust storm of 22 August 2025 developed under the influence of a southern Murghab cyclone moving northeastward (Fig. 1). This type of frontal cyclone development, described in studies of extratropical cyclone climatology [2, 3, 5], is characteristic of hot desert regions in the middle and high latitudes and is

associated with the formation of a low-pressure system along the eastern periphery of a synoptic trough [4, 6, 7].

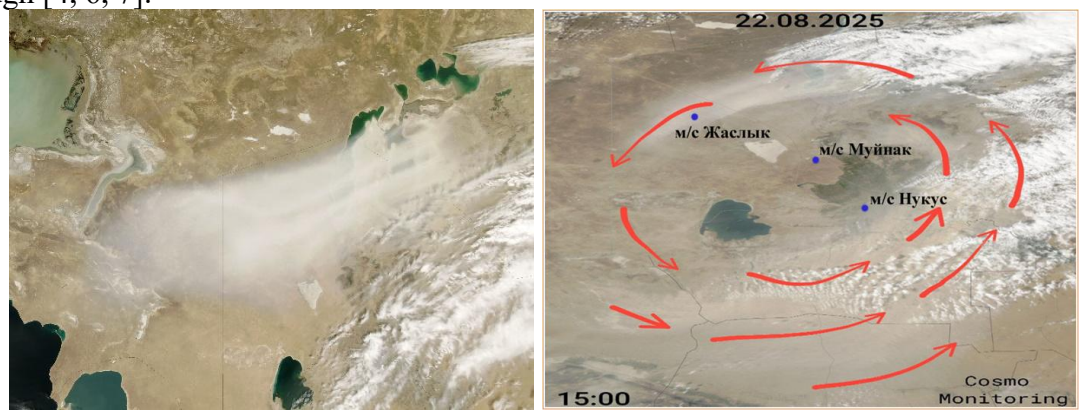


Figure 1. Satellite image of the dust storm [9]

As shown in Figure 1 and the synoptic weather charts (Figure 2), the principal dust source areas were located in the Karakum Desert of northern Turkmenistan and in the southwestern part of the dried Aral Sea bed, along the cyclone periphery where the highest wind speeds were observed. In contrast, the northeastern part of the Ustyurt Plateau did not generate significant dust emissions because light precipitation that had occurred on the previous day increased surface moisture and suppressed wind erosion.

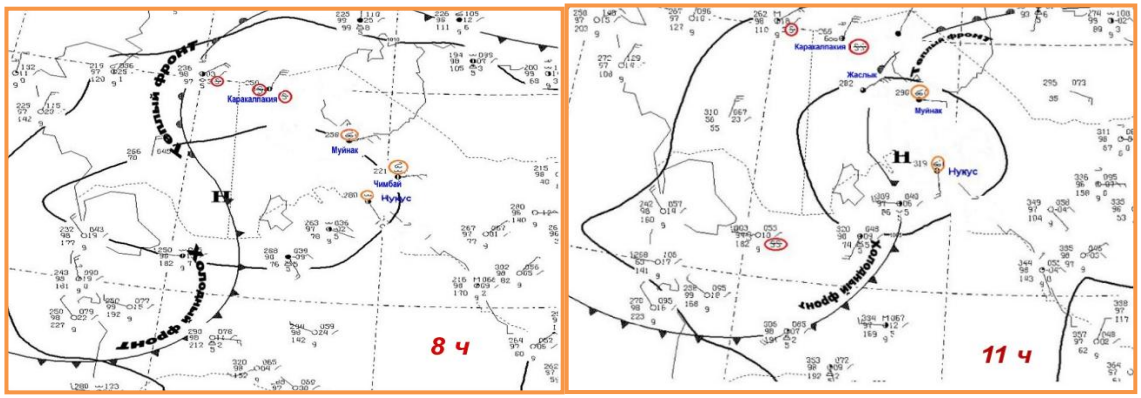


Figure 2. Synoptic weather charts illustrating the evolution of the cyclone at 08:00 and 11:00 local time. Circles denote the principal dust emission sources.

Regarding the spatial variability of the wind field, meteorological observations on 22 August 2025 showed pronounced regional differences in wind direction and speed. At the Karakalpakiya and Zhaslyk meteorological stations, northerly and northeasterly winds predominated, with maximum wind speeds reaching 20–25 m s^{-1}. At Kungrad, the prevailing wind was from the north, with a maximum speed of 20 m s^{-1}. At the Muynak station, northerly winds with speeds of 5–10 m s^{-1} were recorded. The Chimbay and Takhtakupyr stations were characterized mainly by northeasterly winds with speeds ranging from 7 to 12 m s^{-1}. In the remaining central and southern parts of the region, southerly and southwesterly winds prevailed, with wind speeds generally ranging from 7 to 10 m s^{-1}.

Results. During the dust storm, field measurements of airborne particulate matter and meteorological parameters were conducted in the city center of Nukus and in a suburban area

(Figure 3) to assess differences in air quality between the urban environment (Figure 3a) and open terrain (Figure 3b) under dust storm conditions.

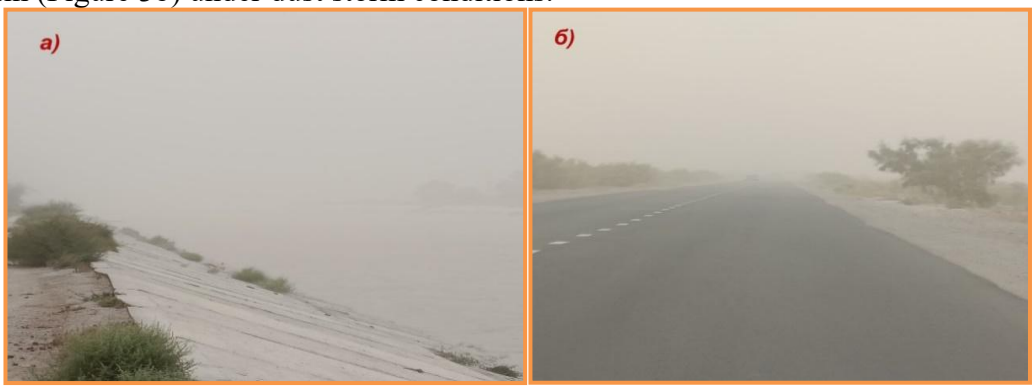


Figure 3. Dust loading in the city center of Nukus (a) at 12:55 and in the suburban area (b) at 13:30 local time on 22 August 2025.

The results of the dust concentration measurements (Table 1) revealed a relatively small increase (9%) in the number concentration of submicron particles in the suburban area compared with the urban site, whereas the increase in the total mass concentration of airborne dust was substantially greater (20%). Particle number concentrations were converted to mass concentrations by assuming a particle density of 2.65 g cm^{-3}, as commonly adopted in previous studies [10, 13].

Table 1.

Number and mass concentrations of airborne dust particles in the **city center of Nukus** and the **suburban area**.

	Particle size, μm	0.3	0.5	1	3	5	10	Total mass concentration (mg m^{-3})
Urban area	Particle count	930459	868533	554907	124320	8719	834	
	Mass concentration (mg m^{-3})	0,124	0,535	2,734	16,54	5,371	4,12	29,41
Suburban area	Particle count	979801	920481	600142	143402	10451	1315	
	Mass concentration (mg m^{-3})	0,13	0,567	2,957	19,08	6,44	6,48	35,65

The graphical representation of the data presented in Table 1 (Figure 4) clearly demonstrates that dust concentrations in the suburban area exceeded those measured in the city center across all particle-size fractions. As shown in Table 2, the exceedance of the permissible concentration limit for PM2.5 was approximately twice that observed for PM10, indicating a substantially greater health risk associated with fine particulate matter during the dust storm.

Table 2

Dynamics of PM2.5 and PM10 Concentrations (μg/m^3)

№	Time	PM_{10} (MPC: 300 μg/m^3)	$PM_{2.5}$ (Maximum Permissible Concentration (MPC): 60 μg/m^3)
1	13:00	1653 мкг/$м^3$ (5,5 Above the permissible limit)	704 мкг/$м^3$ (11,7 Above the permissible limit)
2	14:00	2149мкг/$м^3$ (7,2 Above the permissible limit)	809мкг/$м^3$ (13,5 Above the permissible limit)

3	15:00	1246мкг/м^3 (4,15 Above the permissible limit)	545мкг/м^3 (9,1 Above the permissible limit)
4	16:00	645мкг/м^3 (2,15 Above the permissible limit)	299мкг/м^3 (5 выше нормы)
5	17:00	394мкг/м^3 (1,3 Above the permissible limit)	204мкг/м^3 (3,4 Above the permissible limit)

The data presented in Table 2 also demonstrate the temporal variation in dust composition during a dust storm, with the fine particulate fraction exhibiting greater variability than the PM2.5 fraction (Fig. 4).

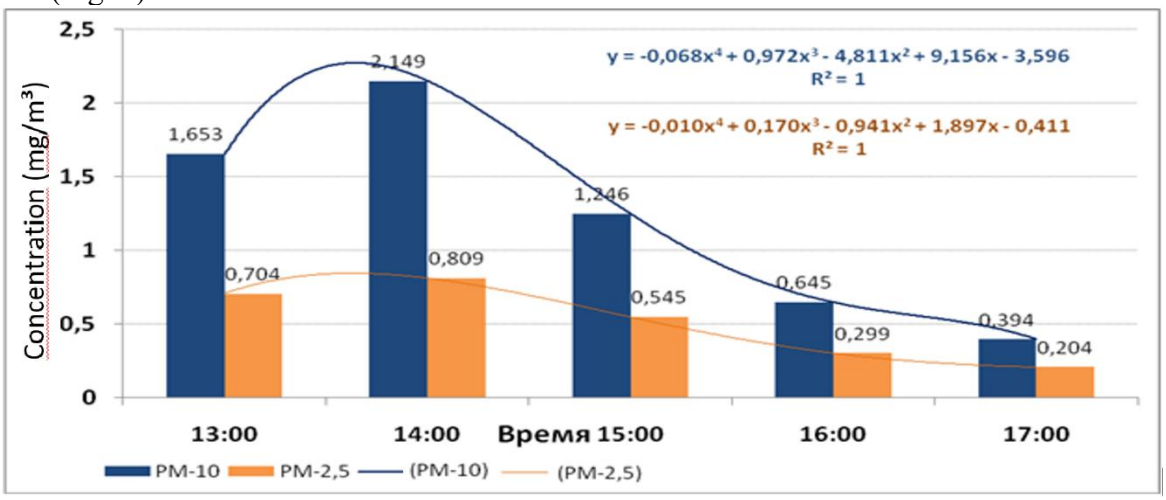


Figure 4. Temporal Dynamics of PM2.5 and PM10 Concentrations

Differences in concentration dynamics are associated with the transport behavior of particles of different sizes, which is primarily determined by their gravitational settling velocity (Fig. 5). In general, the smaller the particle size, the longer its settling time and the greater its transport distance, both vertically and horizontally.

The dust deposition cycle following a dust storm is of considerable importance for assessing its environmental and public health impacts. Due to the difficulty of forecasting dust storms in Uzbekistan, no emergency warnings are currently issued for these meteorological events. Nevertheless, timely information on the duration of health risks is essential for the population, particularly the period during which airborne particulate matter concentrations exceed the daily maximum permissible concentrations (MPCs). We refer to this period as the dust storm relaxation time. To determine the relaxation time, dust concentrations were measured at the same monitoring sites (Nukus city and the suburban settlement of Kum-Aul) 1 and 2 days after the dust storm. The monitoring results presented in Fig. 5 indicate that the PM10/MPC ratio decreases below 1 within one day after the onset of the dust storm, whereas the PM2.5/MPC ratio falls below 1 only after approximately 2.5 days. Submicron particles remain suspended in the atmosphere for 1–2 weeks, thereby prolonging the period of potential exposure and associated health risks.

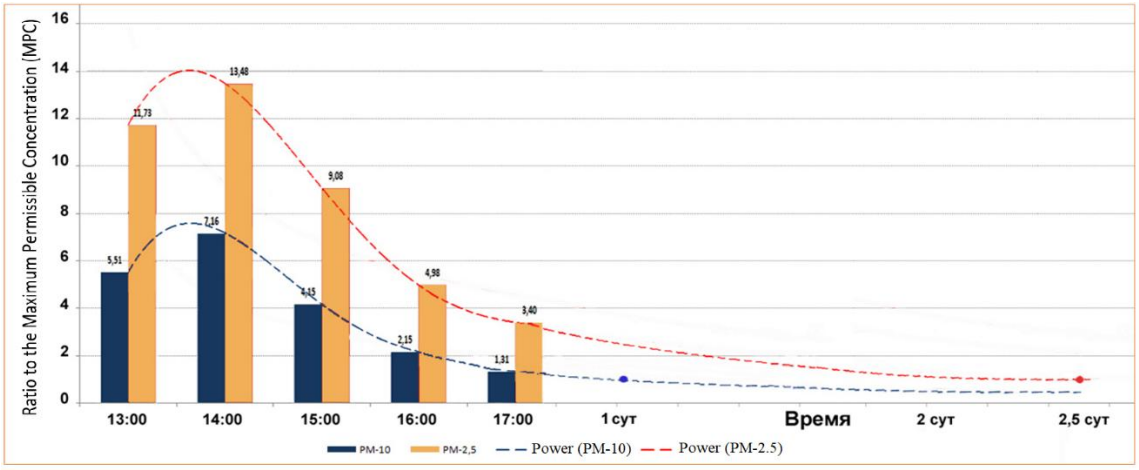


Figure 5. Temporal Dynamics of PM10 and PM2.5 Concentrations Relative to Their Maximum Permissible Concentrations (MPCs)

Based on the measured particulate matter concentrations, conclusions can be drawn regarding the temporal dynamics of airborne dust and the settling time of particles of different sizes (Fig. 5). The projected trends (extrapolated beyond 17:00) of the ratios between the measured concentrations and the corresponding maximum permissible concentrations (MPCs) indicate that the PM10/MPC ratio decreases below 1 approximately 1.5 days after the onset of the dust storm. In contrast, the PM2.5/MPC ratio falls below 1 only after approximately 2.5 days. Submicron particles remain suspended in the atmosphere for 1–2 weeks, thereby extending the period of potential exposure and associated health risks.

Conclusion. The hazards posed by dust storms are comparable to those of natural disasters; however, their adverse effects are often delayed because they are primarily associated with the development of respiratory and other health disorders. The aerodynamic characteristics of dust transport indicate that the deposition of fine particulate matter reaches its maximum in the distal section of the dust plume, typically at distances of 200–500 km from the source area. Consequently, for the population of the Southern Aral Sea region, concentrated within the Lower Amu Darya oasis, dust storms originating from the surrounding deserts represent the greatest environmental and public health threat. The dust storm relaxation time determined in this study provides a scientific basis for issuing timely public advisories and recommending preventive measures to reduce health risks associated with elevated particulate matter concentrations.

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