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НОВЫЕ МЕТОДЫ И РЕЗУЛЬТАТЫ ИССЛЕДОВАНИЙ ЛАНДШАФТОВ В ЕВРОПЕ, ЦЕНТРАЛЬНОЙ АЗИИ И СИБИРИ

Монография в 5 томах

Том II Изучение и мониторинг процессов в почвах и водных объектах

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This monograph shall inform you about up to date methodologies and recent results in landscape research. It is intended as a guide for researchers, teachers, students, decision makers, stakeholders interested in the topic of landscape science and related disciplines. It provides information basis for decision makers at various levels, from local up to international decision bodies, representing the top level of landscape science in a very short form.

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Chapter II/57: GROUND-BASED MEASUREMENT OF AEOLIAN DUST DEPOSITION IN THE ARAL SEA REGION

ГЛАВА II/57: НАЗЕМНЫЕ ИЗМЕРЕНИЯ ЗОЛОТОГО ОТЛОЖЕНИЯ ПЫЛИ В АРАЛЬСКОМ РЕГИОНЕ

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ABSTRACT. The desiccation of the Aral Sea ranks among the largest man-made ecological catastrophes and has become a global symbol for the overexploitation of limited resources and the environmental and socio-economic consequences caused thereby. Formerly the fourth largest inland lake, large parts of the Aral Sea have been transformed into a salty desert – the Aralkum. The exposed lake bed sediments are subject to wind erosion, resulting in white sand and dust storms which have been tracked over several hundred kilometers using remote sensing images. Dust deposition data, on the other hand, requires excessive field work over prolonged periods of time and thus is scarce. In order to learn more about the spatial and temporal dynamics of the dust deposition in the Aral Sea region and in order to evaluate the influence of the Aralkum, the passive dust deposition data from 23 meteorological stations in the Aral Sea basin has been monitored between 2006 and 2012 in the framework of three research projects.

Резюме. Падение уровня Аральского моря, вызванное нерациональным использованием ограниченных водных ресурсов, относится к числу наиболее серьезных экологических и социально-экономических катастроф антропогенно-техногенного характера. Процессы засоления и отступления береговой линии Аральского моря, в прошлом занимавшего по площади четвертое место в мире среди крупных озер, привели к обретению соленной пустыни, носящей название Арал-кум. Сухие донные отложения, подверженные действию ветровой эрозии, вызывают буре песчаные и пыльевые бури, а также аэрокосмической съемки способные к переносу частиц на расстояние несколько сот километров. Для получения достоверной информации о количестве и качественном составе атмогенных отложений необходимо реализовать широкомасштабные пылевые наблюдения в определенных временных интервалах. Результаты, характеризующие особенности пространственной и временной динамики атмогенных отложений, были получены на основе пассивных измерений их количества и качества на 23 метеорологических станциях Аральского региона в период с 2006 по 2012 гг. в рамках выполнения трех проектов.

KEYWORDS: Aral Sea, dust deposition, field measurements, dust storms, arid landscapes

Ключевые слова: Аральское море, аридные ландшафты, атмогенная депозиция пылевых частиц, пылевые измерения, пылевые бури

INTRODUCTION

Large parts of Central Asia are characterized by an arid climate and thus (semi-)deserts are widespread features in the Turan lowland. Wind erosion and the aeolian transport of dust and sand are common processes in this region. While many of those deserts are of natural origins, with the Kyzylkum and the Karakum being the most prominent examples, the overexploitation of the limited water resources for in-
tensive irrigation farming schemes contributes to processes of salinization, soil degradation, desertification, and water body desiccation [1-3], largely increasing the area prone to aeolian processes. The desiccation of the Aral Sea, with 68,000 km² once the world’s fourth largest inland lake, has become a global symbol for the negative impacts of the unsustainable use of limited resources [4-6]. At present, more than 60,000 km² of the former Aral Sea have been transformed into a desert of salty lake bed sediments, called the Aralkum [4-5, 7]. Monitoring the salty dust emissions from the Aralkum is important as the Aral Sea has been a sink not only for salts, but also for agrochemicals and heavy metals and the mobilized dust poses a considerable health risk for the surrounding region [1, 5, 8-9]. Due to the size of the affected area (>1.5 million km²) spread over three countries (Kazakhstan, Turkmenistan, Uzbekistan) and the isolation of large parts of that area, most studies focus on remote sensing as their primary tool for the monitoring of the aeolian sediment transport [10-12]. But while satellite data can provide an area-wide quantification of the transported material and provide insights into the qualitative nature of the airborne dust due to its spectral characteristics, on-site measurements of the dust deposition and laboratory analyses of its mineralogical and chemical properties are needed to complement such a monitoring.

MATERIALS AND METHODS

Carrying out such a ground-based monitoring in the Aral Sea basin was the central aim of the EU-CALTER project [5] and in combination with two other projects (The UNESCO KHOREZM project and the LUCA project [7]) the field measurements included a total of 23 meteorological stations in Kazakhstan, Turkmenistan and Uzbekistan (Fig. 1).

Monthly dust samples were collected between 2006 and 2012 in 3m height, using passive deposition samplers of an inverted frisbee design (Fig. 1), which had been used in Central Asia in previous studies with good results [8-9, 14-15]. This extensive data set was complemented by samplers of the same design, which were only exposed during dust storm events (defined by a visibility of less than 1km). Information about the vertical dust profiles between 0.25 and 16m was provided through additional measurements conducted during dust storms in the Kazakh part of the research area [16-17]. The laboratory analyses included a grain size composition assessment using microscope diameter measurements, the determination of the mineral composition using wavelength dispersive X-ray diffraction, and the assessment of the chemical composition using atomic absorption spectroscopy and X-ray fluorescence. The resulting data sets were grouped by source region (see Fig. 1) and analyzed statistically under special consideration of monthly data for the mean air temperature, the precipitation, the mean and maximum wind speed, and the dominant wind direction.

![Figure 1](image-url) – Dust sampler design, the meteorological stations used for the dust sampling, and their main source regions (base map: [13]; photo: Ch. Opp)
RESULTS AND DISCUSSION

This results section focuses on two of the aspects - the spatial and temporal dynamic of the dust deposition of all non-dust-storm samples, and a separate analysis of the dust storm events recorded during the project duration. The average dust deposition in the Aral Sea basin, across all stations and all years, was 117.2 kg/ha*month (11.7 g/m² per month). The highest deposition rates were detected in the Kyzylkum (247.7 kg/ha*month), with 52% of all samples exceeding the long-term dust deposition threshold of 10.5 g/m² per month (Tab. 1), a value related to respiratory diseases and based on clinical research [18]. The man-made Aralkum ranked second in this assessment with an average deposition rate of 151.5 kg/ha*month and a threshold excess of 45%, while the Karakum, the largest desert in the Aral Sea basin, was characterized by a deposition rate that was only 50% of that detected in the Kyzylkum. Khorezm, as the only research area that is not also a dedicated dust source, showed the lowest deposition rate (60.9 kg/ha*month or 6.1 g/m²*month). But even in this highly cultivated and densely populated agricultural center along the lower Amu-darya more than one fifth of all months (21.3%) had to be considered potentially harmful for the respiratorial system (Tab. 1).

Table 1 – Dust deposition, health threshold excess and average grain size diameter per source region, year and season

<table>
<thead>
<tr>
<th>All dust samples without dust storm events</th>
<th>Avg. dust deposition (kg/ha*month)</th>
<th>% of samples exceeding the health care threshold (10.5 g/m²*month)</th>
<th>Avg. grain size diameter (in mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aralkum</td>
<td>151.5</td>
<td>45.0%</td>
<td>0.0129</td>
</tr>
<tr>
<td>Karakum</td>
<td>125.2</td>
<td>40.5%</td>
<td>0.0018</td>
</tr>
<tr>
<td>Kyzylkum</td>
<td>247.7</td>
<td>52.0%</td>
<td>0.0142</td>
</tr>
<tr>
<td>Khorezm</td>
<td>60.9</td>
<td>21.3%</td>
<td>0.0042</td>
</tr>
<tr>
<td>All data</td>
<td>117.2</td>
<td>34.8%</td>
<td>0.0051</td>
</tr>
<tr>
<td>2006</td>
<td>108.4</td>
<td>38.7%</td>
<td>0.0019</td>
</tr>
<tr>
<td>2007</td>
<td>42.2</td>
<td>13.6%</td>
<td>0.0020</td>
</tr>
<tr>
<td>2008</td>
<td>61.1</td>
<td>7.4%</td>
<td>0.0094</td>
</tr>
<tr>
<td>2009</td>
<td>89.2</td>
<td>21.8%</td>
<td>0.0207</td>
</tr>
<tr>
<td>2010</td>
<td>155.4</td>
<td>45.8%</td>
<td>0.0200</td>
</tr>
<tr>
<td>2011</td>
<td>168.6</td>
<td>55.9%</td>
<td>0.0213</td>
</tr>
<tr>
<td>2012</td>
<td>195.6</td>
<td>50.8%</td>
<td>0.0141</td>
</tr>
<tr>
<td>Spring</td>
<td>115.1</td>
<td>36.9%</td>
<td>0.0065</td>
</tr>
<tr>
<td>Summer</td>
<td>108.7</td>
<td>27.7%</td>
<td>0.0061</td>
</tr>
<tr>
<td>Fall</td>
<td>122.4</td>
<td>27.1%</td>
<td>0.0035</td>
</tr>
<tr>
<td>Winter</td>
<td>110.3</td>
<td>36.8%</td>
<td>0.0034</td>
</tr>
</tbody>
</table>

The analysis of the temporal dynamic showed that the dust deposition rate was higher during fall and spring and lower during summer and winter. The threshold excess, however, was also increased during the winter months, highlighting the cold season as especially important for the monitoring of potential air pollution and health risks (Tab. 1). The overall intensity of the dust transport increased between 2006 and 2012 but this time frame is too short for any interpretation with regards of the influence of climate change vs. natural variability. The average grain size diameter collected in the dust samples was 5.1 µm (fine silt or PM5). The dust from the Karakum was much finer (1.8 µm = clay or PM2) while the Kyzylkum dust was coarser (14.2 µm = medium silt). During spring and summer the average grain size of the dust samples was almost double the value recorded during fall and winter, which might be related to a higher percentage of organic particulate matter during the growing and harvest season. The interannual trend showed a clear increase of the average grain size between 2006 and 2012 (Tab. 1), which is related to the increasing wind speeds detected during the same period.

This spatial and temporal variability of the dust deposition is further increased when the vertical dust profile is considered. Data collected during dust storms in Kazakhstan show that the deposition of material in 3m height is just 8.8% of the material deposited 0.25m above ground (Fig. 2). The most intense dust storm detected during the project duration was recorded in Buzubay in September of 2009 and with a hourly deposition intensity in 3m height of 13.4g/m² (Fig. 2), which would equal approximately 150g/m² per hour close to the ground surface.

The grain size composition shows a similar vertical profile (Fig. 2) with the larger and heavier grains detected closer to the ground and the finer grains clearly dominating in greater heights. The average of all dust samples collected in 3m fits very well into this profile with 77.5% of all
grains belonging to the clay size class (<0.002mm) and only 6.9% to the fine sand class (>0.063mm) or larger. The mineral composition also showed a separation between the lower and the upper layers of the vertical dust profile. The majority of the minerals (>60%; albite, calcite, quartz, clinochlore) were found regardless of the sampling height, but dolomite, illite, and orthoclase were only detected close to the ground while microcline and muscovite were only found in greater heights.

![Figure 2](image)

**Figure 2** – Dust deposition and grain size composition in a vertical profile (0.25m – 16m height) recorded during a dust storm near Aralsk (Kazakhstan) in July 1983

**CONCLUSIONS**

1. The Kyzylkum desert was characterized by the highest overall dust deposition, followed by the man-made Aralkum desert, the remnants of the Aral Sea.
2. 45% of all samples from the Aralkum region exceeded the health-based deposition threshold.
3. The dust related health risk is increased further as two of the most frequently detected minerals (quartz and albite) have a high potential for causing respiratory diseases.
4. The vertical dust profile (0.25m – 16.0m) showed significant changes of the dust deposition, the grain size and the mineral composition with the height, which highlights the importance of monitoring the dust deposition in different heights for maximum representability.

**REFERENCES**


