Central Asia 'Solutions for Water' (S4W) Living Lab under the Central Asia Water & Energy program (CAWEP)

Report: TAKYRS – THEIR DIAGNOSTIC ASSESSMENT, CONSERVATION, PROTECTION AND RESTORATION IN CENTRAL ASIA

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The findings, interpretations and conclusions expressed herein are those of the authors and do not necessarily reflect the views of the World Bank Group, its Board of Executive Directors of the governments they represent.

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1. INTRODUCTION

In addition to the recognition of access to water as a fundamental human right, the 'water diplomacy' is promoted throughout the world as a new political and diplomatic tool to promote multi-stakeholder cooperation. Countries see it as a window for a holistic dialogue to address all issues arising from the need to restore water sources and ensure sound and sustainable consumption of water resources.

In some desert areas of Central Asia, temporal surface runoff from takyr catchment areas is the only source of fresh water for potable and pasture water supply. In the nomadic period, it provided sufficient water for sustainable livestock management and small-scale oasis farming. Local communities could have drawn from the centuries-old experience of takyr water harvesting, storage and use, including respective traditional water supply practices, but they were not further employed and developed because of the construction of major water management facilities in the mid-20th century. The intensive desert development and adverse anthropogenic (including technogenic) impact have resulted into takyr surface degradation and impaired runoff production capacity. In view of the need to address the water deficit, this study is aimed at developing evidenced-based techniques drawing from traditional knowledge of sustainable management of local runoff and protection of takyr catchment areas and includes the following objectives:

1. To assess the status of takyr catchment areas in Central Asia in the current period of changing environment and economic relations.
2. To identify key causes of takyr surface degradation and classify them by stage of their impact on surface runoff generation.
3. To provide an actionable justification of the need to collect and store surface runoff water from takyr catchments and prepare practical recommendations on its sustainable management.

Results of the study will be applied to meet the important water and environmental management objective – to find alternative sources of fresh water in dry areas of Central Asia and to utilize them in a sustainable manner.

1.1. Background and methodology

According to the United Nations Convention to Combat Desertification (UNCCD), Central Asia (CA) is a sub-region of the Asian Region consisting of five countries: Kazakhstan, Turkmenistan, Uzbekistan, Kyrgyzstan and Tajikistan, and takyr catchments occur only in the first three of them [16].

The time of takyr research has been featuring with diverse standpoints concerning the origin and uses of these areas. Owing to their flat and even surface, takyrs attract interest of agricultural specialists as a reserve of irrigated land resources and a source of water for pastures. In addition, their unique environmental specifics make them a target for research and the notion of takyrs has incorporated not only the landscape, but the soil as well. Flatland areas of takyrs and takyr-like soils are often referred to as a kind of clayey deserts. Integrated development of desert land was highlighted in numerous publications, including those with comprehensive literature reviews and up-to-date data on takyrs (as of the publication dates).

A literature review for the period of 1848-1940 is provided by U. Uspanov [30]. This publication contains comprehensive data on the concepts of the takyr origin developed by prominent scientists of that period. In particular, many authors viewed takyrs as purely geological or geomorphic features (Konshin, 1885-1886; Obruchev, 1890; Andrusov, 1889, 1905; Mushketov, 1915; Arkhangelsky, 1914-1915; Natsky, 1916; Fersman, 1926; Fedorovich, 1930; Makeev, 1932). Some scientists focused on the takyr soil analysis (Williams, 1910; Dimo, 1910, 1913, 1915; Neustruev, 1911, 1931; Gerasimov, 1931, 1933; Sushko, 1932; Zonn, 1934). Uspanov collected and reviewed numerous publications and manuscripts, but he did not regard takyrs as a soil body because he excluded effects of the biological factor.

Data on takyrs were provided by a team of authors from several fundamental research institutes [29] who took stock of and generalized available literature data on takyr origin, properties and rehabilitation/irrigation practices. This fundamental research was based on scientific results of the Aral-Caspian Integrated Expedition of the USSR Academy of Sciences led by V.A. Kovda. E.V. Lobova [20] described the takyr soil research in the period up to 1960 and detailed the process of takyr generation. The author provided a classification of takyrs based on morphological and chemical characteristics and a review of published data of that period.

No less important is the definition of takyrs as water catchments because the hydro-physical properties of takyr surfaces vary, depending on their locations. V.N. Kunin highlighted various aspects of runoff generation and management in the Kara-Kum Desert as far back as in 1932; and, in 1959, his in-depth study was published [15]: it was the first study where takyrs were viewed as local catchment areas. Kunin's doctrines were followed up and further developed by G.T. Leshchinsky who designed a method to assess resources of ephemeral surface runoff from takyrs in the desert zone in the USSR and assessed them (providing an in-depth review of respective literature) [19]. That work underlay the author's doctorate thesis and was based on data from stationary observations organized by the National Hydrometeorological Service and undertaken since 1950 on runoff sites in locations with different climatic and environmental conditions. The research was conducted by the core laboratory at the Institute of Deserts of the Academy of Sciences of Turkmenistan established in 1962.

Leshchinsky's studies enabled to classify takyr runoff as a potential water resource and its quality was assessed B.T Kirsta [13]. In 1976, a team of soil scientists from the Institute of Deserts of the Academy of Sciences of Turkmenistan produced a detailed map of takyr zoning for agricultural purposes [17]; and later, A.P. Lavrov, Leader of that Team, assessed the geographical distribution of takyrs in Asia [16].

As regards applied research related to using local runoff for agricultural crop cultivation on takyr soils, it was conducted by the Nebitdag Agroforestry Experiment Station of the Institute of Deserts of the Academy of Sciences of Turkmenistan under the leadership of N.K. Lalymenko. A jointly prepared monograph [18] provides an overview of publications on takyr and takyr-like soil management for crop-growing purposes. In the same period, other research efforts were made in the Karrykul Research Station in the Central Kara-Kum Desert to collect and store ephemeral surface runoff in the form of fresh groundwater lenses with its subsequent use in summertime for watering of animals. Studies led by T.P. Vitkovskaya [6] made it possible to improve the traditional practices to submerse large volumes of rainwater and then pump it out without detriment to the fresh and salted groundwater balance.

If we look at the key areas of takyr research covered in the publications, the following picture will be seen (Table 1): all takyr-related literature reviews and other sources show that the degradation of takyr catchments was not regarded as a great concern in the Soviet period, and this issue was not properly addressed.

Table 1: Key areas of takyr research before 1991

Focus of publications	The number of publications	Share, %
Agricultural crop cultivation	47	32
Surface runoff generation	41	28
Economic aspects of takyr-based water supply, takyr flora and fauna	15	10
Takyrs and takyr-like soils	45	30
Total of reviewed sources published before 1991:	148	100%

The nationalization of natural resources had made it necessary to ensure conservation and sustainable management of the national natural resources. In particular, L.N. Kharitonova published a brief report which was the first information based on satellite imagery demonstrating the extent of the takyr sanding and overgrowth processes, and attempted to classify them by degree of their degradation [36]. In 1999, a stock-taking collection of papers was published to present the studies undertaken by the Institute of Deserts of the Academy of Sciences of Turkmenistan in the English language (in 1998, the the Institute of Deserts of the Academy of Sciences of Turkmenistan was reorganized into the National Institute of Deserts, Flore and Fauna under the Ministry of Nature Conservation of Turkmenistan). The book summarizes the research in this field, including studies on sustainable use of takyr runoff [38]. The report prepared by L.G. Orlovskaya is the last publication with a review of takyr literature of the 20th century, including foreign sources and internet resources [44].

The quantum leap of technology has enabled to undertake studies based on modeling of takyr runoff generation processes, and these include joint studies of scientists from Uzbekistan [35]. In recent years, experiments with using takyrs for crop cultivation are conducted in the Karrykul Research Station of the National Institute of Deserts, Flore and Fauna [26]. International cooperation and implemented research projects enable scientists with shared research interests from research organizations of different countries to prepare joint publications, including those on takyrs [39, 46]. Regional conferences increasingly often offer presentations on conservation of water resources, including resources of local waters [23]. This is primarily associated with the Aral crisis, water quality problems in Northern and Central Asia and global warming. However, so far, there have been no published in-depth studies to assess takyrs' water capacity, degradation causes, protection and conservation via sustainable use of the runoff.

Environmental impact assessments of economic activities, studies to assess the health of ecosystems and their development trends, recommendations on how to address environmental problems – all these are in the domain of geographical ecology [14]. Geographical ecology looks at ecosystems from the perspective of sustainable development through improving the interaction of human society with the environment [8]. This approach enables to examine the structure of and changes in ecosystems in time and space as well as to assess impact of endogenous and exogenous factors on ecosystems [12].

The emergence of geographical/landscape ecology is associated with the name of German geographer Carl Troll (1899-1975). Back in the 1930-ies, he defined it as part of natural sciences integrating environmental and geographical studies of ecosystems. In the USSR, the term 'geographical ecology' was widely used since the 1970-ies after well-known Soviet geographer V.B. Sochava (1905-1978) had referred to it. Geographical ecology developed into a self-standing discipline in the early 1990-ies [10]. But there is no clear and generally recognized definition of the term as yet; its subject matter and objectives are worded in different ways; there is no generally accepted methodology either, particularly, for arid research. The scope of geo-environmental research is basically confined to identification and assessment of adverse anthropogenic impact on the natural environment as a human habitat.

Environmental issues have a special place among geosciences and embrace all kinds of human interaction with the nature [22]. Respective research methods may be largely classified into three categories: general scientific, interdisciplinary and discipline-specific methods and are applied depending on concrete purposes of research [8]. General scientific methods include materialistic dialectics, systems approach and modeling which are common for several sciences. Similarly to geophysics and geochemistry, geographical ecology uses the interdisciplinary method and a great number of ways to understand the objective reality which are pooled into an integrated system designated to address specific goals and needs. This method is intensively developing and its essence often consists in addressing local environmental issues arising from land management. Mathematical processing of obtained results plays an important role in geo-environmental studies. Evidence from observations is processed using statistical analysis methods and geographical information systems (GIS). Geo-environmental research uses GIS for the following key purposes: to ensure sustainable natural resource management; to monitor natural hazards; to assess technological impact on the environment and its consequences, to ensure environmental safety in regions; to conduct environmental assessments (reviews) of business and other projects; and to monitor human life conditions.

We used specific research methods with elements of hydrology, soil science, meteorology, mapping, the balance method and remote sensing. The methods and the logics of the research were defined by the natural specifics and socioeconomic designation of takyr catchments.

1.2 Description of takyrs

The soil density and relatively poor permeability account for the seasonal contrasts of the takyr water regimes. Excessive moisture of the surface soil layer is typical of the rain and snow-melting time and is followed by extreme dryness during the dry season. It enhances soil mineralization, and accounts for the sparsity or complete absence of higher vegetation and relative scarcity of fauna [3]. Takyrs are distinguished with rather sallow soils and subsoils. In springtime, they get moistened to a depth of 10-15 cm and sometimes up to 20-35 cm which leads to washing of the surface layer, but starting from a depth of 10-15 cm, the profile is accumulate salts. The soil is salinized with sulphate chloride and chloride salts, and rarely with sodium salts. Takyrs have carbonate-rich surface soils. The content of CO_2 is 4-12%, and the content of gypsum is not high. The humus content is low (about 0.5%) due to the scarcity of the vegetation cover [20].

The seasonal soil moisture patterns define the takyr plant cover specifics. It consists of primitive aquatic vegetation capable of withstanding long periods (sometimes many years) of droughts in a state of antibiosis. Here, the most prevalent plants are algae: filamentous blue-green of the *Oscillatorium* family (genera *Phormidium* and *Microcoeleus*) [9]. During the rainfall season, they form a 'film' with a biomass of up to 500 kg/ha. There are also lichen takyrs. Sometimes, lichen colonies cover takyrs completely. The prevailing lichen species are *Diploschistes albissimus, Sguamaria lentigera of the Lecanoraceae*, *Caloplacaceae*, *Lecideaceae* families, and other species [11]. During wet periods, the lichen biomass reaches 1,000 kg/ha whereas in dry seasons, they turn into a brittle dry crust.

After drying, takyrs retain a stock of moisture for a short time, saltwort and ephemerals grow in cracks with their vegetation ceasing soon. In depressions, the stock of moisture is retained for a longer time, with the following plant species growing there: saltwort (*Salsola*), tamarisk (*Tamarix*), sagebrush (*Artemisia*), black saxaul (*Haloxylon aphyllum*), camelthorn (*Alhagi persarum*), and harmel (*Peganum harmala*) [27]. These plants occur on the sand dunes surrounding the takyrs, in car tracks, and around wells.

The scarcity of the vegetation cover defines the fauna species composition and populations. However, there are species with their core habitats located on takyrs. In addition, inhabitants of neighboring ecosystems may be found there: they come in search of food and in springtime – for watering. The most common inhabitants of takyrs are small five-toed jerboa (*Allactaga elater*), dwarf fat-tailed jerboa (*Alactgulus acontion*), yellow ground squirrel (*Spermophilus fulvus*), marbled polecat (*Vormela peregusna*), black-bellied sandgrouse (*Pterocles orientalis*) and pin-tailed sandgrouse *(Pterocles alchata)*, desert lark (*Ammomanes deserti*), tawny pipit (*Anthus campestris*), takyr toad-headed agama (*Phrynocephalus helioscopus*), diadem snake (*Spalerosophis diadema*), saw-scaled viper (*Echis carinatus*), cobra (*Elapidae*), Halys viper (*Gloydius halys*), Indian gamma snake (*Boiga trigonatum*) [37].

Though takyrs are not managed for animal grazing, they play a highly important role for cattle farming. Traditionally, takyrs have equipped water-collection sites with water accumulation and storage facilities/reservoirs: khakis (~ takyr ponds), chirles (~ wells) and sardobas (~ underground water tanks). Most wells and boreholes with groundwater reverses are also located on takyrs. Local communities (primarily cattle farmers) are found there as well. Takyrs are exposed to significant anthropogenic pressure because their low substrate mobility makes them convenient for construction of pipelines and roads. E.g., in sandy deserts, so-called dirt roads are mostly laid over takyrs. If artificial irrigation is available, it is possible to sow fodder, technical and food crops on them, and also to create highly productive man-made pastures via accumulation of moisture in special moisture-retaining furrows.

Alongside with the classical algal and lichen takyrs, there are takyrs enriched with arenaceous matter in their upper horizons or with a sand cover, for some reasons. In such cases, higher vegetation is richer there. Sandy takyrs may harbor single plants of calligonum (*Calligonum setosum*), shrub-like saltwort (*Salsola arbuscula*), black saxaul (*Haloxylon aphyllum*) and Turkestan rheumuria (*Reaumuria turkestanica*), and belts of sagebrush (*Artemisia kemrudica* and *Artemisia badhysi*) [1]. This type of takyr ecosystems is a transition to ecosystems of argillaceous deserts on takyr-like soils.

The takyr-like soil surface produces a subdued terrain with sandy hillocks around shrubs, micro-depressions, and - in areas of alluvial cones and delta plains – with feebly expressed ancient river beds. The soils include sandy clays and loams with interlayers of light soils in some places. They have very high moisture retention capacity resulting into the development of semi-shrub plant communities with dominating sagebrush of the *Seriphidium* subgenus and admix of sand sedge (*Carex physodes*) [2].

Takyr-like soils are similar to takyrs in many respects. Their surface 2-6 cm crust also has a polygonal pattern of cracks, but it is not so solid. The sub-crustal horizon (5–12 cm) has mildly expressed imbricated structure, and is brownish or stone colored. The horizon to a depth of 20–30 cm is somewhat compacted and structureless. These soils tend to develop in place of more ancient hydromorphic soils with the latter's structure traced in deeper horizons. In places of soil development on younger alluvial, proluvial and other deposits, the structureless horizon lies on the parent rock. The dispersion and low biomass of the vegetation account for the low humus content (below 1%) in takyr-like soils. There is no carbonate horizon, but in some cases, carbonate 'spots' from water accumulation are clearly visible at the time of drying of the lower horizons of ancient hydromorphic soils under takyr-like soils. The content of CO_2-carbonates is 8–12%, and the content of gypsum is insignificant. Widely-spread chloride-sulphate salinization of takyr-like soils explains their enhanced alkaline reaction [21]. The plant cover depends on the composition and age of the surface deposits, depth of the groundwater and its salinity. Its plant species include sagebrush (*Artemisia turanica*) and saltwort (*Salsola orientalis*). The tree and shrub storey consists of sparsely growing *Halothamnus subaphyllus* and *Salsola richteri*. The grass layer often includes sand sedge (*Carex physodes*) and many other ephemeroids and ephemeral plants. The role of the bulbous bluegrass (*Poa bulbosa*) is particularly important as it often acts as an edificator of plant associations of foothill plains. Lichens are widely spread there, and algae occur on the soil surface [1, 27].

As regards the prevailing vertebrae, they are represented by the same species on both takyrs and fixed sands. Among insects, termites (*Isoptera*) are highly prevalent. Termite nests have a form of compact clayey mounds up to 0.5 m high and are quite common in clay deserts [37].

The most common plant communities are those of tetyr saltwort (*Salsola gemmascens*) and sagebrush (*Artemisia kemrudica*) with gamanthus (*Gamanthus*); and the plant cover consists of sand sedge (*Carex physodes*), anabasis salsa (*Anabasis annua*), and prangos (*Prangos digyma*), as well as such ephemerals as *Lepidium perfoliatum*, *Microcephala lamellata* and *Atriplex aucheri* [27].

Pastures are rather productive: their yield ranges from 0.82 to 1.31 dt/ha, and communities with inclusions of the camelthorn (*Alhagi camelorum*) yield 4 dt/ha and over. In these areas, the plant cover is 38–16% (reaching 95% in the nature reserve), the aboveground plant stock is 3.1 dt/ha (in the nature reserve) and 1.6 dt/ha in grazed areas. Intensive grazing may decrease it to 0.4 dt/ha [2]. These ecosystems significantly suffered from clearcutting of saxaul forests.

1.3 Takyr distribution areas

Takyrs are mostly found in Central Asia, sub-region of Asia occupying 3.99 million km^2 [7]. The eastern coast of the Caspian Sea and the Lower Volga River coincide with the western border while the northern border stretches along the state boundary between Russian and Kazakhstan. In the south and east, the region is demarcated mostly with watersheds of the Kopet-Dag, Pamir-Alai and Tien Shan mountains and the boundaries with Iran, Afghanistan and China. Central Asia is a vast endorheic basin with Lake Balkhash, Aral Sea and Caspian Sea situated in its lowest parts. It stretches from north to south for over 20^o and from east to west for about 40^o. Arid, semi-arid and sub-humid areas occupy more than 90% of Northern and Central Asia.

The recent 50 years have brought about major damages to natural resources in the Aral Sea basin due to human actions and progressing desertification processes. The *cotton-at-any-cost* policy of the former USSR led to critical environmental disturbances in the Aral Sea basin. Located in the Turan Lowland, the Aral Sea had the fourth largest water area in the world (about 68,000 km^2) in 1960. By the end of the 20th century, it dwindled and lost 80% of its water volume and over 60% of its water surface. In addition, the intraregional redistribution of the water resources had other unexpected multiple environmental impact, e.g., enhanced climate continentality, changed vegetation periods, etc. The salty dust emissions from the desiccated Aral Sea bed and higher atmospheric aerosol levels also have adverse impact. The existing large-scale network of channels and dams contributes to losses of water resources due to infiltration and evaporation, it is also to be blamed for the soil and vegetation degradation and secondary salinization proliferation, and impairs agricultural performance in oases. The following areas are hardest hit by environmental disturbances: Karakalpakstan and the Khorezm Oblast in Uzbekistan, the Dashoguz Province and Birata District in North Turkmenistan and also the Kyzylorda Oblast in the southern parts of Kazakhstan where soil salinization and water resource pollution are reducing agricultural outputs, impair the quality of potable water and are detrimental to public health.

From the hydrological perspective, this area may be intrinsically divided into three basins: those of the Aral Sea, Caspian Sea and Lake Balkhash. Only the north-eastern part of Kazakhstan belongs to the basin of the Ob River draining into the Arctic Ocean. The Aral Sea basin occupies about 1.5-2.0 million km^2. Most catchment areas of the Amu-Darya and Syr-Darya Rivers are located in the Pamir-Alai Mountains and Central Tien Shan. The total annual runoff is about 125-130 km^3.

The area of the Balkhash basin is about 0.5 million km^2. The main source of water resources is the Ili River with its annual runoff of about 14-15 km^3. The Balkhash area or *Semirechye* (the *Region of Seven Rivers*) is facing the same problems as the Aral Sea basin: redistribution of water resources, inefficient land uses, environmental and nature conservation issues.

The Caspian Sea is the largest inland lake, and its main affluent streams are the Volga, Terek and Ural Rivers. The north-eastern and eastern coasts of the Caspian Sea are part of Central Asia. The eastern coast of the Caspian Sea has practically no river runoff. The region-specific environmental issues are water level fluctuations in the Caspian Sea and oil and gas industrial operations in the coastal areas.

The region's soils are relatively uneven in quality. Black earth and dark chestnut soils of the flatland and mountainous steppes, gray-brown soils and gray earth of the piedmont plains as well as alluvial soils of the river flood plains and deltas are suitable for agricultural uses. Low-fertility climatophytic soils of the desert plains with their plant cover are used as pastures.

Plant resources include over 20 vegetation types and about 2,000 species comprising the foundation of the desert flora in Northern and Central Asia. In comparison with montane vegetation, the flora of arid and semi-arid plains is less diverse and scarcer. In Central Asia, the bottom and middle altitudinal belts of the mountains have abundant sparse growth of sub-arid and sub-humid deciduous species (*Pistacia, Amygdalus, Prunus, Celtis*) and conifers (*Juniperus*) as well as sub-humid forests (*Juglans, Acer, Malus*). Forest logging and grazing have significantly reduced the forest areas. A key function of mountainous forests is to protect soil and water resources, so, deforestation results into enhanced erosion and desertification processes in the low altitude belt. In the southern mountainous areas (Western Tien Shan, Pamir-Alai and Kopet-Dag), the erosion and desertification processes are particularly intensive due to the enhanced erosion, uneven distribution of seasonal precipitation, greater aridity and, hence, longer time of vegetation revival. The groundwater regime disturbance and forest logging have also reduced the areas of the Tugay forests in river flood plains and deltas and flatland saxaul (*Haloxylon*) stands.

The Kara-Kum, Kyzyl-Kum, Muyun-Kum, Aral Kara-Kum, Ustyurt, Betpak-Dala Deserts, Kazakh steppe and Tien Shan, Pamir-Alai and Pamir mountain steppes are used primarily for grazing and have significant capacity to produce fodder in Central Asia. The grazing land accounts for about 68% in the total area of the region. Natural pastures provide forage for cattle; and it is very important to safeguard sustainably high productivity of the pastures. Such anthropogenic factors as overgrazing, forest logging, ploughing, fires, etc. lead to impoverishment and degradation of the grazing land.

The need to conserve biological and genetic diversity is of particular importance for Northern and Central Asia in view of the aridity and sensitivity of its natural ecosystems. Central Asia has 35 nature reserves with their status officially matching the IUCN's management category of *strictly protected areas*. The nature reserves are distributed very unevenly. There are also protected landscapes (special-purpose PAs) with their status corresponding to the IUCN's management categories 4-5, but their nature conservation significance is limited. The nature reserves are understaffed and their other needs include work space and housing, research staff, supplies and equipment. In addition, these PAs' status is often not observed. In many cases, they are used for business purposes. All the five countries are Parties to the Convention on Biological Diversity and make strong efforts to conserve it.

Over the recent 5 decades, the population of Central Asia tripled to reach about 55 million people. This is explained by improved general living standards and, to some extent, traditionally large families (with many children) in the region. However, the population growth somewhat slowed down in recent years due to the emigration of Russian-speaking people, lowered birth rates and growing mortality in some areas. Approximately two thirds of the countries' population (except for Kazakhstan) lives in rural areas. In the nearest 20-25 years, the population is expected to increase to about 70 million people.

Currently as earlier, agriculture is the prevailing sector in the region. In the countries of Central Asia, agriculture depends on irrigation and is well-developed primarily in areas extending along rivers due to the arid climate. So, the cotton industry - alongside with cultivation of rice and vegetables – is a key source of income. In the recent decade, the areas of irrigated cotton and rice fields tend to get reduced and grain cultivation areas tend to increase in the region. The region's horticulture has low productivity. In this region, grazing management remains extensive, unstable and low technical capacity. Droughts or cold and long winters often kill a lot of cattle. For this reason, sustainable development of cattle farming is impossible without additional fodder production. In spite of the instability, pastoralism is an important source of meat and wool both at the macroeconomic level and at the private household farm level. All the countries of the region have poorly developed infrastructure, especially, in rural areas.

2. MAIN PART

One of the most typical external characteristics of takyrs is their flatness. In fact, the perfectly smooth takyr surface has a specific micro-pattern (with barely noticeable elevations, closed depressions) and minor grades and slopes. The surfaces of some isolated takyrs have 'miniature' inherent elements of river basins, including catchments, slopes and a specific broad linear depression, i.e. 'watercourse' several centimeters deep. These elements are very weakly expressed on takyrs (with the exception of catchments) and often are absent. The 'watercourse' tends to be found in the depressed part of a takyr. When a sandy strip divides a takyr and water comes from one to the other of its parts, such a 'watercourse' emerges between the parts. In large takyr and takyr-like areas with significant temporary runoff, a hydrographic network develops in the form of converging and diverging small wash-ways and и rills, finally lost in the plain. In piedmont plains, takyr and takyr-like areas are split by larger 'watercourses' periodically filled with water from the mountains. From the hydrological perspective, takyrs may be viewed as periodically active streams [19].

2.1 Water capacity of takyrs in the Aral Sea basin

2.1.1 Kazakhstan

In his first research papers, U.M. Akhmedsafin, a well-known scientist, identified the need to use the temporary surface runoff, i.e. the water accumulating on the takyr surfaces during the winter/spring season [4]. Soil scientists from Kazakhstan classified takyr-like soils as a specific genetic type of soils of desiccated alluvial plains [31]. However, according to G.T. Leshchinsky [19], the differences between takyrs and takyr-like soils in the mechanical composition and water-physical properties do not matter for the runoff generation. These differences get levelled as a result of the soil over-crusting and swelling as well as the chemical and biological processes in the surface layer of the soil.

Takyr-like soils developed in dried alluvial plains of the Syr-Darya, Chu, Ili and other rivers with deeply sunken groundwater (5-10 m deep and deeper). These are former seasonally flooded soils of the desert zone, developing over a long time only under the atmospheric moistening; their profile is weakly differentiated [5]. It is possible to distinguish a light-gray porous crust (with its thickness ranging from 2-3 cm to 6 cm), scaly lamellar horizon (6-12 cm), light-brown compacted structureless horizon (15-30 cm) graduating transformed into laminated alluvium. The content of humus is below 1%, the salinization is of the carbonate type (4-9%). Takyr-like soils are part of grazing grounds, but they are also reserved for irrigation as the most fertile and accessible for use.

The takyr profile includes the same genetic horizon as takyr-like soils, but has quite different physical properties. Takyrs occur as small areas in existing and antecedent river valleys, in or near Betpak-Dala, in Mangyshlak and Ustyurt, in such sandy deserts as Kyzyl-Kum and Aral Kara-Kum where they form in closed terrain depressions of different sizes and shapes which act as accumulators of meltwater, solid minerals and soluble salts, deposited from surrounding upper areas. Due to the annual deposits of erosion products and the changing moistening phases coupled with the mechanically heavy structureless parent rock, the takyr surface becomes even and smooth and split by cracks into separate polygonal parts. Table 2 shows the particle-size distribution and content of water-soluble salts of the takyr in the Ustyurt Plateau where the samples were taken from a section [32].

Table 2: Physical and chemical properties of the takyr from the Ustyurt Plateau

Sample depth, cm	Total salts	HCO_2 %	Cl %	SO_4 %	Ca %	Mg %	Na+K %	Particle content, mm	
								<0.001	<0.01
0-5	0.287	0.024	0.122	0.046	0.026	0.013	0.056	9.7	38.9
6-16	0.469	0.017	0.235	0.051	0.043	0.014	0.108	18.0	46.6
20-30	1.590	0.010	0.242	0.855	0.307	0.036	0.149	14.6	38.1
50-60	1.320	0.007	0.125	0.792	0.286	0.027	0.083	9.1	21.7
130-140	1.412	0.010	0.084	0.895	0.276	0.025	0.122	5.6	9.7

In most cases, takyrs are heavily salinized throughout the soil profile. In the case of light salinization, the prevailing salts are sulfates while heavy salinization results into the dominance of chlorides and high total alkalinity. As regards the mechanical composition, takyrs are clayey and heavily loamy and have high contents of silty clay particles responsible for heavy agrochemical and agro-hydro-physical properties of the soils (structurelessness, compact constitution, low water conductivity, etc.) [33]. In such conditions, reclamation of takyrs entails major difficulties, but turns them into perfect catchments where surface runoff is generated after precipitation.

Key determinants of the surface runoff magnitude are as follows: the intensity of runoff-producing precipitation, soil moistening degree before rainfall and catchment area. Aspects related to precipitation, runoff generation, incipient losses and influence of the size of takyrs on the runoff volume are fairly comprehensively highlighted in publications [19] and [28]. The same authors estimated volumes of water generated on takyr and takyr-like catchments in Western and Southern Kazakhstan, respectively (Table 3). Table 3 shows substantial differences in the areas of takyrs and takyr-like soils and runoff volumes reported in different sources on the Kezylorda, Shykment and Jambyl Provinces.

Table 3: Areas of takyrs and takyr-like soils with estimated potential surface runoff volumes

Provinces	Takyr and takyr-like soil area, km^2	Surface runoff, million m^3	Source
Western Kazakhstan			G.T. Leshchinsky, [19]
Jambyl	709	6.98	
Shykment	1,124	9.95	
Karaganda	853	5.97	
Aktobe	11,120	62.71	
Atyrau	4,781	52.59	
Kyzylorda	37,871	134.72	
Total:	56,458	272.9	
Southern Kazakhstan			Yu.V. Ross, [28]
Kyzylorda	4,247	650.2	
Shykment	136	27.1	
Jambyl	641	116.4	
Total:	5,024	793.7	
Kazakhstan			K.Sh. Faizov *et al.*, [34]
Flatland part	80,854	388.1	
Mountain part	1,184	187.1	
Total:	82,038	575.2	

Our calculations were based on the estimates of the areas [34] produced later and with due regard to the current processes of land transformation into takyrs, e.g., in the desiccated Aral Sea bed. It should be also noted water volumes for flatland areas were estimated with the use of the average long-term runoff per km^2 by the method described in publication [19], and water volumes for mountain areas were estimated by the method described in publication [28] because the water balance structure used in this paper took into account the surface runoff generated outside the study area which is typical of mountainous catchments.

In Kazakhstan, the total area of takyrs and takyr-like surfaces is 82,038 km^2 or 3.5% of the country's soil cover. Table 3 shows that these catchments generate 575.2 million m^3 of fresh water in an average water year. These potential water resources may be widely used to address water supply needs of desert pastures. One Kazakh saying (*Zaman akyr – zher takyr*) compares the end of the world with transformation of land into takyrs. Clearly, this refers to takyrs and takyr-like soils with very scarce vegetation on their surfaces or fully devoid of it. However, in the past, people could not even guess that the 21st century would bring the water capacity of these soils to the forefront. This is primarily linked to climate change and fresh water deficit especially in Central Asia. If even an insignificant share of these potential resources (i.e. takyr runoff) is used, it would be possible to improve and - in some areas – to put in place sustainable water supply of pastures and even small-scale oasis-based crop farming. In this context, Kazakhstan's takyr catchment conservation and sustainable management are of particular importance and call for further exploration and research.

2.1.2 Uzbekistan

In Uzbekistan, intensive management and development of arid land has enhanced anthropogenic pressure on the Kyzyl-Kum and Ustyurt desert ecosystems. The use of these desert areas is centuries-old and human impact has not been always positive. Impact of business activities on desert vegetation is chiefly resulting from cutting of shrubs for fuelwood and extensive cattle grazing which depends on the availability of watering places [25]. The existence of water sources has a strong influence on grazing pressure: some desert pastures are not used for a long time per due to the absence of water sources. Underuse of pastures and lack of grazing lead to degradation of the pastures manifested in competitive replacement of pasture vegetation of high value as fodder by mosses and lichens. The reverse side of the problem is known as 'desertification near wells' and calls for reducing the concentration of livestock in pasture areas adjacent to wells. To have more balanced grazing pressure on desert plant communities by way of proper distribution of livestock herds and full utilization of plant resources, it is worthwhile to intensify the work to supply pastures with water where takyr-based water supply is to play a role.

Uzbek soil scientists use the term 'takyr soils' to denote both takyr and takyr-like soils. They are found primarily in old-delta valleys of the Amu-Darya, Syr-Darya and Qashqadaryo Rivers as well as in the deltas of the Zarafshan and Surxondaryo Rivers. There are fairly large areas transformed into takyrs in the Ustyurt Plateau [16]. In the Northern Kyzyl-Kum Desert, clayey lowlands (takyr soils) are abundant to the north of Turtkul, reaching the southern slopes of the Sultan Uvays Dag Range, to the north-west of Kipchak, to the east and north-east of Chimbay and to the south of the Beltau Upland. A wide strip of these clayey surfaces stretches to the south-west of Zhosaly to the Aral Sea. In the Central Kyzyl-Kum Desert, takyrs occur among sands on (Cretaceous-Tertiary) bedrocks in exposure places of clays in lowland sites. They are also abundant in the South-Western Kyzyl-Kum Desert where takyrs co-exist with grey-brown soils in flatland areas. North-west of Bukhara, takyrs occupy a large area in depressions. There is a wide belt of takyrs and takyr-like soils in the south-eastern part of the Kyzyl-Kum Desert [19].

In Uzbekistan, the total area of takyr soils is estimated at 16,030 km^2, including 1,350 km^2 of takyrs [16]. Using the planimetric method with three iterations and large-scale maps for the Kyzyl-Kum Desert (within Uzbekistan), we estimated the area of takyrs and takyr-like soils at 8,670 km^2 [45]. If this figure is summed with the area of the Ustyurt Plateau takyrs (6,000 km^2 or 4,000 km^2, depending on the source [19]) and that of takyrs in the Syr-Darya Province (300 km^2) which do not belong to the Kyzyl-Kum Desert geographically, the the total area of takyr soils is about 15,000 km^2. The reduction of the area may be explained by the use of takyrs for irrigation purposes. In particular, it pertains to takyr-like soils which are not classified as land of priority development. Table 4 shows how the takyr soils are distributed by province within the desert zone in Uzbekistan.

Table 4: Takyr soils in the Kyzyl-Kum and Ustyurt desert pastures

Administrative units and districts		Takyr soil area		Surface runoff, ‘000 m^3
		km^2	%	
Kyzyl-Kum Desert	Karakalpakstan	3,260	21.8	50,384
	Bukhara	2,610	17.4	40,334
	Qashqadaryo	1,735	11.6	26,800
	Navoiy	1,065	7.1	16,482
	Surxondaryo *	300	2.0	2,773
Ustyurt *		6,000	40.1	23,530
Total:		14,970	100	160,303

** - assumed runoff volumes derived from [19]*

For purpose of estimating the temporary surface runoff, 24 takyrs were examined in the south, centre and north of the Kyzyl-Kum Desert. The field study defined the area of each takyr catchment, assessed the surface integrity and degradation, took soil samples for a laboratory analysis, and also included measurements of the infiltration coefficient [40]. In addition, the study included processing of weather records for many years to assess runoff-producing precipitation in spring months as the most productive period for surface runoff generation. Table 5 provides some results of the fieldwork and data analysis.

Table 5: Zonality of runoff generating precipitation, runoff coefficients and volumes in the Kyzyl-Kum Desert

Month	Zonality, degrees north latitude	Precipitation, > 5 mm		Runoff coefficient	Average runoff, million m^3
		Days	%		
March	South 38.0-39.5	2.1	27.0	0.25	15.8
	Centre 39.6-41.5	1.8	25.0	0.24	14.3
	North 41.6-43.5	2.4	28.6	0.28	27.9
April	South 38.0-39.5	2.4	30.2	0.26	12.3
	Centre 39.6-41.5	2.3	29.9	0.25	10.4
	North 41.6-43.5	3.0	37.0	0.31	24.5
May	South 38.0-39.5	2.2	37.3	0.28	6.3
	Centre 39.6-41.5	1.9	34.0	0.29	6.9
	North 41.6-43.5	2.5	40.4	0.34	15.2

The table shows that the days with runoff-generating precipitation (> 5 mm) account for 27-40% in the total number of days with precipitation during per month. The assumed runoff coefficients were both estimated and defined volumetrically at three of the experiment takyrs in the field.

The runoff volume may be easily calculated using the data and the following formula (1):

$$Y = xFn, \qquad (1)$$

where

Y is the runoff volume; x is the monthly precipitation total;

F is the area of takyrs; n is the assumed runoff coefficient.

Table 4 provides estimated temporary surface runoff characteristics for the mean water year (availability level = 50%) for desert areas in Uzbekistan. The total post-precipitation takyr surface runoff is 160.3 million m^3. This estimate is above that of G.T. Leshchinsky (99 million m^3) by 62%. As regards the underestimations in that publication [19], its author writes: "…using the assumption that the estimated takyr-like catchment area is 10 km^2, we are aware that the water resources would be underestimated approximately by half". Taking into account that the estimates provided in [45] pertain only to spring months and do not include the runoff of autumn/winter precipitation, amounting to about 35-40% of the mean annual rainfall, our estimates are more or less on par with the results presented in [19].

2.1.3 Turkmenistan

According to A.P. Lavrov [16] and G.T. Leshchinsky [19], in Turkmenistan, vast areas of takyrs and takyr-like soils are located to the south of the dry Daudan River bed in the Amu-Darya delta and extent to the west from Dashoguz to the southern edge of the Sarygamysh Depression. Large areas of takyrs are found near Shasen and Gyaurkal. In the Western Uzboy River valley, there are isolated spots of small takyrs and takyr-like solonchaks among the locally prevailing solonchaks. There are takyrs in the Upper Uzboy Corridor and in the Unguz Depression. Their area tends to vary from 0.5 to 2 km^2. In the Trans-Unguz Kara-Kum Desert, takyrs occur in the western and southern parts, occupying depressions between ridges (*kyrs*). Takyrs are also developed on slopes of plateaus and ridges. In North-Western Turkmenistan, small takyrs are widely spread. Larger takyrs are usually associated with the *chink*-adjacent belts, accumulating clayey deposits from the terraces (‘*chinks’*). The Krasnovodsk Plateau has few takyrs and they are located mainly in the north-east. In the Lowland Kara-Kum Desert, large areas are occupied with takyrs between the meridians of the Geok-Tepe and Bayram-Ali stations. This is an area of the so-called ‘large takyrs’ extending in the meridional direction and alternating with ridgy sands. Small-sized takyrs are very common among sands in the western part of the Kara-Kum Desert, and the eastern part of this desert has quite a lot of them. In sandy deserts, takyrs are not larger than 3.0 km^2 and are found in flat depressions.

In the interface of the northern foothill plain of the Kopet-Dag with the southern borderline of the Central Kara-Kum Desert, there are big solonchaks areas with takyrs encountered among them. To the south of this area, a wide strip of the Kopet-Dag foothill plain is extending for several dozens of kilometers between Serdar and Bereket and is covered chiefly with takyrs and takyr-like soils which become less abundant closer to the Kopet-Dag Mountains.

A wide belt of takyrs and solonchaks is located between the Kyuren-Dag and Small Balkhan Ranges. Takyrs are also prevalent to the south of the Small Balkhan Range. In the northern foothill plain of the Great Balkhan, takyrs are fewer. Large areas of takyrs are found in the Western Kopet-Dag foothill plain.

There are vast areas of takyr-like soils and takyrs in the Kugitangtau piedmont plain and in the north-eastern part of the Obruchev Steppe. Takyr areas are unevenly distributed across Turkmenistan. About 48% of them are located in piedmont areas with ancient river deltas and the Lowlan Kara-Kum Desert accounting for 24% and 19.6 %, respectively.

G.T. Leshchnsky [19] estimated Turkmenistan’s average long-term temporary surface runoff from takyrs and takyr-like catchments of the 1960-ies at 332,425,000 m^3. According to [24], prior to the year 1988, the total area of the country’s takyr catchments got reduced from 13,003.5 to 11,343 km^2. During the next decade, their area shrank by another 324,000 ha or by 3,240 km^2. Ultimately, the present-day area of takyr and takyr-like catchments is about 8,130 km^2 (62.5% of their initial area), and the surface runoff is 170,250,000 m^3 [24].

Other authors estimate the reduction in the takyr area at 50% [41]. According to the authors, key contributors to the degradation are natural conditions (many years of high humidity or drought), technogenic impact (construction of gas pipelines, collecting and drainage channels, motorways, electric power transmission lines, etc.), anthropogenic impact (cattle driving, construction of sheepfolds, runways and landing grounds, use of vehicles, pollution with household waste, etc.), agricultural and water management operations (utilization of takyrs for irrigation, discharges of and flooding with collector and drainage waters, construction of water reservoirs).

Satellite images for the Ahal Province show that 85% of the takyr catchment area is exposed to severe and highly severe desertification. In addition, only 13.8% of them or 39,711.9 ha can be used for surface runoff harvesting [42]. The differences of the data on degraded takyr land areas from the data of the previous authors is explained with the fact that the Ahal Province is the most economically well-developed region of Turkmenistan and it accounts for higher population density and human pressure on natural resources compared with their national average levels. In view of the lack of a unanimous opinion in the literature about the area of takyrs and takyr-like soils and controversial estimates of their degradation extent, we decided to estimate their areas and compare the results with the data from other authors (Table 6).

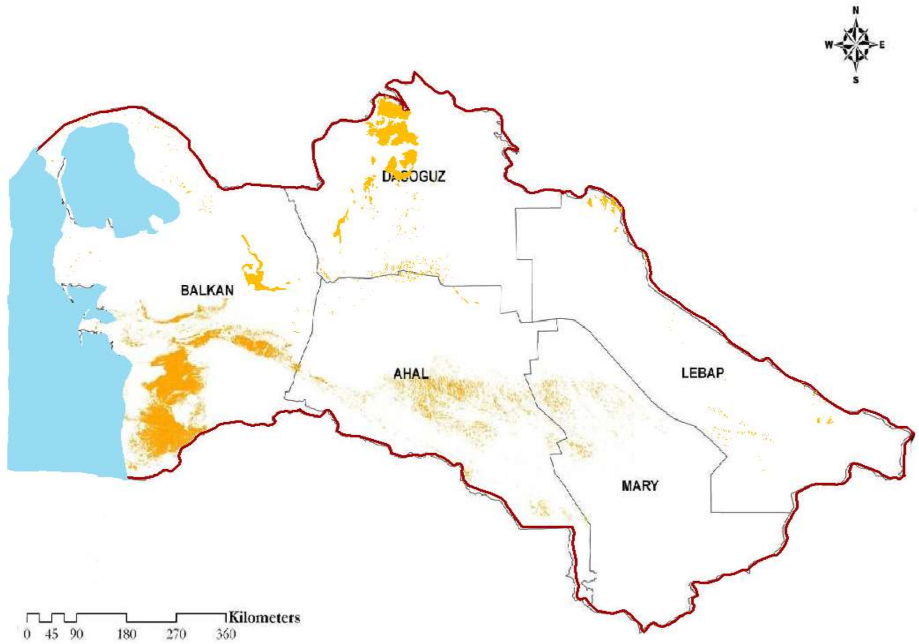
Table 6: The area of takyr catchments in Turkmenistan

Author, year	Takyr and takyr-like soil area, km^2
A.P. Lavrov, 1976	36,000
G.T. Leshchinsky, 1974	31,000
N.K. Lalymenko, 1983	28,000
M.A. Nepesov, K.P. Popov, 2000	8,130
I.D. Mamieva, T.P. Vitkovskaya, M.A. Nepesov, 2000	(50%) 14,000-18,000
Our data	22,524.23

The areas and degradation degrees of Southern Turkmenistan's takyrs (within 36 ° 20'-39 ° 44 'N and 53 ° 30'-62 ° 50'E) were estimated with the help of satellite imagery for the period of 1972-2003 from several sensors. All in all, 11 LandsatMSS images received in 1972-1975 and 10 Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images for 2002-2003 (each in 8 spectrum bands) were analyzed. In addition, to check the deciphering accuracy, high-resolution historical Quick Bird images with coverage of 125 km^2 were obtained and analyzed (Maman et al., 2011).

The takyr catchment area of Northern Turkmenistan was estimated with the help of a map based on NaturalVue [43] which is a seamless mosaic of the whole world consisting of over 8,600 Landsat-7 multispectral true color satellite images with a resolution up to 30 m. The ArcGIS and ERDAS software was used to process the images where the takyr surfaces were digitalized. Figure 1 shows the synthesized map of takyrs in Turkmenistan.

Figure 1: A map of takyr catchments in Turkmenistan



Summing up the results for Northern and Central Asia as a whole, it should be noted that the total area of the region's takyr catchments is 119,532.23 km^2 and their surface runoff is 977.04 million m^3 (Table7).

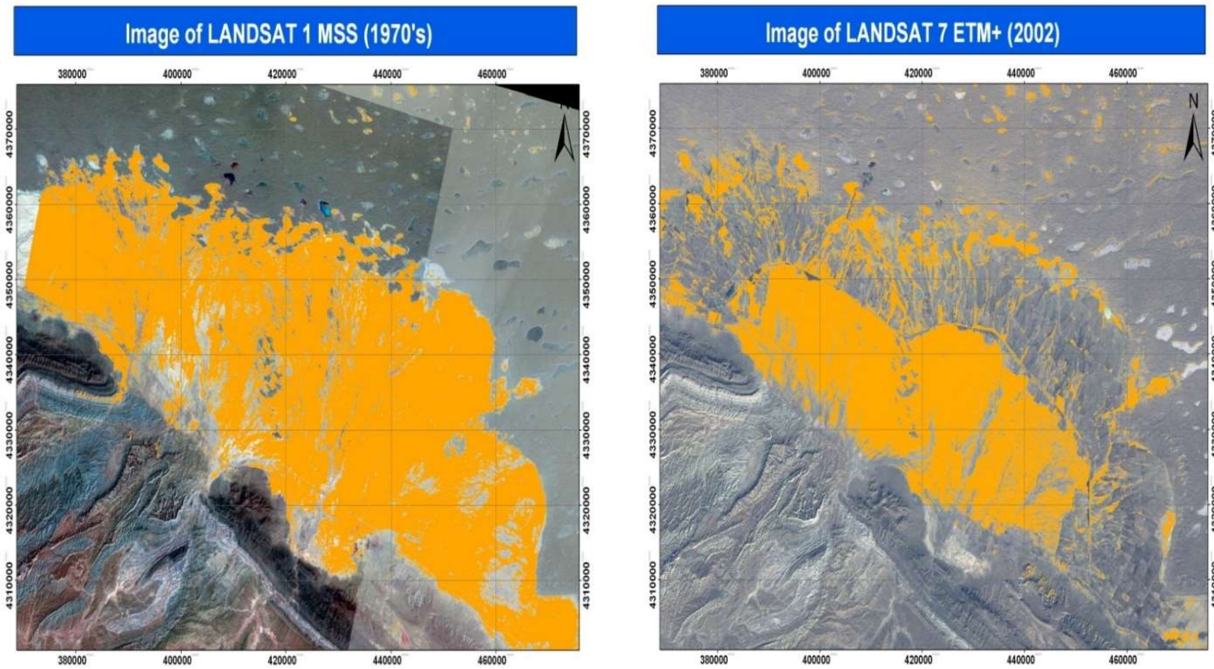
Table 7: The area of takyr catchments in Northern and Central Asia and their temporary surface runoff

Country	Area, km^2	Runoff, million m^3
Kazakhstan	82,038	575.2
Uzbekistan	14,970	160.3
Turkmenistan	22,524.23	241.54
Northern and Central Asia - total	119,532.23	977.04

2.2 Degradation of takyr catchments and ways of their conservation and restoration (in Turkmenistan)

The reduction of takyr catchment areas may be accounted for by the degradation of their surfaces. Using the below space images for 1970 and 2002 (Figure 2) as an example, it is possible to assess the pace and extent of the degradation [79].

Figure 2: Shrinking takyr area in Western Turkmenistan



V.N. Kunin and G.T. Leshchonsky [62] noted that takyr and takyr-like soils could develop and exist under the following conditions: the groundwater depth of at least 3-4 m; and temporary stagnation of surface waters because of minor surface slopes. Today, this definition should include an additional essential condition which is the takyr surface crust integrity, i.e. it should not be destroyed under the influence of natural and human factors.

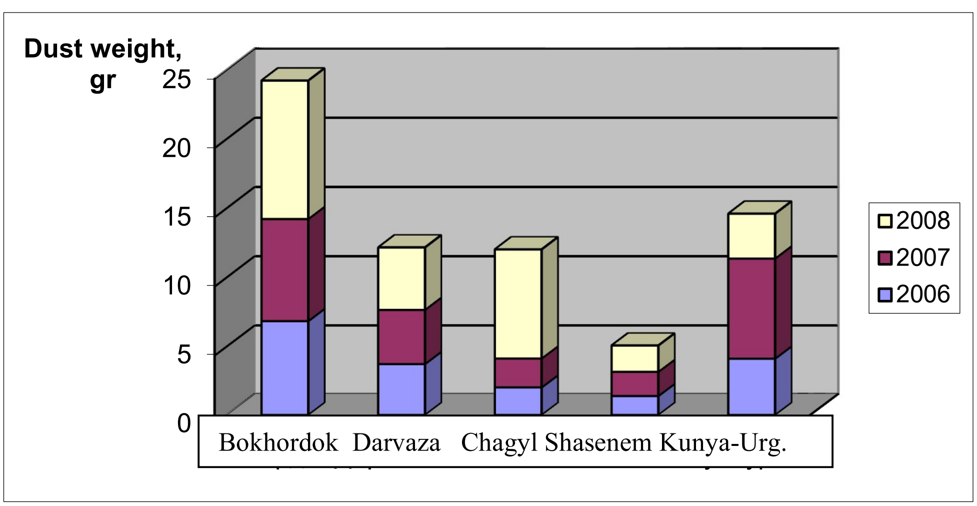
It is known that the takyr crust is very hard and can be destroyed under the influence of natural and human factors only if they are sufficiently strong. But its destruction does occur which is confirmed by many years of observations over the hypsometric tints of the Sovma takyr in the Central Kara-Kum Desert. This takyr had been produced by alluvial deposits in the ancient delta of the Tejen River, and its thick surface is losing an average of 0.06-0.07 cm of aeolian substance per year as it is blown out [48]. In different desert areas of Central Asia, on sand-covered takyrs and takyr-like deposits of the Zeravshan and Murghab Rivers, such silt/dust discharges amount to 0.16-0.33 cm per year [68].

A key cause of the release of silt/dust particles from the takyr crust is wind erosion associated with the seasonal wind-driven sand flows on the takyr surfaces in the latitudinal direction. This may be visually observed during the time of strong winds when a dust haze is hovering over takyrs (Figure 3). Due to the high contents of PM10 and PM2.5 dust particles in takyr surfaces, they were classified as potential sources of dust storms in the Sub-Aral region [81].

Figure 3: Dust rising from a takyr surface

Dust storms occur when a strong wind is driving smallest soil participles from the land surface. Strong winds (whirlwinds and hurricanes) fill the air with both fine earth which does not stay in the air for a long time and aerosols. Aerosols are light solid particles, freely floating in the air (dust, soot, slat and organic matter particles, etc.) as well as water droplets with saline and acid solutions. Depending on its origin, an aerosol belongs to one of the following six types: marine, sulfate, biogenous, smoke, volcanic or desert aerosols [47]. It is drought and dry winds which cause dust storms blowing out the desert aerosol into the troposphere; they are instigated by intensive soil tillage, cattle grazing, cutting of trees and shrubs for fuelwood. Fine earth dust does not stay in the air for a long time and falls down as dry atmospheric precipitation. Precipitation of such dust is particularly high in takyr landscapes (Figure 4) with its rates being higher in desert areas and lower in oases (the area of Kunya-Urgench is exposed to extra dusting due to discharges from the desiccated Aral Sea bed).

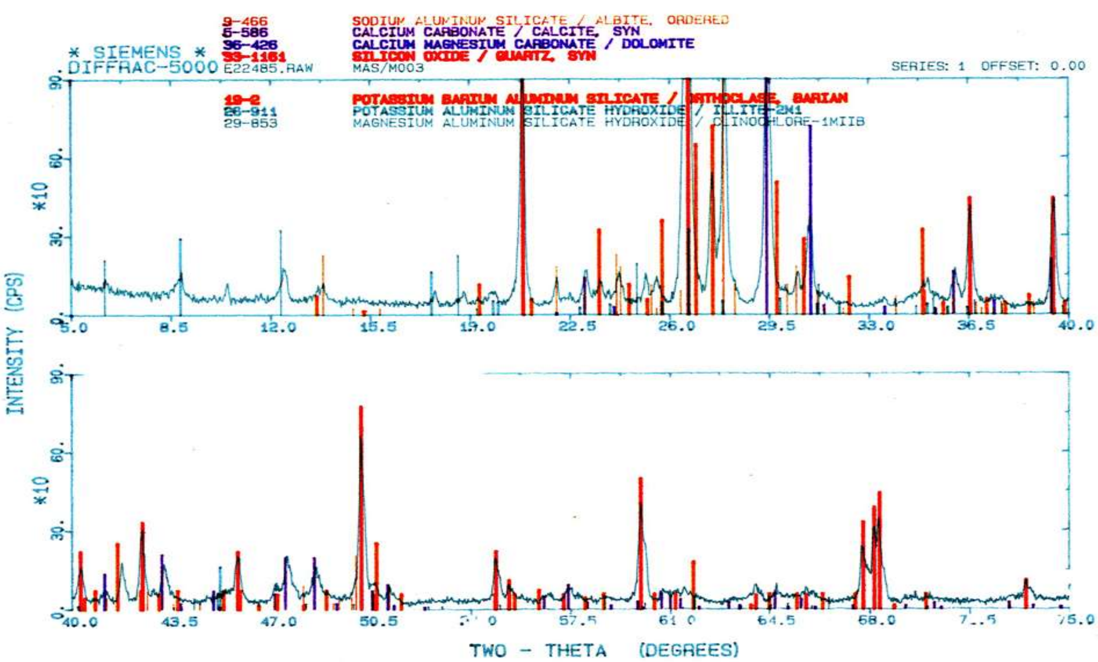
Figure 4: Dust precipitation in different areas in Turkmenistan



As demonstrated by a spectral analysis of the dust collected in the Aral Sea region [77], the dominant elements of its composition were such minerals as quartz, calcite and dolomite (Figure 5) in most dust samples. Apart from the core minerals, there was also illite, and its content surpassed that in soil samples collected simultaneously with the dust samples.

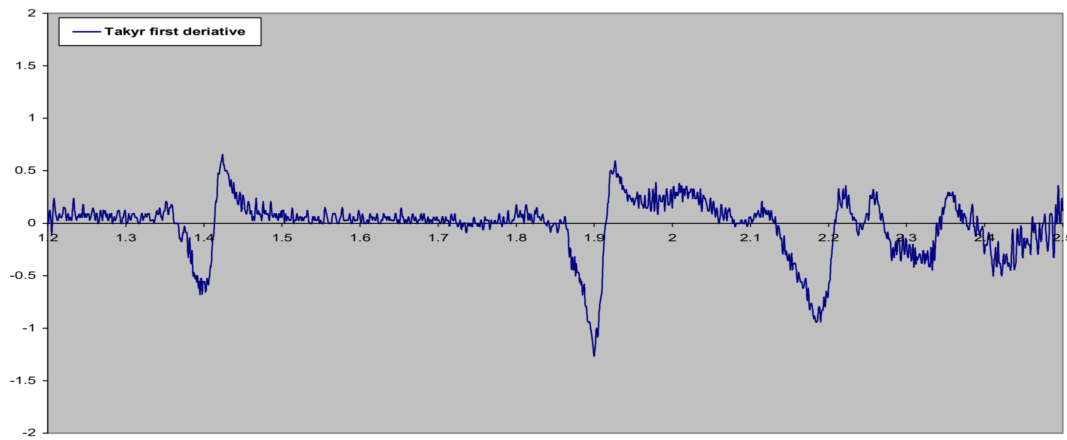
Illite is very plastic clay like kaolinite and is a sedentary product. We have established [79] that in terms of its spectral reflection, illite is identical to takyrs (Figure 6). This fact indirectly confirms the assumption [81] that takyrs are 'suppliers' of dust particles into the atmosphere.

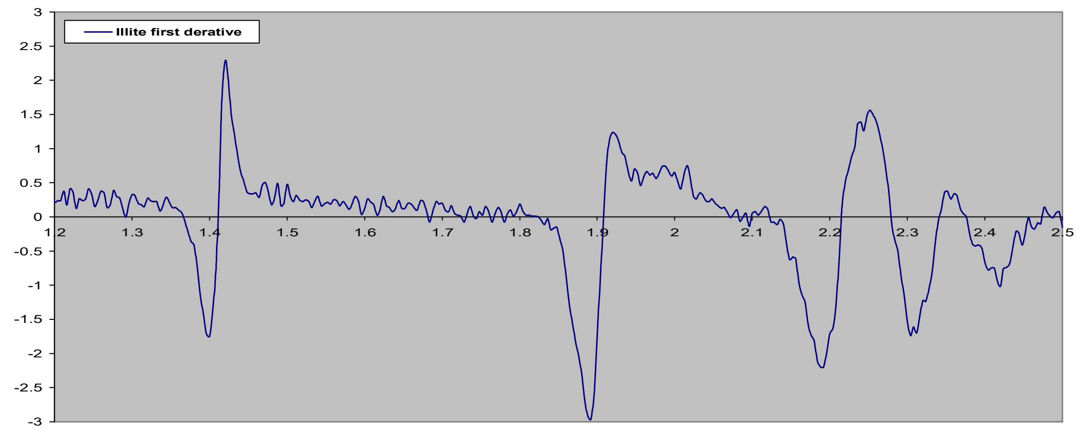
Figure 5: Results of the dust spectral analysis by the x-ray diffraction method (XRD)



In the study area, takyrs are found in depressions between barchans; so, it is quite probable that the abrasive wind-driven sand 'grinds down' their surfaces or sand grains are partially decomposed into smaller silty constituents after collision with the hard takyr crust.

Figure 6: Spectral reflection of the takyr and illite produced with the help of a FieldSpecFR spectrometer with a wavelength range of 350-2,500 nm





2.2.1 Takyr erosion processes

So far, there have been no studies to understand the possibility and mechanism of dust generation from the collision of sand grains with the surface of takyrs caused by the wind and sand flow. According to the theory of impact, the collision-caused loss of mechanical energy is estimated on the basis of the coefficient of recovery (K). So, for a sand grain moving along a takyr surface, K = 0.6-0.7. Then, the loss of energy for sand grains (fraction of 0.15-0.20 mm) may be calculated using the following formula [56]:

$$n = 1 - K^2 \qquad (2)$$

i.e. 'n' in % amounts to 51-64%. This is calling for special consideration as it is known that the saltation paths of sand grains are parabolic with one of the branches extending along the flow. In the wind-driven sand flows, the average velocity (V_{av}) of sand grains could be estimated using the following approximation [57]:

$$V_{av} = 0.42(V_{1.0} - 4), \text{ m/sec} \qquad (3)$$

where $V_{1.0}$ is the wind velocity at a height of 1 m from the sand surface.

The theory of impact [60] introduces the notion of critical velocity (V_c). The critical velocity is understood as the falling velocity of a body needed for it to collapse. For a sand grain, V_c may be approximately estimated if the average velocity is assumed to be equal to the critical velocity: $V_{av} = V_c$, using the following formula:

$$2.4\ V_c = V_{1.0} - 4,\ \text{m/sec} \qquad (4)$$

In the case of solving this problem, it is not the critical velocity *per se* which is of particular interest, but the wind velocity integrated in the formula (1.4)

$$V_{1.0} = 2.4\ V_c + 4,\ \text{m/sec} \qquad (5)$$

Table 8 (below) provides average values of V_c for some substances. It shows that the average value of critical velocity is 26 m/sec for rocks, and 20 m/sec for takyrs. Formula (5) is used to estimate the wind velocity corresponding to these values of the critical velocity: $V_{1.0}$ = 66.4 m/sec for rocks, and $V_{1.0}$ = 52 m/sec for takyrs. So high wind velocities (twice as high as the hurricane velocity), are not observed in deserts.

Table 8: Critical velocities (V_c) for some naturally occurring materials

Substances	*V_c, m/sec*
Rocks	26
Quartz	93
Takyr	20

In this context, we share our viewpoint with respect to the critical velocity immediately in point of impact of a sand grain with a takyr surface. The point of impact is called the point of contact of sand grains with the takyr substratum. Most sand grains are angular; so the area of impact of a sand grain with a takyr surface is very small at the points of contacts; therefore, the strength of the collision (at the point of contact) may increase approximately ten times. In other words, a decrease of the contact area is tantamount to an increase of the strength of the impact [68]. So, formula (5) is as follows:

$$V_{1.0}= 0.24\ V_c + 4,\ \text{m/sec} \qquad (6)$$

then, $V_{1.0}$ = 10.24 m/sec for rocks, and $V_{1.0} =$ 8.8 m/sec for takyrs.

The operation principles of sandblasting machines are well-known: flying sand grains have abrasive impact on a solid material (glass, metal, etc.), i.e. deglaze it or polish. In our case, what is happening at the point of contact is primarily destruction of the takyr crust material as it is softer and less durable than the quarzitic or arcose sand grains. In view of the lack of precise and reliable data on the critical velocity and area of impact at the points of contacts, we provide only tentative estimates. The above described process of takyr destruction may theoretically explain the generation of dust on takyr surfaces during the passage of a wind-driven sand flow. Though bare soils are less resistant to erosion than turf soils, the crust shields the takyr from wind erosion. However, the cohesive force of clay particles in the durable takyr crust permits the wind-driven sand flow to destroy it and blow out dust particles from its surface (Figure 7).

Figure 7: A takyr degraded due to wind erosion

The takyr crust may be also destroyed due to water or splash erosion during rain showers. During a shower, the falling drops possess significant energy and splash around before generating the surface runoff. Colliding with the takyr crust surface, the drops splash, thus, detaching small silty particles of the soil [69].

Incipient erosion is a short-time and intensive phenomenon. Splash erosion destroys the takyr surface to a varying degree, the takyr crust cracks disappear, and water infiltration drastically decreases. Due to the mismatch between the actual precipitation rates and infiltration capacity of takyrs, runoff starts on their surface and is accompanied with washing out of silty particles and salts. Our observations show that the suspended sediment load of the silty takyr water is 10-12 gr/l, i.e. the solid runoff from takyrs amounts approximately to 150-200 t/km^2/year [66].

At the initial stage of the runoff generation, water is filling the micro-depressions on the takyr surfaces, and then, the surface runoff from the entire area goes toward the most expressed side slope. First, erosion products are deposited in micro-depressions where they form fine silt/clay sheets turning into rolls after drying out and such rolls are called 'desert papyruses. Moreover, the 'papyruses' are quite easily ruined and gone with the strong winds in a wind-driven sand flow. When the depressions are filled, the surface runoff and wash-off cover the total area and run as a silty torrent along the meso-relief slope where linear erosion manifestations develop. The surface runoff with erosion products fills natural or man-made depressions and is quickly filtered reaching the edges of the sands in some places.

2.2.2 Intensification of aeolian processes due to climate change

The main micro-morphological feature of takyrs as specific soils is the 'mixed loam' in them [75]. The development of the 'mixed loam' may be accounted for by the 'sanding', i.e. filling of the takyr crust cracks with aeolian sand. The cracks change their locations [63], and the aeolian material is drifted in them by the wind and is assimilated in the original homogeneous soil mass as bands or clusters which merge with each other later to produce micro-zones with different structural proportions and, gradually, the takyr crust loses those of its properties which support the functioning of the takyr as a catchment area. The statement that takyr surface cracks change their locations is liable to dispute in the light of the recent case studies of Chinese specialists [82]. In the case of clay soils similar to takyrs in mineral composition, it is demonstrated that the alligatoring pattern changes only in the first two moistening/drying cycles, and further, it remains unchanged. In future, the intensification of aeolian processes will push the mix loam development, and its presence (even in the least quantities) is evidence of the beginning of soil degradation [75].

To forecast the development of aeolian processes, it is necessary to know forth-coming changes not only in precipitation and air temperatures, but also their related evaporation rates. It would enable to estimate changes in the values of the integrated indicator, i.e. the aridity index. In the first half of the 21st century, the most significant changes of the water balance may occur in closed drainage areas. The evaporation is growing from 300 mm in the Volga River basin to over 500 mm in the Aral Sea basin [53]. At the same time, precipitation is expected to increase, but within very narrow limits: from 200 mm in the Volga River basin and in the northern part of the closed drainage region to 100 mm around the Caspian and Aral Seas. In the same period, Central Asia's closed drainage areas will face more than doubled evaporation [53]. Therefore, warming is expected to bring about further acceleration of the drying of inland areas with respective reduction of the surface and underground water reserves with concurrent substantial lowering of the water level in closed water bodies and even disappearance of some of them. According to a forecast of moisture conditions for Eurasian desert areas, in the first half of the 21st century, the deficit of water resources will not only persist, but even grow.

A scenario of the United Kingdom Meteorological Office (UKMO) shows that the atmospheric CO_2 concentration would be doubled approximately in 2050-2075. It would lead to significant growth in the mean annual and seasonal air temperatures in the temperate zone, including Central Asia. The expected climate change would impair the region's moistening conditions to result into an increase in the area of Eurasian deserts and reduction in the area of semi-deserts and steppes. A minimum warming would shift the borderlines of the humidity zones to the north by 50-100 km and a maximum warming would lead to their shift by 350-400 km [52].

As regards global warming in the 21st century, the comprehensive Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) also provides different scenarios of growing concentrations of greenhouse gases and aerosols to show that the average global and average annual surface air temperature would rise by 1.6^0 C – 4.8^0 C in the period of 1990-2100 [55].

The gradual climate warming is directly linked with the moist air inflows from the ocean to terrestrial areas. This entails the development of more humid climate in most parts of the Globe. However, it does not pertain to southern inland areas (including Central Asia) where aridity is gradually enhancing due to the insufficient influx of humid air and increased evaporation from the earth surfaces resulting into water resource losses. These changes are conductive to the development of wind erosion processes in semi-desert and desert areas and their aggravation due to increasingly growing human pressure.

Our investigations confirm that the period of 1990-2001 brought about a rise in the annual air temperature by 0.8^0C-1.0^0C in Turkmenistan [70]. Since the 1990-ies, the natural weather background has been contributing to the enhancement of the deflation processes with intensive dust generation on takyrs and emergence of moving sands around them, and such trends are anticipated to persist during the first 25 years of the 21st century.

A distinctive feature of the takyr surfaces consists in the fact that in undisturbed conditions, they are not oversanded even when they are surrounded with moving sands owing to a specific air flow conditions on takyr surfaces (Figure 8). The light surfaces of takyrs are heated up less than their surrounding sands and a somewhat colder air cap forms over a takyr surface whereas on highly heated sand surfaces, rising currents are observed. Such an aerodynamic effect leads to diversions of the terrain forms of the moving sands as they move near takyrs from their initial direction by 30-35^0. For this reason, when a takyr surface and its adjacent area are not disturbed, there is no threat of its over-sanding [49].

Figure 8: An undisturbed takyr

In recent years, the intensive use of takyr surfaces has been disturbing the evolved equilibrium of the aeolian processes, and, first of all, the aerodynamic conditions [67]. When the takyr crust is broken, it becomes rougher and the surface is sanded over. When intensively managed takyrs are surrounded with moving sands, their aerodynamic processes are disturbed and, as a result, the barchans cease to divert their movement aside from the takyrs and, instead, advance directly on their surface. There, the wind-driven sand flow starts to produce intense sand emissions, generating sand deposits in windless areas of man-made obstacles and on uneven parts of the surface. These sand deposits intercept a significant portion of the atmospheric moisture precipitated on the takyr because sand has high moisture retaining capacity, and it becomes difficult or impossible to collect surface runoff.

2.2.3 Degradation stages

In the description of the takyr transformation into sandy pastures in the Zhana-Darya Plain, the following three development stages of sand deposits are identified [58]:

1. *The stage of discrete micro-sources of sand deposit development.* Its indicators include sparsely growing *Anabasis salsa* (*biyurgun*) thickets occurring in cracks of takyr surfaces. A small hummock of the typically aeolian shape emerges near each plant with the size of the hummock being under 3-5 cm. It is stabilized by annual plants and its size increases as litter (with its salts and organic residue) is accumulating there. In areas with particularly dense *Anabasis salsa* growth, the peripheral parts of neighboring small hummocks merge to create continuous silt and sand deposits.

2. *The stage of discrete sand islets.* Its indicators include clusters of the *Seriphidium terrae-albae* with some *Salsola orientalis* and *Poa bulbosa* growing on sand deposits which are from 10 to 50 cm thick. The rugged borderline of the sand 'islets' is smoothly and unnoticeably passing into the takyr with the transitional belt covered with *Anabasis salsa* with merged small hummocks.

3. *The stage of a continuous sand 'raincoat' with self-standing big sand hummocks.* Its indicators are clusters of saltwort (*Salsola arbuscula*) with occasional single plants of *Aellenia subaphylla*, *Salsola orientalis* and rarely occurring *Salsola richteri* and even more rarely occurring black saxaul (*Haloxylon aphyllum*). On the hummocks, the sand is 1.0-2.5 m deep, and between the hummocks, the sand layer thickness is 0.5-1.0 m, and there are sand 'islets' with incipient sand deposits along the borderline.

However, such a framework of grassland indicators is not fully applicable for takyr catchment degradation because the surface runoff generation is obviously impossible at the third stage. Saturation of a sand deposit with moisture and runoff of water excess along a degraded takyr surface cease earlier, perhaps, at the stage of the scattered 'islets'. It is difficult to verify this assumption because seasonal rainfalls followed by surface runoff are few.

L.N. Kharitonova [76] made an attempt to classify takyrs by their degradation degree using satellite data. Takyrs were divided into 5 categories on the basis of such a criterion as the proportion of clean (non-degraded) and overgrown, over-sanded, flooded and tilled areas within them. To count the number of takyrs of each category, the author used their simple classification into non-degraded, insignificantly degraded (up to 30 % of the area), moderately degraded (from 30% to 70 %), highly degraded (over 70 % of the area) and completely degraded takyrs. But no experimental measurements of the runoff were made to prove that it was possible to use the first three categories of takyrs for rainwater collection; and the study simply ignored smaller takyrs (under 1 km^2).

Table 9: Technical specifications of a small rainfall simulator

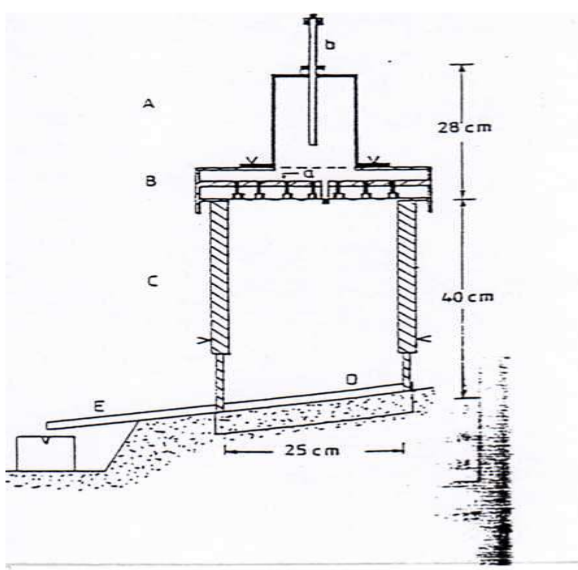
Simulated rainfall characteristics	Quantitative characteristic	Unit of measurement

Magnitude of rainfall simulation	18	mm
Duration	3	min
Intensity	6	mm/min
Average water drop height	0.4	мм
Drop diameter	5.9	mm
Drop weight	0.106	gr
Number of capillaries	49	pcs
Kinetic energy of rain drops	3.92	$J/m^2/mm$
Test surface area	0.0615	m2

It is very difficult to establish a reliable relationship between the runoff coefficient and takyr surface integrity if multiple, repeated measurements are needed. Therefore, we used a small artificial rainfall device – the Kamphorst rainfall simulator [78]. This small simulator was designed by Dutch scientist A. Kamphorst from the Wageningen Agricultural University for field and laboratory research to understand erosion-related soil properties, infiltration and surface runoff. The key specifications of the device are provided in Table 9.

The device consists of five parts and their vertical section is shown in Figure 9. It operates as follows: it has a 1,200 ml reservoir connected with a sprinkling head; water is released from the sprinkling head through 49 capillaries (a); the rate of water release through the capillaries is determined by their length and inner diameter; the pressure in the sprinkling head is regulated by way of moving the aeration tube (b) upward or downward to exclude the influence of the temperature factor. It is necessary to monitor the intensity of the standard rain shower.

Figure 9: The Kamphorst Rainfall Simulator



Legend of Figure 9: A – *a cylindrical reservoir for water with a built-in pressure regulator;* B – *a sprinkler for the production of the standard rain shower;* C – *metal walls with 'legs' to support the sprinkler;* D – a *metal ground frame to prevent lateral movement of the water;* E – *a gutter to collect the runoff and sediments in the sample collection box;*

Runoff measurements were made on seven takyrs with different degrees of their surface degradation in the Central Kara-Kum Desert. In addition, takyr surfaces were mapped using GPS (to show the vegetation cover, takyr crust degradation stages, etc.). As a result, four surface types (degradation stages) were identified with their shares of the takyr area estimated by the transect method [80]. On surfaces of each of the four types, multiple, repeated measurements were made to assess runoff generation with the help of the small rain simulator. Table 10 shows the dependence of the surface runoff volume on the takyr surface degradation degree and estimated degradation progressing in the examined takyrs.

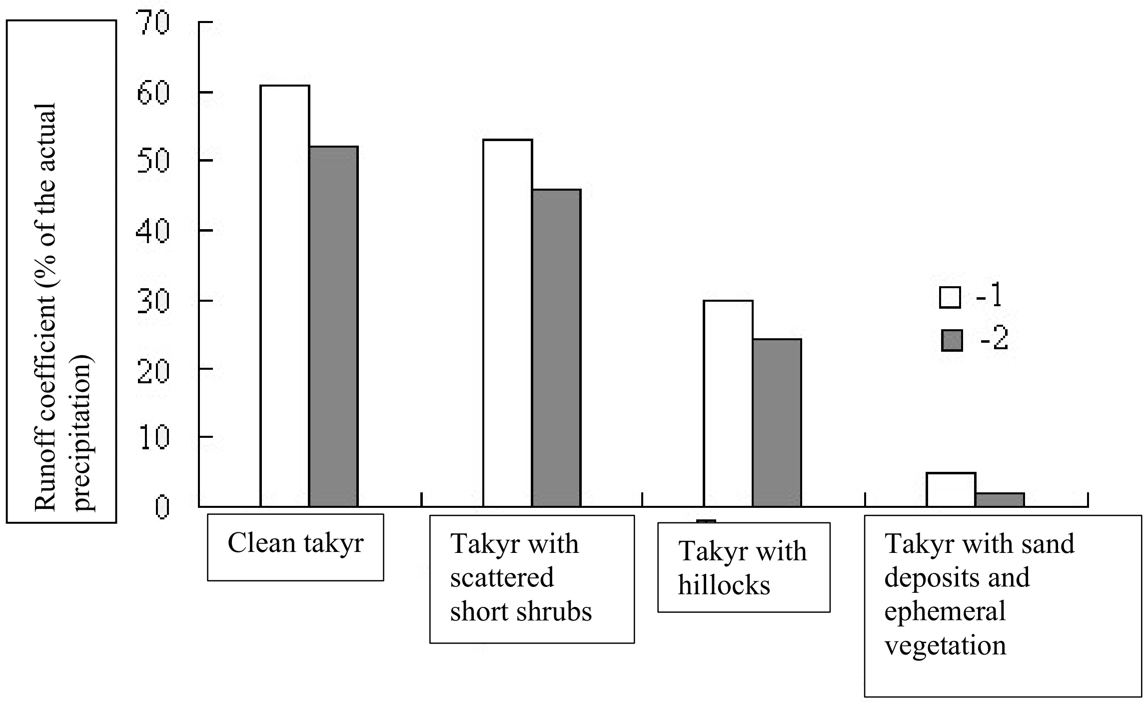
Table 10: Runoff as a function of takyr degradation degree

Surface type	Runoff coefficient, %	Occurrence on takyrs, %	
		Undisturbed	Degraded
Clean	60	79	32
Some scattered shrubs	51	18	34
Sandy hillocks around shrubs	30	3	22
Sand and ephemeral plants	5	0	12

Such experiments were undertaken not only in the Central Kara-Kum Desert, but also on takyrs in Western Turkmenistan. Minor differences in the runoff coefficients are accounted for by the quantities of silt and clay contained in the takyrs of these two geographical areas. For illustration purposes, the results are provided graphically (Figure 10).

Non-degraded takyrs with clean surfaces have fairly high runoff coefficients: 60 % of the actual precipitation flowing down from their surfaces in the form of temporary surface runoff. The occurrence of scattered shrubs on their surfaces reduces the runoff volume by up to 10 % because of the tillage of the soil by their roots and water infiltration. Vegetation is a contributor to the accumulation of sand and emergence of sandy hillocks around shrubs which absorb some of the moisture. For this reason, the runoff coefficient of a takyr surface with sandy hillocks and vegetation is 30%, i.e. twice as low as its potential value. If there are sand deposits with ephemeral vegetation on the surfaces of takyrs, their runoff coefficients drop to the minimum of 5%. A takyr cannot act as a catchment any longer if its surface has a 4-5 cm thick sand deposit.

Figure 10: Correlation of takyr surface degradation degrees with the runoff coefficients in the Central Kara-Kum Desert (1) and Western Turkmenistan (2)



In the past, to improve the fresh water collection conditions, local communities diligently eradicated all plants appearing on takyrs to prevent generation of sand deposits. On takyrs, the only type of housing was felt tents of a streamlines shape which did not create major obstacles on the way of wind-driven sand flows and, in addition, were installed for a short time. Takyr used for catchment purposes should not be used for housing construction, and the livestock population they support should be regulated to maximize the takyr surface conservation. Takyrs are resilient owing to their self-restoring capacity, their surface irregularities are eventually filled with the suspended matter present in the silty water of the temporary runoff. But this process takes much time; therefore, protective measures should planned on a sound basis with a view to ensuring prevention of as much of the transferred sand as possible from depositing on utilized takyrs. The flows of sand drastically subdue if the sands located on the windward side of takyr-like surfaces are stabilized by vegetation or are fixed. A result of this process is gradual blowing out of aeolian deposits and reduction of their sizes. One of the causes of the emergence of moving sands is overgrazing of the pastures adjacent to water harvesting takyrs.

2.2.4 Conservation of water harvesting takyrs

The *Kara-Kum* Cattle Farm is located in the Ruhabad District of the Ahal Province which was used as an example under our study to assess the impact of grazing and is a large sheep and camel breeding farm in Turkmenistan. Distant pastures of this farm occupy an area of 867,000 ha in the Central Kara-Kum Desert. Though most of the pastures are located in sandy desert areas, they have some areas with spots of clayey desert areas (takyrs), solonchaks desert areas (depizes) and stony desert areas (kyrs). Due to the harvesting of *Haloxylon*, *Aristida*, *Salsola richteri* and *Calligonum setosum* for various livelihood purposes and overgrazing with subsequent gradual enhancement of the technogenic impact, about 40% or 346,800 ha of the distant pastures are prone to degradation and have areas of bare barchan sands and partially overgrown sands which turned into barchans.

A key cause of the degradation is the eventual loss of the traditional grazing practices. Since the 1960-ies, shepherds have been increasingly widely using vehicles (motorbikes, cars, trucks, tractors), and in some cases, it has led to free (almost unshepherded) movements of large sheep flocks in the pastures. It is noteworthy that passages of vehicles on moistened takyr surfaces inflict substantial damage, leaving deep, quickly overgrown furrows (Figure 11).

Figure 11: A takyr surface ruined by vehicles

Unfortunately, in cattle farms, not all shepherds stay overnight in the field with their flocks and use animals as a personal transportation means. Sometimes, sheep flocks are released into isolated areas within distant pastures and the shepherd visits the sheep only when it is time to drive them to water. As a result, the sheep are moving without restraint in any direction within the area set aside for them in the distant pasture, they eat only part of the grass and trample the other part of the grassland with the vegetation turning into chaff and becoming dirty. During free, unshepherded grazing of a flock, sheep eat grass in areas covered with the so-called *chygyr*,[*)] i.e. a network of paths trampled down by sheep as evidenced by their numerous hoof-prints. In this way, fodder properties of the plants are impaired over a short time on the entire grazing area.

It is a rather difficult to ensure even consumption of the grassland resources by the cattle, and different counties address this issue in different ways. E.g., in Australia, Germany, Russia and other countries, cattle grazing takes place in rangelands with abundant grass and water within

[*)]The work '*chygyr*' has the following two meanings: 1) sort of a network developed on distant pastures as a result of merging numerous and sometimes bare trails trampled down by sheep hoofs. Depending on the density and height of the grass growth, presence or absence of turf and nature of the soil cover, *chygyr* can be hardly noticeable or expressly tramped when sandy, stony or other surfaces are exposed; 2) an area of a distant pasture where a sheep flock is grazing at a given time.

fenced areas sequentially used (enclosed grazing). Until the animals consume all the grassy vegetation, they are not driven out from the fenced area. The other parts of the pasture are not used during this period. The *Kara-Kum* Cattle Farm's distant pastures have a sparse and scarce plant cover and low yields (about 1.5-2.0 dt/ha), that why it is impossible to practise enclosed pasturing there. So, it is necessary to enhance supervision over the compliance with the 'circular' rotational grazing rules with gradual movement away from the centre to the edge of the area. When well-established on a grazing area, such a grazing practice enables to have part of the pasture 'set at rest' and to ensure even consumption of forage plants.

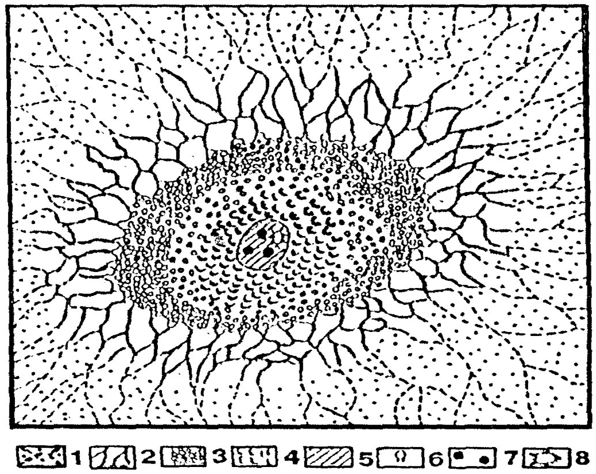
Currently, in view of the increased frequency and severity of droughts, on the one hand, and enhanced impact of human activities, on the other hand, it is necessary to utilize pastures with their division into plots. The division of distant pastures into isolated areas around watering points provides enabling conditions for better conservation of the vegetation and good nutrition for sheep. Moreover, the traditional grazing practice of dividing pastures into strips increases the yield of pastures by 15-20% compared to pastures with haphazard grazing.

In most areas surrounding the depressions (takyrs) where cattle watering wells are located, land is degraded. Massive concentration of cattle around the wells causes severe soil damages and emergence of moving sands. Wells-adjacent grazing creates belts of pasture degression of different stages (Figure 12).

Areas of distributed grazing hardly differ from natural pastures. Closer to a well, there is a ring of the permanent cattle driveway and overgrazing with a multitude of continuously 'updated' trails. The trails merge as one moves towards the well to produce a ring of broken sands with hillocks. Consequences of multiple repeated cattle driving include complete destruction of the vegetation and emergence of aeolian sands.

An effective way to restore wells-adjacent tree, shrub and associated vegetation is to properly arrange cattle driving to watering sources and back to the pasture. To address this 'over-mature' issue, it is necessary to enforce the following rule: all the year round, the shepherd should drive the flock to the watering well and, then, back to the pasture from one defined side. Prior to this, it is necessary to establish from which side there is a strong movement of sands towards takyrs and then advise the leeward side for cattle driving.

Figure 12: Pasture degression proliferation around watering sources as a function of the intensity of grazing and cattle driving (not to scale, [50]).



Legend for Figure 12: *1 – distant pastures (plant cover from 25% to 75 %); 2 – the ring of permanent cattle driving; 3 – the ring of broken sands with residual hillocks; 4 – the ring of aeolian barchan sands; 5- the takyr; 6 – the felt tent; 7 –the wells; 8 – the sheepfold.*

In the management and operation of distant pastures, a difficult task is to ensure evenly distributed grazing pressure. Overgrazing of some areas and undergrazing of other parts result from the uneven spatial distribution of watering places or their disrepair. Wells are usually maintained to be operational and takyrs lose their water collection capacity unless they are duly treated. So, operations to clean takyrs from the overgrowth and sand deposits can, to some extent, ensure more or less even utilization of distant pastures.

3. CONCLUSION: findings and recommendations for CA countries

In the course of several millennia, many generations of humans exerted various impact on natural landscapes in Central Asia, but it has been particularly tangible in the recent 100 years. Oil and gas exploration and development, cutting of tree and shrub vegetation, concentration of large cattle populations near wells and settlements, irrigation land expansion, construction of utilities and other facilities, diversion of drainage waters deep into the desert – all these have led to temporary disturbances in the environmental balance. These destructive processes are accelerated and exacerbated due to the extreme natural conditions and complicate the environmental situation. Nowadays, the region is expanding the scope of experiments and applied research aimed at combating the above adverse factors. Results of such activities help to improve the natural environment and to ensure sustainable use of its resources and successful implementation of the UN Convention to Combat Desertification (UNCCD).

This literature review and the studies enable to update the estimates of the areas of takyr catchments in Northern and Central Asia and their surface runoff. The work was conducted with the use of a geo-environmental research methodology for arid areas in Central Asia. The review of numerous literature sources revealed that earlier, no comprehensive studies of this kind had been conducted to identify ways of conservation and sustainable management of this unusual landscape with its unique ecosystem and soil type. At this point, it should be noted that the total area of takyr catchments of the study region is 119,532.23 km^2 with their surface runoff amounting to 977.04 million m^3 which may be regarded as an alternative fresh water source.

In Central Asia, takyr catchment areas exist in three countries: Kazakhstan, Uzbekistan and Turkmenistan. There are practically no takyrs in Kirgizstan; and in Tajikistan, small takyr areas were almost fully used for irrigation, according to A.P. Lavrov (1984). In Kazakhstan, it appears impossible to estimate the number of ploughed and degraded takyrs because there is no consensus among soil scientists about the area of the takyrs. Judging by the comparison of the latest estimates of takyr and takyr-like soil areas provided in the publication of K.Sh. Faizov *et al.* (2001) with the data from A.P. Lavrov (1984), their area increased by over 20,000 km^2. It may be explained by the fact that the earlier assessment considered only the soils in the desert part of the country though takyr-like soils also occur in mountain river valleys. Furthermore, the latest studies drew from remote sensing data which enabled to detect ongoing processes of takyr generation, including those on the desiccated Aral Sea bed. In Uzbekistan, according to our estimates, the recent 30 years saw a reduction in the area of takyr soils by 1,060 km^2, primarily due to agricultural land uses. In Turkmenistan, the degradation of takyr catchment areas has very extensive consequences and we estimate the degradation at 5,500-13,500b km^2 which is comparable with data of other authors varying from 4,900 (Nepesov, Popov, 2000) to 14,000-18,000 km^2 (Mamieva *et al*., 2000). As a consequence, the surface runoff decreased by over 90 million m^3. In the context of the water resource deficit in the Aral Sea basin and global warming, any further development of the degradation processes would have adverse impact; so, it is necessary to find a way to address this geo-environmental problem based on scientific evidence.

The shrinkage of water collecting takyrs occurs not only due to anthropogenic factors, but also due to natural environmental processes. Wind erosion associated with the seasonal wind-driven sand movement along the takyr surface is a key driving force of the degradation. This is evidenced with: (a) lowering of the hypsometric tints of takyrs by 0.06-0.07 cm per year and those of takyr-like soils – by 0.16-0.33 cm per year; (b) the high level of silt deposits (among the highest in the world) in areas of takyr occurrence, e.g., in the mixed landscape with ridgy sands and takyrs near Bokurdak where there are many takyrs, it is 762 kg/ha; near Erbent where takyrs are fewer, it is 535 kg/ha per month, and in the gypsum desert with its only single takyrs near Darvaza, it is 331 kg/ha per month; it oases, this rate is still lower; (c) presence of illite both in the dust and in the takyrs; and (d) the theory of dust generation through collision of sand grains with the takyr surface during the passage of the wind-driven sand flow with the wind velocity needed for the start of abrasive action of sand grains on a takyr being equal to 8.8 m/sec. The takyr crust is also destroyed by water erosion during shower rains and the suspended sediment load of the silty takyr water may reach 10-12 gr/l.

Climate change will enhance the deflation processes with intensive dust generation on takyrs and contribute to the emergence of moving sands along their edges. This is another environmental factor which will accelerate takyr degradation together with wind and water erosion. As regards anthropogenic factors impairing the stability of the sand around takyrs and contributing to sanding of their surfaces, they are overgrazing and vehicle traffic.

Non-degraded takyrs with clean surfaces have high runoff coefficients (60%). Mild degradation starts with the occurrence of individual shrubs on the surface which reduce the runoff coefficient by 10 %. Vegetation contributes to sand accumulation and generation of hillocks around the shrubs which absorb part of the moisture. Therefore, if a takyr surface has hillocks and vegetation, it is deemed to be at the moderate stage of degradation and its runoff coefficient is 30%. The runoff coefficient drops to its minimum (5%) when the surface of a takyr acquires sand deposits with ephemeral plants. A highly degraded takyr ceases to function as a catchment area when its sand deposit is 4-5 cm thick. The takyr crust integrity is vitally important for conservation of the existing flat terrain and is an indicator of water harvesting capacity of takyrs regardless of their types.

As for takyr protection and restoration efforts, we deem it necessary to focus on sand stabilization in the surrounding areas with a view to reducing the invasion of sand to takyr surfaces. To prevent the emergence of moving sands around takyrs, it is advisable to apply traditional grazing management practices, enabling to avoid overgrazing and, in this way, to preserve the vegetation cover which is a natural sand stabilizer. When a great number of livestock animals keep concentrating around watering places, it is necessary to align the cattle driving arrangements through maximizing the use of the leeward side of takyrs. If there are populated settlements on takyrs, it is advisable to undertake land reclamation operations on the adjacent barchans, engaging local communities to raise their awareness and to ensure sustainability of such interventions.

To this end, it is necessary to conduct additional field studies, including testing and introduction of a full cycle of sand stabilization operations: from planting stock production and agricultural treatments to methods and timeframes of using of mechanical protection means and forest shelterbelt establishment operations, including the choice of the most appropriate spacing, planting, thinning and protection of the forest stands. It would be quite suitable to use drainage water from the reservoir system of the Turkmen Altyn Asyr Lake (Golden Age Lake) with mineralization of 3-5 gr/l for charge watering.

The runoff generation observations provide evidence to assert that takyr micro-catchments have higher runoff coefficients than larger takyr catchment areas where runoff losses are big. It would be more appropriate to use smaller takyr areas for forest shelterbelt establishment with the black saxaul to be the forest dominant species. In this context, it is necessary to empirically establish the optimal water consumption rates for the plants under the conditions of irrigation from the surface runoff. It is advisable to establish forest shelterbelts by way of planting in water accumulating trenches as well as to use 'green umbrellas' in pastures and the dry farming practices for forest shelterbelt establishment.

In some areas of Central Asia, the runoff from takyrs and takyr-like soils remains the only water source. E.g., in Turkmenistan, such areas include the northern part of the Central Kara-Kum Desert, Trans-Unguz Kara-Kum and South-Western Turkmenistan. They are situated far from permanently available water sources, and underground waters are highly mineralized in these areas. In view of high investment costs of construction of water supply pipelines in grazing areas and even impossibility to have return on some of such investments, takyr conservation and sustainable management remains very cost effective and socially beneficial.

REFERENCES